Eco. Env. & Cons. 30 (2) : 2024; pp. (642-652)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2024.v30i02.039

Investigating the drinking and irrigation suitability of the groundwater in the middle Ganga River basin of Muzaffarpur district, India

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(Received 18 September, 2023; Accepted 13 November, 2023)

ABSTRACT

Groundwater is one of the most prominent natural resources which is widely used for drinking and purpose worldwide. In the present study, samples from 25 dug well sites of Muzaffarpur district, were collected and subjected for the analysis of drinking and irrigational suitability of groundwater in the year 2020. The groundwater was predominantly alkaline in nature, with moderately hard to very hard water type. The groundwater of the study area was revealed fit for drinking purposes, based on the findings of weighted arithmetic water quality index (WAWQI) result. Six irrigation indices namely Sodium Absorption Ratio (SAR), Percentage Sodium (%Na), Residual Sodium Bicarbonate (RSBC), Potential Salinity (PS), Magnesium Ratio (MR), Kelly Ratio (KR) along with Wilcox and United States Salinity Diagram (USSL) were used to evaluate the suitability of groundwater for irrigation. All the sampling sites were categorised as excellent based on SAR and %Na values. RSBC values indicated all the sites as satisfactory whereas PS values designated them as 'good to poor.' MR rendered 28% of the sampling sites as unsuitable for irrigation while 100% of the samples were suitable based on KR values. Proper management and judicial use of groundwater is essential to safeguard this precious natural resource.

Key words: *Muzaffarpur, Groundwater, Water quality, SAR, USSL.*

Introduction

Groundwater is an invaluable natural resource which plays a key role in maintaining the economy of the country (Zhou *et al.*, 2020). It is used globally to fulfil the requirements of drinking, domestic, agriculture, and even industrial purposes due to shortage, easy assesiblity, and contamination of other surface water resources (Marghade *et al.*, 2021; Rajaiah *et al.*, 2021). Natural and anthropogenic activities such as local climate, geological factors, and agricultural practices have all been known to affect groundwater quality (Bouderbala, 2017). Due to rapid population growth, urbanisation, industrialization, and land-use change, groundwater quality has deteriorated over time and its effect is more pronounced in developing countries (Aggarwal *et al.*, 2021). Studies conducted in the recent decade have reported the presence of various contaminants, including heavy metals, fluoride, and nitrates, exceeding permissible levels for safe consumption (van Vliet *et al.*, 2021; Devi and Nair, 2021). These pollutants pose substantial health risks to local communities dependent on groundwater for drinking, and agricultural purposes. Zhang *et al.* (2019) has reported that range for hardness, and NO_3^- have sur-

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passed the grade III Chinese national groundwater quality standard, and groundwater quality has drastically worsened owing to population growth, social, and economic development, and excessive use of groundwater. Masindi and Foteinis (2020) conducted a large-scale survey of 42 different borewells in the Sub-Saharan region of South Africa and reported high levels of anions such as Nitrate, Chloride and Fluoride suggesting urgent need for improvement in the ineffective drainage system of the area. The problem of groundwater quality deterioration is not limited to a specific country or continent but has become a common issue for most developing regions of the world. A total of 19 states in India are suffering heavily due to Fluoride and Arsenic contamination with elevated levels of several other physico-chemical parameters (Gugulothu *et al*., 2022; Ravindra *et al.,* 2022; Elbeltagi *et al.,* 2022). Singh *et al.* (2022) conducted water quality assessment in Malwa, Punjab and found that only 10.85% of groundwater samples were suitable for drinking, while all samples exhibited poor quality for irrigation. In an investigation, it was established that roughly 60% of examined groundwater samples of Coimbatore were categorized under poor water quality as per WQI rating due to industrialization. Aryan *et al.* (2023) found that a minor portion of Patna's groundwater samples surpassed recommended levels for electrical conductivity, and potassium ions, while maintaining good suitability for irrigation, necessitating consistent monitoring and comprehensive management for sustained quality across various uses. Muzaffarpur district of Bihar is world famous for delicious 'Shahi Leechi' and 'China Leechi' and is also referred to as "Land of Leechi". From economic point of view, it is an important district of Bihar. The city has a net groundwater availability of 1075.52 MCM, and extracts nearly 572.77 MCM groundwater annually (CGWB, 2013). Moreover, it has allocated 108.39 MCM groundwater for domestic and industrial purposes upto the year 2025. It has a population size of 48.01 Lakh individuals in 2011, is expected to rise by 37.42 % by 2030 (Census, 2011). Thus, to monitor the quality of groundwater, and build a proper conservation plan becomes essential to sustain such large population size. However, the increase in population size, linearly increases the demand of groundwater supply, which eventually led to quality deterioration, and shortage of groundwater. Besides, drinking, and domestic uses, agriculture is the most common source of livelihood as gross cropped area is around 285000 hectares (BACP, 2013).81.1% of the cultivable land is irrigated with the help of borewells signifying the importance of groundwater in the district (BACP, 2013). The assessment of the quality of water used in agriculture is critical for predicting its long-term use and increasing productivity (Wagh *et al.,* 2018). Several studied have been conducted on the physico-chemical analysis, and quality assessment of groundwater in the district of Muzaffarpur (Kumar, 1986; Mumtazuddin *et al.,* 2012; Singh, 2015; Singh *et al.,* 2018; Singh, 2022), yet limited study has reported to use weighted arithmetic water quality (WAWQI) and irrigation indices to monitor the groundwater quality for drinking and irrigation purposes. Water Quality Index is a technique that expresses water quality in an easily understandable, and stable single numeric expression. It overcomes the complexities of interpreting long list of physico-chemical variables, and facilitates comparison of different data set in a single frame. Thus, is used by many researchers in the past few decades to transfer the information in a more generic term (Debels *et al.,* 2005; Mohammadpour *et al*., 2016; Rivera-Rodriguez *et al*., 2019; Wagh *et al*., 2019; Adimalla *et al*., 2019; Ravindra *et al*., 2022; Sunitha *et al*., 2022). As we navigate the challenges of urbanization, industrial expansion, and increasing agricultural practices, it is crucial to recognize the sensitive zones, and preserves the invaluable resource of groundwater for generations to come. Therefore, the present study aimed spatially map the drinking, and irrigational suitability of groundwaterin the Muzaffarpur district of Bihar.

Materials and Methods

Study area

Muzaffarpur district is the 9th largest district of Bihar covering an area of 3173 sq km. It has a mean elevation of 47 metres and is located between latitudes of 25^{O} 54'N and 26^{O} 23N' and longitudes of 84^{O} 53'E and 85^{O} 45'E. The district is drained by the rivers Burhi Gandak, Baghmati, and Baya, which usually flows in the south-easterly direction (CGWB, 2013). Calcareous, fine sandy loamy, coarse sandy loamy, clayey, and sandy soils are found, with the first three accounting for 98.13 percent of total soil percentage in the district (BACP, 2013). The annual rainfall averages between 1100 and 1300 millimetres.

Data procurement and statistical analysis

The data for 25 sampling locations was extracted from Central Ground Water Board's website (Ground Water Year Book, 2021) and was used to calculate water quality index, and various irrigation indices. Statistical analysis was performed using software such as Microsoft Excel 2021, and the respective map, and graph were plotted using ArcGISv10.5, and SPSS version 22.0.

Water Quality Index Estimation

The assessment of WQI emerges as an effective tool to concise the information of different physico-chemical parameters into a single value. The calculation of WQI, begins with the estimation of unit weight for each selected parameter, followed by the determination of the relative unit weight (W_n), and quality rating (Q_n) of respective parameters. The numeric value obtained for the WQI is finally compared with the range of WQI classification for the water quality interpretation. Descriptive calculation of WQI is given below.

$$WQI = \frac{\Sigma W_n \times Q_n}{\Sigma W_n} \quad \text{eq.(1)}$$

Where, W_n and Q_n is the relative unit weight and quality rating of the n^{th} physico-chemical variables respectively. The relative unit weight (W_n) can be calculated using equation (2), and quality rating (Q_n) can be calculate using equation (3).

$$W_n = \frac{K}{V_s} \quad \text{eq. (2)}$$

Where, K is the proportionality constant, and it is calculated using the equation K = 1/”1/V_s.

$$Q_n = \left[\frac{(V_n - V_i)}{(V_s - V_i)}\right] \times 100 \quad \text{eq. (3)}$$

Where, V_n is the observed value of various physico-chemical parameter. V_i is the ideal parameter value, which is taken 0 for all other parameters, except for pH (V_i = 7). V_s is the standard acceptable value for the n^{th} water quality parameter.

Irrigation Suitability analysis

Different irrigation water quality indices, such as the 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), are used to determine whether groundwater is suitable for irri-

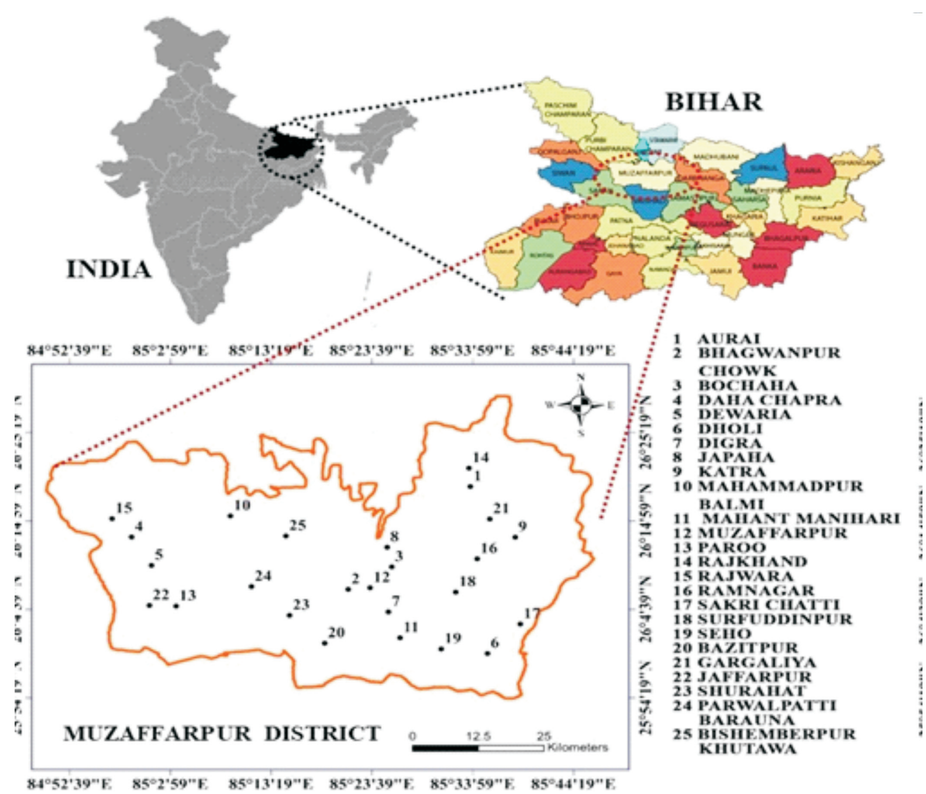

Fig. 1. Map of the study area.

gation. It is calculated using equations (4-9) listed below. Additionally, the Wilcox diagram and the US Salinity Laboratory's diagram were developed to examine the combined impacts of EC, SAR, Na^+, and salinity.

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \text{eq. (4)}$$

$$\% \, Na = \frac{Na+K}{Na+K+Ca+Mg} \times 100 \text{eq. (5)}$$

$$RSBC = HCO_3 - Ca \text{eq. (6)}$$

$$PS = Cl + \sqrt{SO_4} \text{eq. (7)}$$

$$MR = \frac{Mg}{Ca+Mg} \times 100 \text{eq. (8)}$$

$$KR = \frac{Mg}{Ca+Mg} \text{eq. (9)}$$

Results and Discussion

Analytical result and water type

Table 1. Summarises the statistical details of 13 physico-chemical parameters analysed for the groundwater samples of Muzaffarpur, district. The result revealed alkaline groundwater condition, with a maximum value of 8.1, whereas, total hardness (TH) varied from moderately hard to very hard (95-370 mg/l) water category (Sawyer, 1994). The clear dominance of divalent cations was noted with the average concentration of 47.76 + 16.06 mg/l for Ca^{2+}, and 21.68 + 12.74 mg/l for Mg^{2+}. The abundance order of anions was revealed to be HCO_3^-> NO_3^-> Cl^-> SO_4^{2-}> F^-. The high level of divalent cations to the groundwater aquifer is mainly attributed to the geological input from carbonate rocks, and ion exchange processes (Khatri *et al*., 2020). In this context, the studyconstructs the Chadha plot to reveal a distinct clustering of data points within the rectangular field. This clustering indicates that the concentrations of calcium, magnesium, and bicarbonate ions are consistently elevated relative to other ions, signifying the prevalence of the Ca-Mg-HCO_3 hydrogeochemical facies in the study area (Figure 2). The plot's effectiveness lies in its ability to showcase the spatial distribution of these ions, substantiating the dominance of Ca-Mg-HCO_3 as the major hydrogeochemical facies in the study area. The prevalence of the Ca-Mg-HCO_3 water type in the groundwater of the Middle Ganga River Basin can be attributed to a combined influence of geological, hydrological, and geochemical factors. The geological composition of the area, characterized by carbonate rocks such as limestone and dolomite, facilitates mineral dissolution, the release of calcium (Ca) and magnesium (Mg) ions into the aquifer (Kumar *et al.*, 2023). Weathering processes, driven by prolonged interactions between groundwater and aquifer materials, contribute to the release of these ions, while the presence of bicarbonate (HCO_3) ions stems from the dissolution of carbon dioxide (CO_2) from the atmosphere or organic matter. Among the non-carcinogenic anions F^- and NO_3^- were noted to vary from 0-0.22 mg/l and 0-75 mg/l respectively. Although, the mean concentration of F^- and NO_3^- has not exceeded the acceptable limit of BIS (2012) water quality standards for drinking purpose, yet, high level of NO_3^-in 12% of groundwater samples signifies the influence of agricultural or domestic protuberance (Wu *et al*., 2020; Zhang *et al*., 2020).

Table 1. Statistical summary of various physico-chemical parameters in the study area.

	MIN	MAX	AVG	STD	BIS (2012) Acceptable Limit
pH	7.6	8.1	7.81	0.16	6.5-8.5
EC	201	871	477	152.11	750
TH	95	370	208.80	60.10	200
Ca^{2+}	8	72	47.76	16.06	75
Mg^{2+}	4	60	21.68	12.74	30
Na^+	0.02	24	4.73	6.75	200
K^+	0.08	4.2	0.55	0.83	12
HCO_3^-	73	329	221.36	67.20	200
Cl^-	4	75	19.32	20.66	250
SO_4	0	63	8.04	16.62	200
NO_3	0	75	19.78	20.20	45
F^-	0	0.22	0.04	0.06	1
TDS	121	523	286.64	91.29	500

Note: Unit in mg/l, Except EC (μS/cm) and pH.

Water quality of the groundwater

Ten physico-chemical variables were subjected for the estimation of water quality index, using weighted arithmetic water quality index (WAWQI) method (Tiwari and Mishra, 1985). The calculated WQI value ranged from 24.6 to 54.9, and has classified groundwater sample from "good" to "poor" category (Figure 3). Neary, 8% sample falls in excellent category, while 76% and 16% are categorised as good and poor class of water for drinking purpose respectively.A non-significant variation in the water quality at different sampling locations of the study area is, probably due to the similar geological conditions, throughout the studied stretch (Kumar *et al.,* 2023). However, marginal higher value of WQI at site 2, 5, 13, and 15 is due the increasing input of ionic species that has elevated the concentration of TDS at the respective sites. The aforementioned scenario has been validated with the help of a multivariate statistical tool called as Principal Factor Analysis (PFA). The effect of each water quality variables (WQVs), and water quality (WQI) on their respective principal factor in a PFA was assessed for the given data set using varimax rotation in SPSS ver. 22.0 software. For further interpretation, the four main components with eigenvalues >1 and a total variance of 76.826% were deemed significant (Table 2). According to (Liu *et al.,* 2003), factor loading more than 0.75 are deemed "strong," between 0.50 and 0.75 are considered "moderate," and between 0.3 and 0.5 are considered "weak." The result revealed a high factor loading of WQI (0.857) is associated with a strong factor loading of EC (0.835), Mg^{2+} (0.827), Cl^- (0.847), along principal factor 1 (PF1), suggests the role of these physicochemical variables in controlling the groundwater quality in the studied area. A higher value of Mg^{2+} and a moderate loading of HCO_3^- (0.611) in PF1 corroborates with the previous discussion of carbonate rock dissolution (Figure 2), and prevalence of reverse ion exchange process. Further, strong factor loading of Cl^- and moderate loading of NO_3^- also validates the finding of anthropogenic contribution of these ions in deteriorating groundwater quality of the area.

Spatial variation in the groundwater quality for drinking purpose in depicted in Figure 4. A lower value of water quality index has been demarcated with green colour, which ismarked red at its higher values. The higher value of water quality index is distributed more towards the North-Western part of

Table 2. Showing factor loading of selected water quality variables (WQV) and water quality index (WQI) after varimax rotation.

	Rotated Component Matrix			
	Component			
	1	2	3	4
pH	.157	.424	-.658	-.199
EC	**.835**	.440	.094	.042
Ca	.057	**.909**	.157	.127
Mg	**.827**	-.208	-.149	.064
Na	.251	-.057	.389	.620
K	.128	-.677	.131	.339
HCO3	.611	.616	-.196	.353
Cl	**.847**	-.034	.170	-.038
SO4	-.027	.172	**.779**	-.069
NO3	.411	-.013	.205	-.786
WQI	**.857**	.091	-.294	-.273

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 7 iterations.

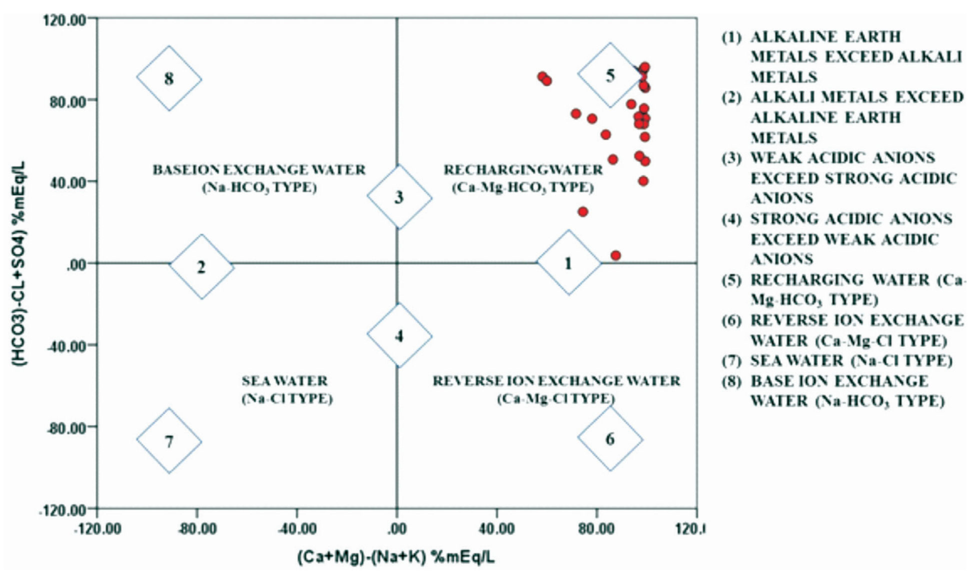

Fig. 2. Chadha plot showing major hydrogeochemical facie in the study area.

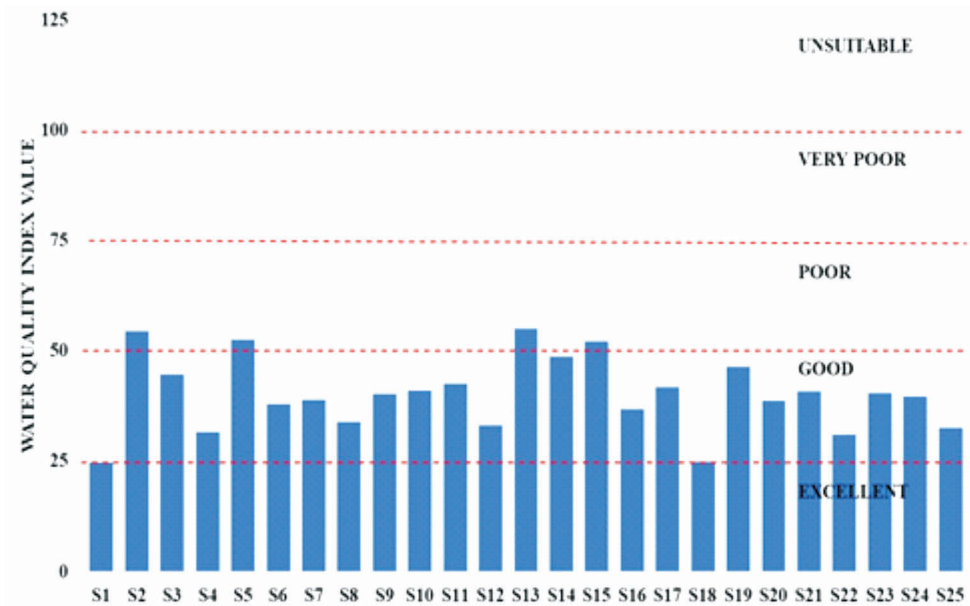

Fig. 3. Water quality classification for the 25-sampling locations of the study area.

the study area, whereas it remains low in the central and North-Eastern parts of the district. Notably, the sites that were marked with relatively higher WQI values, have a higher concentration of electrical conductivity, owing to dissolution of mainly Ca^{2+}, Mg^{2+}, Cl^{-}, NO_3^{-} ions. The presence of calcareous rocks, quaternary deposition of alluvial sediments, and the reverse ion exchange process in the studied region might have elevated the level of divalent ions in these regions. However, an increase in the chloride ion concentration is attributed to poor seepage system, issues related to waterlogging, and a rise in NO_3 level is mainly contributed by fertilizers used in agricultural practices (Fu *et al.*, 2021).

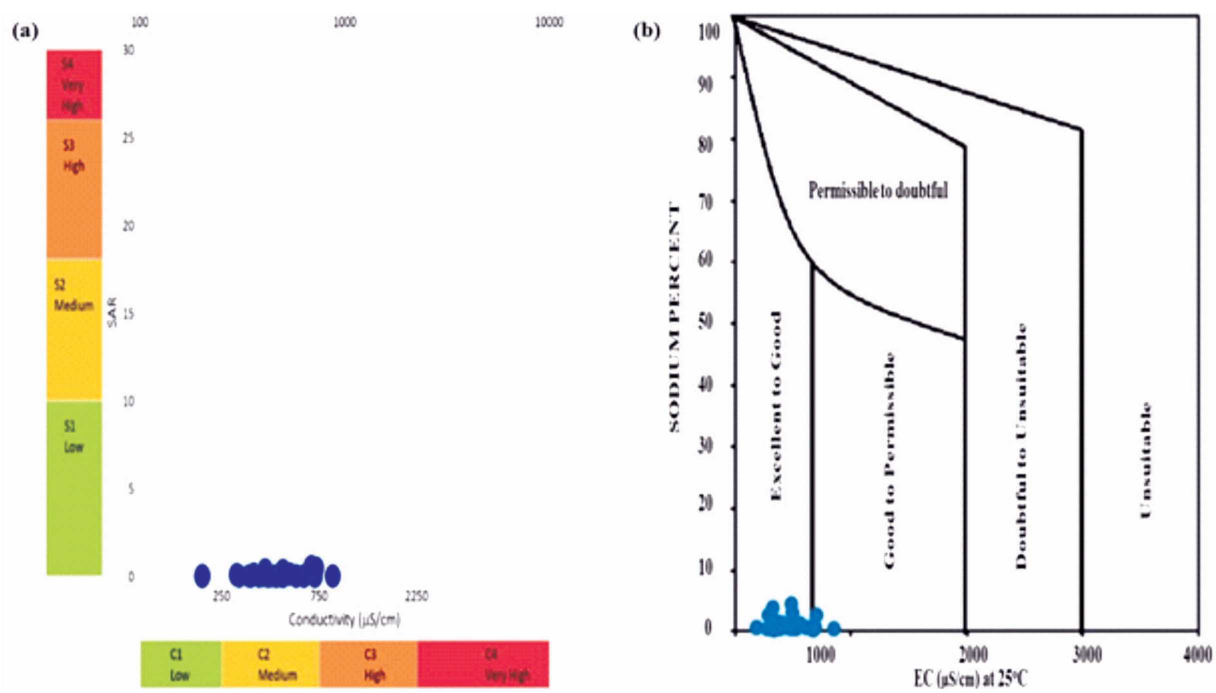

Fig. 4. (a) USSL and (b) Wilcox diagrams showing irrigation suitablity of groundwater samples at Muzaffarpur in 2020.

Irrigation suitability of groundwater

The statistical summary of various irrigation suitability indices, with their classification, and % of samples falling in the respective classes has been shown in Table 3. The values are taken in mEq/l for the computation of all the given indices. Sodium Absorption Ratio (SAR) was formulated by (Richards, 1954) that gives an estimate of alkali damage to the crops (Zhou *et al.,* 2020). Based on the SAR values, all the groundwater samples were classified as excellent for irrigation. To construct the United States Salinity Laboratory diagram (USSL) diagram, SAR values were plotted against EC (USSL, 1954). The diagram divides the study area into C1S1, C2S1, and C3S1 categories, with 92 percent of the samples falling in the C2S1 zone, indicating a medium salinity-low sodium hazard, and 4 percent falling in the C1S1 and C3S1 zones, indicating a low salinity-low sodium hazard and high salinity-low sodium hazard, respectively (Figure. 5a). Groundwater in the C1S1 and C2S1 classes can be used for all crops, but in the C3S1 category, only certain semi-tolerant crops can be grown (Ghalib *et al.,* 2017).

Similarly, sodium hazard is also measured in terms of %Na (Wilcox, 1955). The values ranged from (0.05-4.20) mEq/l (Table 1). All the groundwater samples are of excellent quality based on %Na values as the value computed was <20 (Table 1) which is also confirmed by Wilcox diagram (Figure. 5b). The permeability of the soil is reduced when the sodium ion concentration in the water increases (Ghalib *et al.*, 2017). A continuous use of water with high sodium concentration eventually compacts the structure of soil, as it gets adsorbs on the soil particle (Aryan *et al*., 2023). According to the Wilocx diagrams 84% of the samples are in excellent quality for irrigation, and 16% as good to permissible for irrigation.

The spatial distribution of irrigation suitability plays a pivotal role in optimizing agricultural productivity, and sustainable water resource management. Spatial analyses of parameters such as the Sodium Absorption Ratio (SAR), Percentage Sodium (%Na), Magnesium Ratio, Kelly Ratio, Residual Sodium Bicarbonate (RSBC), and Potential Salinity have been shown in Figure 6. The colour green has been used to indicate a lower concentration of irrigation indicators, whereas red has been used to indicate a higher concentration. The elevated level of most of the SAR and % Na^+ is distributed more towards the South-Western part of the study area, whereas marginally higher value was noted in the lower regions. In general, a higher level of the aforementioned indices suggest the prevalence of monovalent cation over divalent cation the regions (Joshi *et al.,* 2021). An elevated level of Na^+, the ion exchange process in the area, and the compo-

Table 3. Statistical summary of different irrigation indices used.

Sl. No.	Parameters	Min	Max	Avg	Class	Quality	% of Sample	Reference
1	SAR	0	0.53	0.01	<10	Excellent	100	Richards, 1954
					10-18	Good	0	
					18-26	Doubtful	0	
					>26	Unsuitable	0	
2	%Na	0.05	4.20	1.01	<20	Excellent	100	Wilcox, 1955
					20-40	Good	0	
					40-60	Permissible	0	
					60-80	Doubtful	0	
					>80	Unsuitable	0	
3	RSBC	-1.19	2.91	1.24	<5	Satisfactory	100	Gupta, 1983
					5-10	Marginal	0	
					>10	Unsatisfactory	0	
4	PS	0.11	2.41	0.63	<5	Excellent To Good	100	Doneen, 1962
					5-10	Good To Injurious	0	
					>10	Injurious To Unsatisfactory	0	
5	KR	0	0.26	0.05	<1	Suitable	100	Kelley, 1940
					>1	Unsuitable	0	
6	MR	9.90	78.76	42.04	<50	Suitable	68	Raghunath, 1987
					>50	Unsuitable	28	

sition of soil with greater clay content might be some of the reason limiting water penetration through the groundwater aquifers (Kamaraj *et al.,* 2021; Fu *et al.,* 2021).

Kelly's ratio (KR) is defined by the ratio of sodium to calcium and magnesium (Kelly, 1963). The maximum observed value of KR was 0.26, and the mean value was 0.05. KR values greater than 1 suggest an excess of sodium concentration hence is considered unfit for irrigation. All the samples are suitable for irrigation based on KR values (Figure. 5c). However, marginal elevation of KR observed at South-Western pockets of the study area. Aryan *et al.* (2023) reported the dominance of Ca-Mg-HCO_3 hydro geochemical facie, with the reverse ion exchange process has prevailed throughout the studied region. Since, limited geochemical evidence has been reported for the sudden fluctuations in the sodium level at some sampling locations, the rise in the Na^+ concentration is might be an influence of anthropogenic protuberances like use of agricultural fertilizers, seepage of domestic discharge through the groundwater aquifer.

Magnesium Ratio (MR) is a measure of Magnesium hazard suggested by Raghunath (1987). Groundwater samples with value less than 50 are considered as suitable whereas values greater than 50 are rendered unsuitable. Figure 5d shows the spatial graph magnesium ratio of different sampling locations in the study area. The Northern regions of the study area was clearly marked with high magnesium ratio. Based on Raghunath (1987) classification, 68% of the samples are suitable for irrigation, while remaining is unsuitable for irrigation. Samples with MR value > 50, suggests a higher level of magnesium in the groundwater, which is due to the presence of carbonates weathering, and reverse ion exchange processes prevailing in the study area (Fu *et al.*, 2021). Excessive magnesium ions in the groundwater might affect the crop yield by reducing soil quality (Bouderbala, 2017). Similar to the magnesium ratio, the Residual Sodium Bicarbonate Concentration (RSBC) is elevated more towards the northern regions, with slight increase marked at the Eastern region. RSBC is an important irrigation index proposed by Gupta (1983) that categorises groundwater based on bicarbonate ion concentration. The calculated values of ''RSBC'' are presented in Table 1. Based on these values, all the groundwater samples were categorised as satisfactory for irrigation (Figure 5e). Excess HCO_3^- ion in the groundwater can precipitate $CaCO_3$ from solution in the soil and raise the Na^+ ion concentration in the water that hinders nutrient uptake by plants (Chaudhary

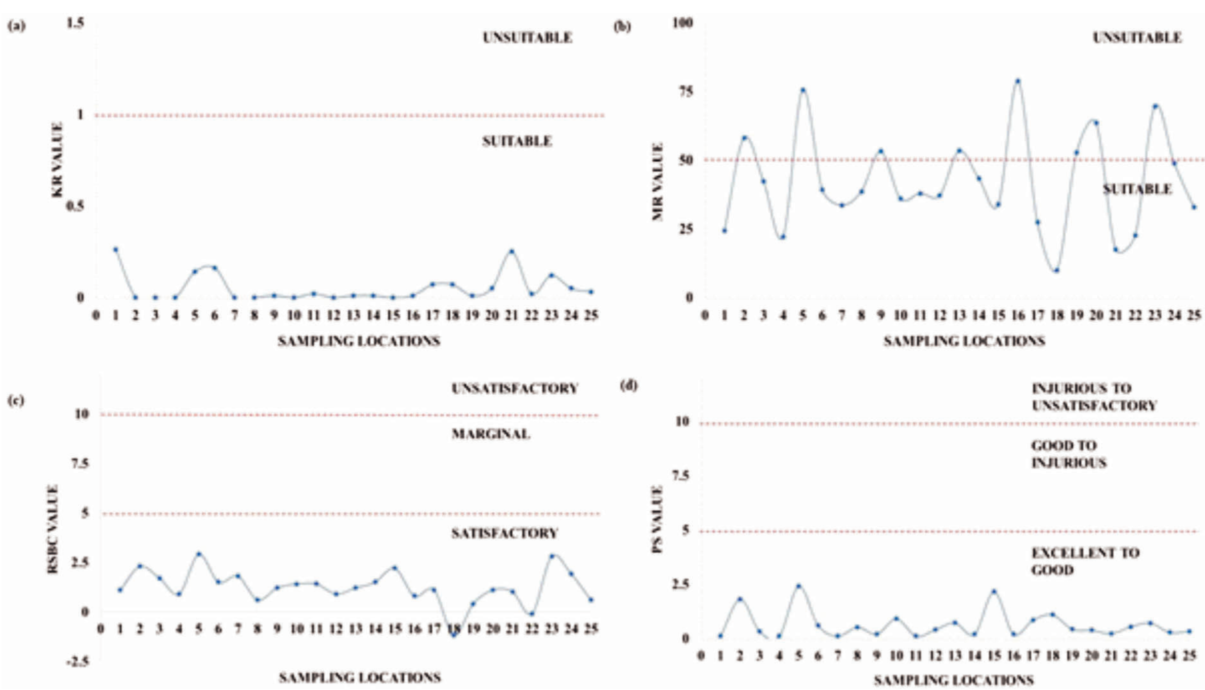

Fig. 5. Graph showing relative value of different indices in the study area. (a) Kelly ratio, (b) Magnesium ratio, (c) Residual sodium bicarbonate value, (d) Potential Salinity.

and Satheeshkumar, 2018).

Potential Salinity (PS) is an irrigation index that determines irrigation suitability based on Cl^- and SO_4^{2-} ions concentration in the water. Unlike, other irrigation indices the higher level of PS was noted towards the North-Eastern regions. The mean PS value was 0.63 with highest value at S5 (Figure 5f). An increase in the potential salinity at S2, S5, S13 is attributed to relatively higher concentration of Cl^- in the respective areas. Poor drainage system, waste water effluents, and surface contamination of animal wastes might have a role in the marginal elevation of Cl^- level in thses regions (Abbasnia *et al*., 2019).

Further, hierarchical Cluster Analysis has been performed to categories primary group sampling location based on different irrigation indices that are alike, and most probably has similar source of respective ionic constituents (Kumar *et al*., 2023). The hierarchical tree of sampling locations exhibited three distinct clusters, as shown in Figure 7. Cluster 1 consists of sites S9, S13, S19, S2, S5, S23, S10, S16, cluster 2 consists of S10, S12, S8, S11, S7, S15, S25, S3, S14, S24, S6, and cluster 3 consists of S1, S21, S4, S22, S17, S18. Irrigational suitability among the sites decreases in the order cluster 3> cluster 2> cluster 1. Sites included in cluster 1 are the sites that are marked with marginally higher value of magnesium ratio, and residual sodium bicarbonate concentration. This indicates a higher value of Mg^{2+}, and a lower concentration of Ca^{2+} has caused excess of bicarbonate to combines with Na^+ ion to form residual sodium bicarbonate (Shukla and Saxena, 2020). Additionally, higher sodiumbicarbonate concentration is detrimental for soil texture as it hinders the percolation of water into the groundwater aquifer. Moreover, excess of Mg^{2+} over Ca^{2+} is might be due to the weathering from dolomite rocks, and the dominating reverse ion exchange mechanism in the study area (Kumar *et al.,* 2023).

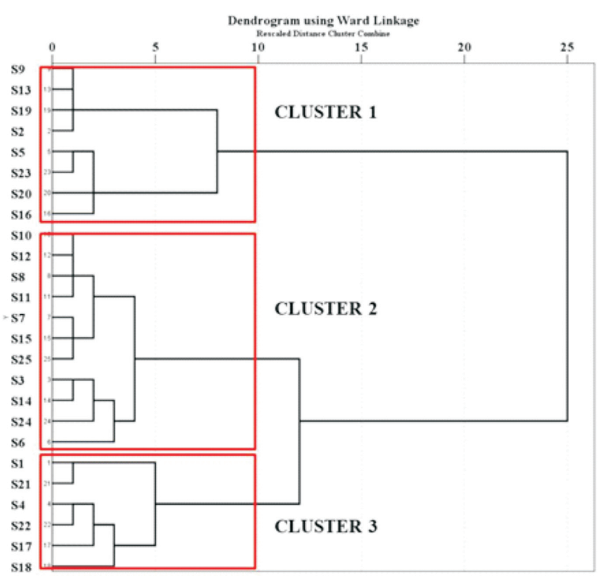

Fig. 6. Hierarchical cluster analysis grouping different sampling locations based on the irrigation suitability indices.

Conclusion

The study aimed to assess the suitability of groundwater for drinking, and irrigation purpose in Muzaffarpur district of Bihar. WAWQI, and Various irrigation indices such as SAR, %Na, RSBC, PS, MR, KR were applied along with Wilcox and USSL diagrams for complete evaluation of groundwater status. The groundwater was note fit for drinking purposes. The Wilcox diagram categorises groundwater samples into excellent to good and good to permissible classes. United State Salinity Laboratory diagram depicted that majority of the samples fall in medium salinity-low sodium hazard whereas one sample falls in high salinity-low sodium hazard. Based on SAR, %Na, RSBC, PS and KR values all the samples were suitable for irrigation. MR values indicate that 28% of the sampling stations are affected by Magnesium hazard. Different irrigation indices consider different variables and thus give different result. A comprehensive approach therefore needs to be applied to calculate an IWQI (Irrigation Water Quality Index). Therefore, the study being the most recent and preliminary documentation on the drinking water quality and irrigational suitability can aid Government of Bihar to build proper management plan, so that maximum utilisation of the groundwater resources, with minimal harmful impacts can take place.

Acknowledgements

The authors are thankful to CGWB, Bihar, for providing the physico-chemical data needed for this research, and all members of the Environmental Biology Laboratory at Patna University, Patna.

Declaration of competing interests

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work of this paper.

Funding information

The article did not receive any funding.

Conflict of Interest: None

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