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Assessment of surface and sub surface ground water quality index for irrigation purpose of Araria District of Bihar State using Remote Sensing and GIS

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Abstract

Ground water is the most important natural resources in koshi region of Bihar. Ground water quality assessment is essential to maintain the soil and crop productivity to higher labels without damaging the soil health. 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 (surface and sub-surface) 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 (surface and sub-surface) and give a comprehensive account of spatial and seasonal variation in its physico-chemical characteristics and irrigational suitability using GIS-based approach. Two forty-five groundwater samples were collected seasonally (pre-monsoon, monsoon and post-monsoon) from different locations of Araria district of Bihar in 2020–2023 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. The suitability of groundwater for irrigation was evaluated with the help of sodium adsorption ratio, percent sodium, residual sodium bicarbonate, magnesium hazard, and potential salinity. Based on different irrigational indices, 20% of surface water sample s of Araria district were unfit for irrigation in terms of PH, and 30% unfit in terms of TDS.30% of ground water samples of from tube well of 75-100 feet depths were unfit for irrigation in PH.35%,22.5%,15%, and 22.5% sample from tube wells of 15-30 feet depth were unfit for irrigation in terms of EC,TDS,NA and Nitrate respectively.35%,22.5%,15% and 22.5% sample from tube wells of 15-30 feet depth were unfit for irrigation in terms of EC, TDS, Na, and Nitrate respectively in Narpatganj. Kursakarta block of Araria district.

Keywords: Groundwater, GIS, spatial variation, seasonal variation, irrigational suitability, physico-chemical parameters

Introduction

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) [15]. 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. issues, primarily concerning public health (Nabi *et al.*, 2019; Zerbo *et al.*, 2020) [17, 25]. In India, agriculture is one of the most critical sectors of the economy. Good water qual ity is required for irrigation purposes to prevent damage to sensitive crops (Barua *et al.*, 2021; Kurdi *et al.*, 2013) [3, 16] and sustain current agricultural production. Therefore, ground water quality monitoring must be done regularly (Khan *et al.*, 2020; Suleiman *et al.*, 2020) [14, 20]. 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) [2, 4, 8, 9, 11] and India (Thankachan *et al.*, 2020; Al Maliki *et al.*, 2020; Srivastava, 2019; Prabhakaran & Seetharaman, 2020; Kadam *et al.*,

2021) [21, 1, 19, 13]. As per the literature review, no prior study on the assessment of groundwater quality based on irrigation indices in Araria 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) [18], Bhagalpur (Verma *et al.*, 2018) [22]. According to a national sample survey, 30.5% of Bamboo Boring It is most popular among small and marginal cultivators of North – Eastern part of Bihar. The Bamboo Tube-wells (BTWs) provide an excellent example of intermediate technology well suited to the needs of small sized land holdings. It may be mentioned that a BTW is essentially a shallow tube well but drilled up to a depth of only 50 ft. to 80 ft. But the shallow tube wells are comparatively deeper (up to 200 ft.) and tap more aquifers than the bamboo tube-wells. The traditional BTW was cased with a pipe made of bamboo strips. Originally the casing consisted of six strips of bamboo tied to steel rings of about 4" to 6" diameter and wrapped with coir strainer. A BTW consists of 3 bamboo pipes of 20 ft. length. Generally, three bamboos are used in a BTW. One or two laborers can finish the bamboo strips. One labour may wrap the coir strainer on bamboo pope. About 4 to 5 kg of coir strainers are used in a 20 ft. bamboo pipe. In this may about 15 kg coir strips are used in a BTW. The materials used are locally available and village labourers may easily finish the total work. The only skilled technician needed is the village blacksmith for iron rings. Six bamboo strips are circularly laid over iron rings of 4" to 5" diameter and fixed to rings with nails and iron wires. Then coir string is tightly bound around the bamboo frame. About 20 iron rings are used in a 20 ft. length bamboo frame. Thus the bamboo tube well has brought the tapping of ground water well within the means of small cultivators. The top 15 to 20 ft. portion of the casing is now replaced by the metal pipe to avoid the cutting of coir strainer by rats. Coir strainer has been replaced by plastic net and plastic wire., Araria and some part of Bhagalpur districts of Bihar. In the beginning the Bihar State Tube-well Department had several objections to the efficiency of BTW. The bamboo was easily affected by air and water, destroyed by white ants and rodents and could not resist the soil pressure. But the severe drought of 1972 turned out to be the proverbial 'blessings in disguise' for the districts of Saharsa and Purnea. As part of the programme to step up rabi production, the Government of Bihar, placed funds at the disposal of the district collectors for sanctioning loans to small farmers for sinking bamboo tube wells. To cap all it is extremely cheap and easy to handle. It does not require great skill or technical dexterity to operate the system. Besides it can be installed in a day and that also with local labour and materials easily and locally available. 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). 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 Araria district, situated in South Bihar alluvial plains (latitude 25° 56' and 26° 33' N; longitude 87° 23' and 87° 41' E) with an area of 28300 ha (Fig. 1). Araria district is covered by SOI topographical sheets on the scale of 1: 50,000 which are used as base map along with satellite imageries. The weather here is usually wet and humid; 80% humidity and the annual average rainfall is 1224mm, whose 80% rainfall is between July and September.

Methodology of sample collection and analysis

In the present study, 245 groundwater samples were collected seasonally from different depth (0-15), (15-30), (30-45), (45-60), (60-75), and (75-100) different sampling sites during 2020–2023. 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 Total solid, pH, electrical conductivity (EC), total dissolved solids (TDS), Ca²⁺, Mg²⁺, Na⁺, K⁺, HCO₃[–], Nitrate, sulphate, 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. 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), 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) [10].

Results and Discussion

Physico-chemical analysis

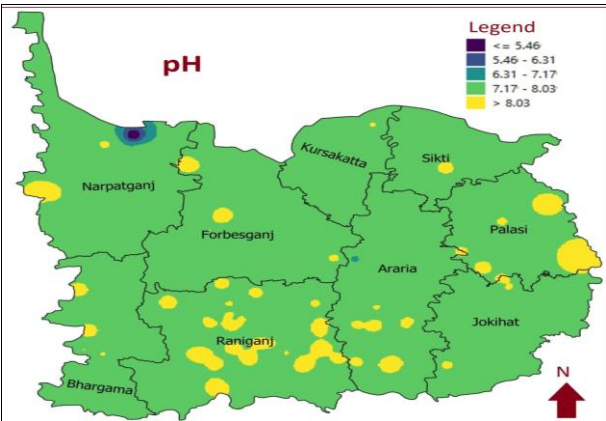
The statistical summary of the physico-chemical parameters has been represented in Table 1.

Table 1: pH, EC and TDS of surface and ground water samples

Sl. No.	Depth (feet)	No. of sample	pH				EC				TDS			
			Range (Optimum 6.5-8.2)		Samples beyond the optimum range		Range (Optimum 0.25-2.25)		Samples beyond the optimum range		Range (Optimum 25-550 ppm)		Samples beyond the optimum	
			Min.	Max	No.	%	Min.	Max	No.	%	Min.	Max	No.	%
Surface water														
1	0	10	7.5	8.4	2	20	0.25	0.78	0	0	55	590	3	30
Underground water														
2	0-15	15	7.2	8.8	3	20	0.25	2.45	5	33.3	140	780	3	20
3	15-30	40	7.2	8.5	4	10	0.35	2.55	15	35	145	1150	9	22.5
4	30-45	20	7.5	8.6	3	15	0.45	2.40	4	20	124	750	4	20
5	45-60	125	7.6	8.4	10	8	0.56	2.35	12	9.6	155	1050	25	8
6	60-75	25	7.7	8.6	3	12	0.58	1.4	0	0	150	552	3	12
7	75-100	10	7.2	8.9	3	30	0.75	1.35	0	0	320	657	1	10
	Total	245			28				36				45	

pH

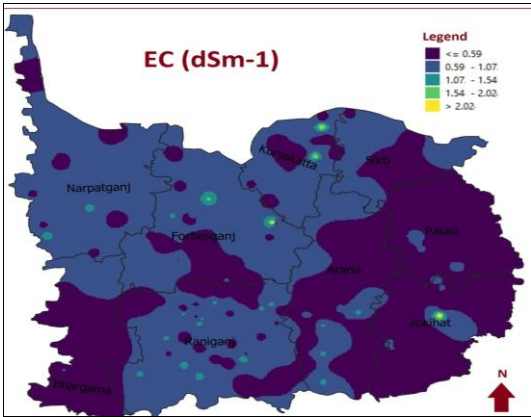
The spatial distribution map of pH in the study area indicates only 20% surface water sample of Araria district were unfit for irrigation in terms of PH. Rest all of the water samples were within the desirable limits (6.5–8.5) of BIS, 2012 standards (Fig. 1). Significant spa tial variation in pH was 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. 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.



Electrical conductivity (EC)

Figure 2 represents the spatial distribution of EC in the study area, and a high concentration of EC was observed in the eastern portion and a portion in the south part of the area. 35%, 22.5%, 15%, and 22.5% samples from tube well of 15-30 feet depth were unfit for irrigation in terms of Electrical conductivity (EC), TDS, Na, and Nitrate respectively. 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) [12, 1]. It is observed that the concentration of EC was maximum in post-monsoon; positively skewed values were noted only during monsoon and post-monsoon.



Total dissolved solid (TDS)

The spatial distribution map showed that TDS in most water samples from the Southern site was above the desirable limit of 500 mg/L as prescribed by BIS (2012) (Fig. 3). 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

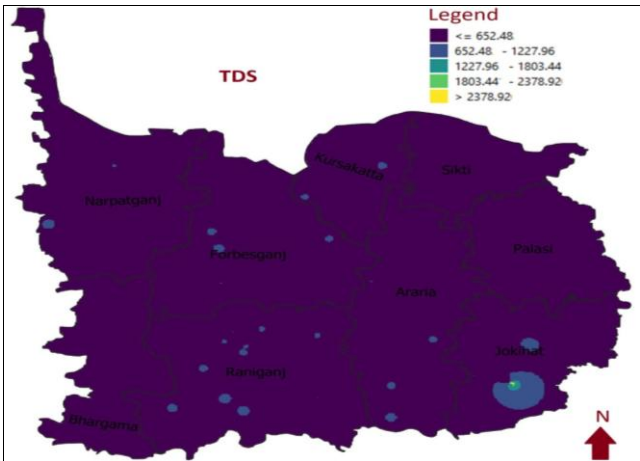
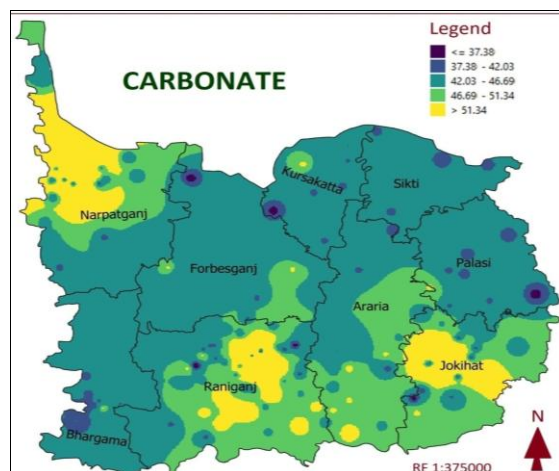


Table 2: Carbonate, Bicarbonate and Potassium of surface and ground water samples

Sl. No.	Depth (feet)	No. of sample	Carbonate (CO ₃ ²⁻) mg/l				Bicarbonate (HCO ₃ ⁻) mg/l				Potassium (K ⁺) mg/l			
			(Optimum 50 mg/l)		Samples beyond the optimum range		(Optimum 60 mg/l)		Samples beyond the optimum range		(Optimum 2.5mg/l)		Samples beyond the optimum	
			Min.	Max	No.	%	Min.	Max	No.	%	Min.	Max	No.	%
Surface water														
1	0	10	55	69	2	20	45	72	3	30	0.32	1.5	0	0
Underground water														
2	0-15	15	40	52	3	20	56	72	4	26.6	0.45	1.3	0	0
3	15-30	40	42	55	10	25	52	75	13	32.5	0.46	1.2	0	0
4	30-45)	20	43	56	3	15	53	72	4	20	0.43	1.20	0	0
5	45-60)	125	40	55	10	8	50	70	13	10.4	0.32	1.3	0	0
6	60-75)	25	45	50	3	12	42	55	3	12	0.31	1.0	0	0
7	75-100	10	42	51	2	20	43	52	0	0	0.35	1.0	0	0
	Total	245			31				33					

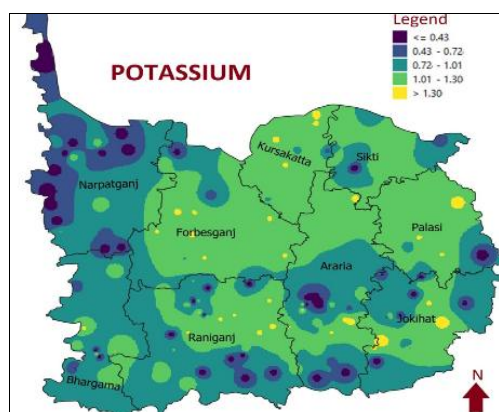
Carbonate ion (HCO_3^-)

The spatial distribution map of carbonate ion revealed that the entire study that the 30% surface sample was beyond the desirable limit of 60 mg/L as set by BIS (2012) (Fig. 4). The maximum value of surface sample 72 mg/L and minimum value 45 mg/L. In case of underground water sample at depth of (15-30) feet 32.5% sample were beyond the desirable limit of 50 mg/L as set by BIS (2012).



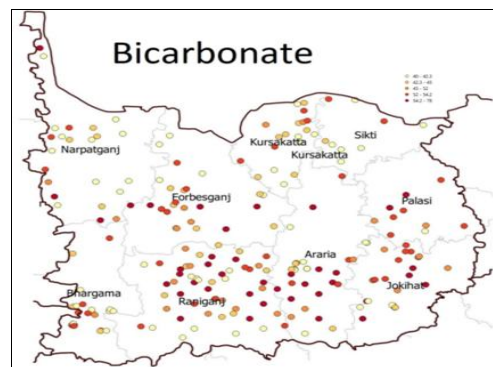
Potassium ion (K^+)

Spatial variation in K^+ ion revealed that the majority of sampling sites were within the prescribed limit of BIS (2012) except eastern areas (Fig. 5) 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 (Mar ghade, 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 20% surface sample was beyond the desirable limit of 50 mg/L as set by BIS (2012) (Fig. 6). The maximum value of surface sample 69 mg/L and minimum value 55 mg/L. In case of underground water sample at depth of (45-60) feet 25% sample were beyond the desirable limit of 50 mg/L as set by BIS (2012). 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. 6). ANOVA revealed significant spatial variation in bicarbonate ion values



Conclusion

The study was undertaken to evaluate the current groundwater status for physico-chemical characteristics and irrigation purposes at Araria district, 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.

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