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Comprehensive Assessment of Quality Index of Groundwater of Selected Government Schools in Patna District of Bihar, India

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Abstract

Purpose: This study assesses groundwater quality in Government Schools of Patna, Bihar, with a focus on its impact on student health and education. Groundwater, a critical resource for drinking and sanitation, is increasingly compromised by urbanization, industrialization, and inadequate waste management.

Methodology: Utilizing the Groundwater Quality Index (GWQI), water samples from schools were analyzed for parameters such as pH, total dissolved solids (TDS), alkalinity, conductivity, total hardness, calcium, magnesium, sulphate, nitrate, chloride, fluoride, and iron ion concentrations were analysed using standard devices. A correlation matrix of twelve parameters, among themselves and with water quality index (WQI) was constructed.

Findings: The values of all parameters were within the permissible limits (BIS: 2012) except iron concentration was found to be exceeding the prescribed standard limit. WQI has revealed the suitability of most of water samples for drinking not in all samples collected from fourteen different Government Schools. As findings revealed significant contamination in few schools, posing health risks, these issues adversely affect student attendance and academic outcomes.

Unique contribution to Theory, Practice and Policy: This research aligns with Sustainable Development Goal 6, aiming to ensure clean water access and underscores the urgent need for sustainable groundwater management in educational institutions. The results serve as a call to action for policymakers, educators, and stakeholders to prioritize water quality improvements, safeguarding children's health and fostering a conducive learning environment.

Keywords: *Groundwater, Government Schools, Sustainable Development Goals, Water Quality Index, Correlation Matrix, Physiochemical Parameters, Health Risks*

JEL Codes of Classification: *Q01, Q25, Q28, I00, C13, C43*

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INTRODUCTION

Bihar is located in the eastern part of the country. Bihar state lies between 83º 20' and 88º00' E Longitudes and 24º 15' and 27º 23' N Latitudes. It shares international border with Nepal in the north and is bounded in the east, west and south by West Bengal, Uttar Pradesh and Jharkhand states respectively. The state covers geographical area of 94,163 sq.km and has its capital at Patna. Bihar is mainly a vast stretch of very fertile flat land. It is endowed with several rivers namely Ganga, Son, Bagmati, Kosi, Budhi Gandak, and Falgu. Central part of Bihar comprises of some small hills, for example the Rajgir hills. The topography of Bihar can be easily described as a fertile alluvial plain occupying the Gangetic Valley. The plain extends from the foothills of the Himalayas.

In the north to a few miles south of the river Ganges as it flows through the state from the west to the east. Bihar is richly endowed with water resources, both the groundwater resource and the surface water resource. It has considerable water supply from the rivers which flow within the territory of the State. Ground water resources are dynamic in nature and are influenced by multiple factors, including irrigation activities, industrialization, and urbanization. Although changes in groundwater systems occur gradually, their cumulative impacts can be catastrophic (Baghvand et.al.2010). Regardless of the type of pollution—whether chemical (Baghvand et.al.2012) or bacteriological (e.g., bacteria and viruses) (Schijven e.t al. 2010)—aquifers are significantly affected. Consequently, the monitoring and conservation of this critical resource are imperative (Suvarna et.al. 2012).

Bihar is undergoing fast economic development with its impact on lifestyle, natural resources and environment. But economic growth has persisting inadequacies. Groundwater is one of the major sources of potable water in Patna City. Over abstraction of this limited resource, in addition to erratic waste disposal in surface waters, enhances the contamination of groundwater. It thus becomes obligatory to identify suitable management strategies to balance development without compromising on environment or public health (Sukumaran et.al. 2015).

WHO/UNICEF Joint Monitoring Programme (WHO/UNICEF, JMP 2024) produces internationally comparable estimates of progress on drinking water, sanitation and hygiene (WASH) and is responsible for monitoring the Sustainable Development Goal (SDG) targets related to WASH. This data update presents national, regional and global estimates for WASH in schools, with a special focus on menstrual health. Based on current trajectories, nearly 1 in 4 schools, or 23 percent, lack a basic drinking water service. 99 out of 138 countries with estimates had more than 75 per cent coverage of basic drinking water services in schools in 2023.

The United Nations' Sustainable Development Goal (UN SDG 2015) aims to "ensure that all girls and boys complete free primary and secondary schooling by 2030". The United Nations' 6th Sustainable Development Goal [SDG 6) calls for universal and equitable access to safe and affordable drinking water by 2030 (UN SDG 6 2015). Monitoring the quality and accessibility of water collected and consumed by household and school children will be essential to achieving these goals. A key element in achieving these goals is ensuring a healthy school environment, particularly access to clean drinking water to meet students' daily needs. Since children spend a significant portion of their day at school, access to safe drinking water is essential for their health and an indicator of effective water quality management (Chung et. al. 2009).

Schools are meeting places for children from diverse family backgrounds and can also become nodal centers for transmission of infections through contact with contaminated water, food, air, soil and surfaces. It helps children realise their full potential and prepares them for a healthy adult life, which can contribute to the growth of the nation

Students in elementary, middle, and high schools need to articulate ideas about water systems, derived from everyday experience and water monitoring activities that educators can build upon (Spellerberg et. al. 2004).

Contaminated drinking water poses serious health risks, exposing children to waterborne diseases such as cholera and typhoid, which can escalate into epidemics (Ahmed et al 2015).Each year, diarrheal diseases claim the lives of approximately 1.5 million children under five years of age (Dora et al 2015). Thus, providing clean drinking water is critical to supporting children's education, helping them enrol on time, complete their studies, and achieve their full cognitive potential (Evans et. al. 2014).

In the present study, the drinking water quality of 14 different Government Schools located in Patna district of Bihar. For calculation of water quality, parameters pH, total dissolved solids (TDS), alkalinity, conductivity, total hardness, calcium, magnesium, sulphate, nitrate, chloride, fluoride, and iron were selected for analysis. WQI was calculated and primary aim of work was to review the suitability of ground water for drinking in 14 selected Government Schools.

Research Gap

This assessment is expected to bridge existing knowledge gaps and contribute to a holistic understanding of groundwater challenges in Bihar, with a focus on mitigating risks to children's health. By addressing water quality issues at the grassroots level, this study aligns with the broader goals of ensuring safe drinking water access as enshrined in the SDG 6 (United Nations Sustainable Development Goals SDG 6 2015).

METHODOLOGY

The study was conducted to assess the Groundwater Quality Index (GWQI) in fourteen government schools (Table 1) of Patna, Bihar. Sampling locations were selected based on geographic distribution, proximity to potential contamination sources, and accessibility. Samples were collected and stored in sampling kits maintained at 4^{o}C brought to the laboratory for detailed analysis. Under this project total 12 parameters were studied (Table 1) following the methods (APHA 2017) reported from our laboratories (Kumar et. al. 2024, Anand et. al. 2024).

Calculation of Water Quality Index (WQI)

The GWQI was calculated using weighted arithmetic mean, where each parameter was assigned, a weight based on its relative significance in water quality assessment. The index was categorized into five classes ranging from "excellent" to "unsuitable for drinking" as per the Bureau of Indian Standards [BIS, 2012]. In this study, each parameter was assigned a unit weight (Wu) on a scale of 1–5, where value 1 represents the least health effect and value 5 represents the most adverse health effect the parameter causes when present in drinking water. This unit weight (Wu) of the parameter was then used to calculate the relative weight (Wr). This was done by finding the quotient of the specific unit parameter weight and the sum of all unit weights, as shown by the following equation:

$$Wr = \frac{Wu}{\sum Wu}$$

Wr = Relative Weight *Wu= Unit Weight*

The quality rating (Qr) is calculated by the following equation:

$$Qr = 100\left[\frac{Vn - Vi}{Vs - Vi}\right]$$

1. *Qr = Quality Rating*
   Vi = Ideal Value
   Vs = Standard Value
   Vn = Observed Value

Note: ideal for all parameters to be taken zero except for pH ideal value i.e. 7.0.

The subindex value of the parameter is calculated by following equation:

$$PIs = WrQr$$

PIs = subindex Value of the parameter

Water Quality index (Table-2) is obtained by the sum of all the parameter Subindices Value as shown in following equation:

$$WQI = \sum PIs$$

RESULTS AND DISCUSSION

Drinking water facility was available in all schools. Twelve schools with bore water facility were using the same source for both general use however two schools with hand bore well as the source .The basic statistics of groundwater chemistry and permissible limits under BIS 2012 are represented in Table 1.

Table 1: Basic Statistics of Groundwater Chemistry and Permissible Limits under BIS 2012

Sample	pH	Conductivity µS/cm	T.D.S mg/l	F^- mg/l	TH mg/l	Ca^{2+} mg/l	Ma^{2+} mg/l	Alkalinity mg/l	Cl^- mg/l	Iron mg/l	SO_4^{2-} mg/l	NO_3^- mg/l	Turbidity
BIS	6.5-8.5	-	500	1.0-1.5	200-600	75-200	30-100	200-600	250-1000	0.3	200-400	45	1.0-5.0
S1	7.05	622.9	404.8	0.31	216	65.73	12.63	280	29.98	1.77	10.6	1.20	1.2
S2	7.31	794.3	516.2	0.23	280	22.44	54.32	300	69.96	0.87	15.7	29.16	3.6
S3	7.45	603.3	392.2	0.21	248	22.44	46.56	318	17.99	2.45	7.6	0.51	1.1
S4	7.38	646	420	0.19	196	17.63	36.86	330	17.34	0.97	8.8	1.61	1.4
S5	7.30	704.7	458	0.23	244	19.23	47.53	294	31.98	2.96	12	19.58	2.1
S6	6.79	582.4	378.6	0.28	208	40.08	26.19	294	15.99	1.26	8.4	0.01	0.05
S7	7.27	817.1	532	0.27	228	33.66	34.92	300	49.97	0.20	16.2	23.03	1.5
S8	6.54	2092	1360	0.14	448	32.06	89.24	362	145.92	0.13	67	33.95	3.6
S9	7.74	650.1	422.6	0.26	236	24.04	42.68	292	41.97	1.79	13.3	0.39	1.2
S10	6.92	898.0	584	0.18	268	19.23	53.35	346	67.96	2.09	14.7	0.01	1.7
S11	7.36	964.8	628	0.16	304	16.03	64.02	328	71.96	3.16	16.2	26.07	3.4
S12	6.77	848.9	552	0.18	200	17.63	37.83	342	35.98	0.12	22.5	18.35	2.5
S13	7.44	715.2	464.8	0.25	220	24.04	38.80	294	47.97	0.35	14.6	2.24	1.0
S14	6.82	873.5	568	0.20	252	16.03	51.41	320	61.96	0.83	16	1.72	1.4

The pH values of drinking water samples ranged from 6.77 to 7.45. Total Dissolved Solids TDS of water is considered as the most important parameter to measure the quality of a water sample because it is directly correlated and affected by increased turbidity, hardness, alkalinity and conductivity of tested water samples. High concentrations of TDS, with limits value more than 300 mg/l is not suitable for drinking purposes. The acceptable range of TDS is 500 mg/l. In the present study, the value of TDS in the analyzed water samples varied between 404.8 and 1360 mg/l, as shown in Table. High values of S7, S8, S10, S11, S12, and S14 were observed which was above BIS permissible limit. High TDS influence the other qualities of water such as taste, hardness, corrosion properties, influences osmoregulation of freshwater organism (Prasad et. al. 2019).

Measurement of bicarbonates, carbonates, sulphates and chlorides of calcium and magnesium dissolved in water contributes to the degree of hardness of water sample. The desirable limit of total hardness is 200 mg/l whereas the maximum acceptable limit is 600 mg/l. The hardness, alkalinity, conductivity of analyzed water samples varies from 196- 448 mg/l, 280 –362 mg/l, 622.9 -2092 μS/cm, respectively. Magnesium ranged between 12.63 and 89.24 mg/l. The presence of magnesium normally increased the alkalinity of the soil and groundwater. Calcium ranged between 16.03 and 65.73 mg/l. Of all the collected drinking water samples, calcium concentration is higher than magnesium in S1. This can be explained by the abundance of carbonate minerals that compose the water-bearing formations as well as ion exchange processes and the precipitation of calcite in the aquifer.

The permissible limit of chloride in drinking water is between 250 and 1000 mg/1. In the present study, the results of chloride in all sampling sites range between 15.99 and 145.92 mg/l.

Sulphate comes in groundwater from mineral deposits in the rocks in form of sulphates. They form oxides, in contact with water. Also, there is an infiltration of industrial effluents contaminated with sulphates. High levels of sulphate in the drinking water supply can impart bad taste. According to the guidelines of Indian standard (IS:10500) maximum permissible value 200–400 mg/l. Data represents that the sulphate values in all the 14 sampling sites ranged between 7.6 and 67 mg/l. The Nitrate value ranged between 0.01 and 33.95 mg/l in all the sampling sites.

Iron represented the dominant cation in the analyzed in all drinking water samples as it varied between 0.12 and 3.60 mg/l. Iron concentration of drinking water. Minerals are micronutrients that are required in a small amount for our body. Excess amount of this creates harmful effect to our body. Similarly, Iron is a mineral that performs various roles in our body including formation of Hb. Iron may enter our body in both ferrous and ferric form The widespread presence of iron for ground water samples was also recognized as a serious problem by the authorities leading to stricter guideline by the Bureau of Indian Standards (BIS) in form of reduced maximum permissible limit for iron concentration in drinking water from 1 mg/L to 0.3 mg/L (BIS, 2012). The chemical analysis for water samples showed that all water samples except S7, S8, and S12 have iron concentration beyond the permissible limit of 0.3 mg/L. The iron concentration in these samples ranged from 0.13 to 3.16 mg/L (Table.2).

Potential sources of iron contamination in groundwater include industrial activities, agricultural runoff, and domestic sewage. The samples S5 and S11 have highest concentration of iron, because of the water flow household wastewater and existence of nearby drainage system into site S5 and location of school with water sample S11 near railway track. It has been reported that soils become contaminated with iron pollutants because of railroad tracks abrasion and electrochemical corrosion. Iron (general) concentration in soils of research site area corresponds to 6000-10000 mg/kg. Iron (general) concentration in surface run-off of research site area corresponds to 3.5-8.3 mg/L (Alexandr et.al. 2016).

WQI can help us to decide overall water quality. WQI provides a value with a quick and understandable explanation of water quality. BIS29, US EPA44 and WHO standard 12 parameter values were used for the calculation of WQI for different water samples (Table.2). WQI value calculated for sites S7, S12 and S13 was 21.99, 18.94 and 21.02, respectively. These results show that the water of these sites is suitable for drinking as it comes in the range of 00 –25. Additionally, the WQI value calculated for S1- S4, S6- S10 and S14 was 35.99, 32.51, 46.91, 25.7, 28.88, 36.39, 40.01, 43.43 and 27.15. The values are in the range of 26–50 for which shows that the water samples from these sites is suitable for drinking after normal treatment. However, the WQI values in sites S5 and S11 are more than 50, which are stated as poor quality of drinking water and needs treatment (Wiłkomirski et.al. 2011).

A correlation matrix of twelve parameters, namely, pH EC, TDS, chloride, fluoride, iron, total hardness, total alkalinity, calcium, magnesium, sulphate, and conductivity, among themselves and with water quality index (WQI) was constructed and is shown in Fig-1

Table 2: Water Quality Index

Sample	Source of Water	Latitude Longitude	WQI	WQS
S1	Hand bore well	25.6245562 85.041863	35.99	Good
S2	Bore well (Tap water)	25.638612 85.055965	32.51	Good
S3	Bore well (Tap water)	25.64856 85.078168	46.91	Good
S4	Hand bore well	25.64856 85.078168	25.71	Good
S5	Bore well (Tap water)	25.626591 85.123366	55.59	Poor
S6	Bore well (Direct)	25.62134 85.139954	28.88	Good
S7	Bore well (Tap water)	25.61682 85.170422	21.99	Excellent
S8	Bore well (Direct)	25.610139 85.199522	36.39	Good
S9	Bore well (Tap water)	25.575549 85.064156	40.01	Good
S10	Bore well (Tap water)	25.590664 85.109989	43.43	Good
S11	Bore well (Tap water)	25.599796 85.128638	62.70	Poor
S12	Bore well (Direct)	25.598356 85.151163	18.94	Excellent
S13	Bore well (Tap water)	25.605383 85.167071	21.02	Excellent
S14	Bore well (Tap water)	25.600594 85.186682	27.15	Good

Fig.1

	pH	*TDS*	*EC*	*TH*	*Ca Hard.*	*Mg Hard.*	*Alkalinity*	*Chloride*	*fluoride*	*Iron*	*nitrate*	*Sulphate*
pH	1											
TDS	-0.56479	1										
EC	-0.5649	0.999999	1									
TH	-0.37402	0.92259	0.922617	1								
Ca Hard.	-0.20637	-0.04188	-0.04164	-0.0642	1							
Mg Hard.	-0.22997	0.815877	0.815789	0.892831	-0.50678	1						
Alkalinity	-0.52134	0.685576	0.685355	0.561913	-0.46314	0.694464	1					
Chloride	-0.43204	0.930305	0.930234	0.928403	-0.10002	0.847144	0.574894	1				
fluoride	0.313248	-0.6276	-0.62738	-0.58996	0.672418	-0.81316	-0.92257	-0.57181	1			
Iron	0.398105	-0.32683	-0.32698	-0.0433	-0.09532	0.005677	-0.18221	-0.2676	-0.0103	1		
nitrate	-0.20324	0.62649	0.626162	0.626694	-0.14602	0.607264	0.311703	0.643419	-0.40981	-0.1657	1	
Sulphate	-0.56298	0.980156	0.980287	0.868475	0.022879	0.739889	0.621704	0.883389	-0.54223	-0.42722	0.61388	1

TDS exhibited a significant positive linear correlation with sulphate (0.98), total hardness (0.92), total alkalinity (0.68) and Conductivity (0.99). Conductivity has positive correlation with chloride (0.92) as their R-value was near to one as shown in Fig-1. Alkalinity and hardness both are moderately to positive correlated with chloride (0.57, 0.92) and sulphate ion (0.62, 0.86). Conductivity is correlated to both alkalinity (0.68) and sulphate (0.98). A good positive correlation of WQI was noticed with iron, and higher Fe concentrations might have been the results of interaction of underground oxidized iron minerals with organic matters present and can be due to the dissolution of Fe_2CO_3 present in rocks at a low pH (Mondal et.al.2011). Another reason for high Fe concentration may be due to the presence of microbial contamination and removal of dissolved oxygen by them, leading to reduced conditions and under theses reducing conditions, the solubility of Fe-bearing ores (siderite, marcasite, etc.) increases in water, leading to the increment in concentration of dissolved iron in groundwater.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This research studied the groundwater quality assessment for drinking concluded that most of the ground water samples are fit for human consumption. Obtained results of tested water samples were within recommended limits of Bureau of Indian Standards (BIS) except iron concentration. Based on WQI results, the entire study area comes under excellent to good water quality except ground water of the samples S5 and S11 collected from two locations have indicated poor quality of drinking water, therefore needs treatment before consumption.

Recommendations

As findings revealed significant contamination in few schools, posing health risks, these issues adversely affect student attendance and academic outcomes. Regular monitoring of water samples from the schools is required so that any kind of contamination can be detected and an early solution be administered for the well-being of the students who are the backbone of any society and economy.

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