

Physico-Chemical Evaluation of Groundwater Quality in the Sherghati Block of Gaya District, Bihar

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Abstract

Across the rural blocks of Gaya district, Bihar, groundwater remains the chief source of drinking and irrigation water, particularly in areas such as Sherghati, where surface water supply is seasonal and unreliable. This study looks at the physico-chemical condition of groundwater drawn from ten sampling points across Sherghati block during the pre-monsoon period. The parameters examined — pH, electrical conductivity, total dissolved solids, total hardness, calcium, magnesium, chloride, sulphate, nitrate, fluoride, iron and alkalinity — were tested following standard APHA procedures [1]. The values obtained were checked against the permissible limits set out in BIS 10500:2012 [2] and by the WHO [3], and a Water Quality Index (WQI) was derived using the weighted arithmetic index method [4]. With an average WQI of 175.98, groundwater quality in the block ranges from good to unfit for drinking at several locations, largely because of excess iron, fluoride, nitrate and hardness. Statistical and graphical assessments — including bar charts, a pie chart and correlation analysis — pointed to both natural (geogenic) and human-induced (anthropogenic) sources of contamination. The study calls for regular monitoring, appropriate treatment measures and community-level awareness efforts to safeguard public health in the region.

Keywords: *Groundwater Quality; Physico-Chemical Parameters; Water Quality Index (WQI); Sherghati, Gaya (Bihar); BIS/WHO Standards*

1. Introduction

Water ranks among the most essential natural resources underpinning life, agriculture and industrial growth. Leonardo da Vinci is often credited with describing water as the force that drives all of nature, and this holds especially true for rural India, where groundwater meets more than 80% of domestic and irrigation demand through wells, hand-pumps and tube-wells [5]. Groundwater quality is shaped both by natural processes — rock-water interaction, residence time and the character of the aquifer material — and by human activities such as agricultural run-off, poor sanitation planning, and disposal of industrial or domestic waste [6,7].

Sherghati, a sub-divisional town and community development block in the southern part of Gaya district, Bihar, lies along the banks of the Morhar River. Geologically, the area sits at the junction of hard-rock and alluvial zones on the fringe of the Chhotanagpur plateau, and groundwater occurs both in weathered or fractured crystalline rock and in shallow alluvial aquifers running along the river [8]. The block's economy is largely agrarian, and groundwater is drawn extensively through dug wells and hand pumps, both for household use and for irrigating paddy, wheat and vegetable crops.

In recent years, residents of Sherghati and neighbouring villages — Amethi, Barachatti, Imamganj, Dumaria, Banspahari, Fatehpur, Nimchak Bathani, Kharaon and Rampur — have raised concerns over brackish-tasting water, yellowish-brown staining of clothes and utensils (a sign of excess iron), scale build-up from hardness in cooking vessels, and stomach ailments during the hotter months. The Central Ground Water Board has likewise flagged iron and fluoride as growing concerns across parts of Gaya district [9,10].

Even so, detailed, block-level physico-chemical data for Sherghati remains scarce, which limits informed planning by the Public Health Engineering Department (PHED) and local Panchayati Raj institutions.

1.1 Statement of the Problem

- No up-to-date, station-wise physico-chemical data exists for groundwater across Sherghati block.
- Dependence on groundwater is rising as surface water supply grows scarcer and more unpredictable.
- Local reports of iron contamination, hardness and nitrate build-up remain unverified by quantitative data.
- No combined Water Quality Index assessment exists to clearly convey risk to non-technical stakeholders — panchayat members, residents and PHED officials.

1.2 Objectives of the Study

1. To examine the physico-chemical characteristics (pH, EC, TDS, TH, Ca, Mg, Cl^- , SO_4^{2-} , NO_3^- , F^- , Fe, alkalinity) of groundwater collected from ten locations in Sherghati block.
2. To compare the recorded values against BIS 10500:2012 and WHO drinking water standards.
3. To calculate the Water Quality Index using the weighted arithmetic index method and classify the samples accordingly.
4. To trace probable geogenic and anthropogenic sources of contamination through statistical and graphical analysis.
5. To propose corrective measures and management strategies for ensuring safe drinking water supply in the study area.

1.3 Study Area

Sherghati block (situated roughly between latitudes 24.55°–24.75° N and longitudes 84.75°–84.95° E) lies about 45 km south-west of Gaya town, within Bihar's Magadh division. The block experiences a sub-humid, sub-tropical monsoon climate, with average annual rainfall of around 1000–1100 mm, most of it received between June and September [11]. Elevation ranges from 95 to 140 m above mean sea level, and the terrain is undulating — lateritic uplands to the south giving way to alluvial plains bordering the Morhar River and its tributaries in the north. Ten locations — Sherghati Town, Amethi, Barachatti, Imamganj, Dumaria, Banspahari, Fatehpur, Nimchak Bathani, Kharaon and Rampur-Sherghati — were selected for sampling to ensure adequate spatial coverage of the block.

2. Materials and Methods

2.1 Sample Collection

Ten groundwater samples were drawn from hand pumps and tube wells (35–70 m deep) during the pre-monsoon months of April and May, a period chosen because solute concentrations tend to peak under the driest hydrological conditions [12]. Each sample was collected in a pre-washed, 1-litre HDPE bottle after running the pump for 5–10 minutes to clear stagnant water, following standard APHA (2012) guidelines [1]. Samples set aside for cation analysis were acidified with a small amount of concentrated HNO_3 to bring the pH below 2, preventing precipitation, while those meant for anion and physical-parameter testing were left unacidified and stored at 4 °C until analysis.

2.2 Analytical Methods

Field measurements of pH and electrical conductivity (EC) were taken using calibrated digital meters. Total dissolved solids (TDS) were determined both gravimetrically and by estimation from EC, using the relation $TDS \text{ (mg/L)} \approx 0.64 \times EC \text{ (}\mu\text{S/cm)}$ [13]. Total hardness, calcium and magnesium were measured through EDTA titration; chloride via the argentometric (Mohr) method; sulphate by turbidimetry; nitrate using UV-spectrophotometric screening; fluoride with the SPADNS colorimetric method; iron via the phenanthroline colorimetric technique; and total alkalinity by acid titration — all in line with APHA (2012) Standard Methods for the Examination of Water and Wastewater [1].

Parameter	Method / Instrument	Reference
pH	Digital pH meter (electrometric)	[1]
Electrical Conductivity	Conductivity meter	[1]
TDS	Gravimetric / EC-based estimation	[1,13]
Total Hardness	EDTA titrimetric method	[1]
Calcium & Magnesium	EDTA titrimetric method	[1]
Chloride	Argentometric (Mohr) titration	[1]
Sulphate	Turbidimetric method	[1]
Nitrate	UV-Spectrophotometric screening	[1]
Fluoride	SPADNS colorimetric method	[1]
Iron	Phenanthroline colorimetric method	[1]
Total Alkalinity	Acid titration method	[1]

Table 1. Parameters and Analytical Methods Used

2.3 Water Quality Index (WQI) — Numerical Method

The Water Quality Index condenses several water-quality indicators into a single dimensionless number, making it easier to convey overall water condition to planners and the public [4,14]. This study applies the weighted arithmetic index method originally proposed by Brown et al. (1972), carried out in three stages: Step 1 — Unit weight (W_i): Each parameter is given a weight that is inversely proportional to its recommended standard value (S_n):

$$W_i = k / S_n, \text{ where } k = 1 / \sum (1/S_n)$$

Step 2 — Quality rating (q_i): For each parameter, a rating is calculated relative to its permissible standard (S_n) and an ideal reference value (V_o , taken as zero for all parameters except pH, where $V_o = 7$):

$$q_i = [(V_i - V_o) / (S_n - V_o)] \times 100 \text{ (for pH); } q_i = (V_i / S_n) \times 100 \text{ (for all other parameters)}$$

Step 3 — Water Quality Index: The overall WQI at each station is the weighted average of all the quality ratings:

$$WQI = \sum (W_i \times q_i) / \sum W_i$$

The resulting values are grouped as follows: below 50 = Excellent; 50–100 = Good; 100–200 = Poor; 200–300 = Very Poor; above 300 = Unfit for drinking, based on the classification put forward by Chatterji and Raziuddin (2002) and Ramakrishnaiah et al. (2009) [12,15].

Parameter	BIS Desirable Limit (Sn)	Unit	Unit Weight (Wi)
pH	6.5–8.5	-	0.02591
TDS	500	mg/L	0.00044
Total Hardness	200	mg/L	0.00110
Calcium (Ca ²⁺)	75	mg/L	0.00294
Magnesium (Mg ²⁺)	30	mg/L	0.00734
Chloride (Cl ⁻)	250	mg/L	0.00088
Sulphate (SO ₄ ²⁻)	200	mg/L	0.00110
Nitrate (NO ₃ ⁻)	45	mg/L	0.00489
Fluoride (F ⁻)	1.0	mg/L	0.22022
Iron (Fe)	0.3	mg/L	0.73407
Alkalinity	200	mg/L	0.00110

Table 2. BIS (2012) Desirable Limits and Computed Unit Weights (Wi) for Each Parameter

2.4 Worked Numerical Example (Sample Station: Sherghati Town)

To demonstrate the calculation procedure, the complete step-wise WQI computation for the Sherghati Town sample is set out below. The unit weight (Wi) for each parameter (Table 2) was multiplied by its quality rating (qi), obtained from the observed value (Vi); the sum of these products ($\sum Wi \cdot qi$) was then divided by the sum of the weights ($\sum Wi = 1.000$) to give the station's WQI.

Parameter	Vi (Observed)	Sn (Standard)	Wi	qi	Wi × qi
pH	7.6	8.5	0.02591	40	1.036
TDS	612	500	0.00044	122.4	0.054
Total Hardness	340	200	0.0011	170	0.187
Calcium	78	75	0.00294	104	0.305
Magnesium	34	30	0.00734	113.33	0.832
Chloride	142	250	0.00088	56.8	0.05
Sulphate	64	200	0.0011	32	0.035
Nitrate	28	45	0.00489	62.22	0.305
Fluoride	0.6	1	0.22022	60	13.213
Iron	0.42	0.3	0.73407	140	102.77
Alkalinity	288	200	0.0011	144	0.159
Total			$\sum Wi = 1.000$		$\sum (Wi \times qi) = 118.947$

Table 3. Step-wise WQI Calculation for Sherghati Town (Illustrative Example)

WQI (Sherghati Town) = $\Sigma(W_i \times q_i) / \Sigma W_i = 118.947 / 1.000 = 118.95$, which places it in the "Poor" category (100–200). Iron ($W_i \cdot q_i = 102.77$, roughly 86% of the total index) and fluoride ($W_i \cdot q_i = 13.21$, about 11%) were the leading contributors to this elevated score — a direct result of iron's very high unit weight, driven by its stringent BIS limit of 0.3 mg/L. The same procedure was applied to the remaining nine stations, with the results reported in Section 3.

2.5 Statistical Analysis

Basic descriptive statistics — mean, standard deviation, minimum and maximum — were worked out for each parameter, together with the percentage of stations exceeding the BIS desirable limit for every parameter. Spatial patterns were visualised using grouped bar charts, a WQI bar chart, a pie chart of quality categories, and a dual-axis line chart tracking pH and EC together, an approach broadly consistent with graphical methods used in comparable regional hydrogeochemical studies [16,17]. Standard spreadsheet and statistical tools were used throughout.

3. Results and Discussion

3.1 Physico-Chemical Characteristics

Tables 4 and 5 summarise the physico-chemical data recorded across the ten stations. pH values ranged from 7.1 to 8.4 (mean 7.73), pointing to a mildly alkaline character typical of carbonate-bearing alluvial and weathered crystalline aquifers along the Gangetic fringe [18]. Electrical conductivity ranged from 720 to 1560 $\mu\text{S}/\text{cm}$ (mean 1079 $\mu\text{S}/\text{cm}$), reflecting moderately high ionic content, broadly in line with findings from elsewhere in the Gaya–Nawada groundwater belt [8,19].

Station	pH	EC ($\mu\text{S}/\text{cm}$)	TDS (mg/L)	T. Hardness (mg/L)	Alkalinity (mg/L)
Sherghati Town	7.6	980	612	340	288
Amethi	7.9	1120	705	410	335
Barachatti	7.2	860	540	280	240
Imamganj	8.1	1340	845	460	372
Dumaria	7.4	790	495	260	222
Banspahari	8.3	1480	932	520	405
Fatehpur	7.1	720	452	240	205
Nimchak Bathani	7.8	1050	660	380	310
Kharaon	8.4	1560	985	560	428
Rampur-Sherghati	7.5	890	560	300	250

Table 4. Physical Parameters of Groundwater Samples (Sherghati Block)

Station	Ca (mg/L)	Mg (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	F ⁻ (mg/L)	Fe (mg/L)
Sherghati Town	78	34	142	64	28	0.6	0.42
Amethi	92	42	178	88	52	1.2	0.85
Barachatti	64	26	96	42	18	0.4	0.28
Imamganj	104	48	210	112	61	1.6	1.12
Dumaria	58	24	84	38	15	0.35	0.22
Banspahari	118	54	245	128	68	1.8	1.35
Fatehpur	52	21	76	34	12	0.3	0.18
Nimchak Bathani	86	38	160	76	44	0.9	0.68
Kharaon	128	58	268	138	74	2.1	1.58
Rampur-Sherghati	68	28	102	46	21	0.5	0.31

Table 5. Major Ion Concentrations of Groundwater Samples (Sherghati Block)

TDS values fell between 452 and 985 mg/L; eight of the ten stations (80%) crossed the BIS desirable threshold of 500 mg/L, though none exceeded the permissible ceiling of 2000 mg/L applicable where no alternative source exists [2]. Total hardness (240–560 mg/L) was above the 200 mg/L desirable limit at every station, placing the groundwater in the "hard" to "very hard" category under the Sawyer and McCarty classification [20] — the result of dissolving calcium- and magnesium-bearing minerals such as calcite, dolomite and feldspar present in the weathered crystalline and alluvial rock [21].

Figure 1. Spatial Variation of Key Physico-Chemical Parameters against BIS (2012) Desirable Limits

Chloride levels (76–268 mg/L) remained under the BIS desirable limit of 250 mg/L everywhere except Kharaon, which crossed it slightly — likely because of nearby domestic wastewater seepage [22]. Sulphate concentrations (34–138 mg/L) stayed within acceptable limits across the board. Nitrate, however, exceeded the 45 mg/L threshold at four stations — Amethi, Imamganj, Banspahari and Kharaon — most plausibly linked to fertilizer application and, in some cases, leakage from nearby on-site sanitation systems close to shallow wells [23,24].

Fluoride concentrations spanned 0.30 to 2.10 mg/L, crossing the 1.0 mg/L desirable limit at four stations, with Kharaon (2.10 mg/L) and Banspahari (1.80 mg/L) also exceeding the BIS permissible ceiling of 1.5 mg/L. This is generally attributed to the weathering of fluoride-bearing minerals such as biotite and apatite within the underlying crystalline rocks of the Chhotanagpur Gneissic Complex [25,26]. Iron was the most frequently exceeded parameter, going past the 0.3 mg/L limit at 7 of the 10 stations (70%) — matching the yellowish staining and metallic taste reported by residents, and consistent with known iron-enrichment patterns in Bihar's alluvial and lateritic aquifers, driven by reducing (low-oxygen) subsurface conditions [9,27].

3.2 Descriptive Statistics

Parameter	Mean	Std. Dev.	Min	Max
pH	7.73	0.45	7.1	8.4
EC ($\mu\text{S}/\text{cm}$)	1079	278.6	720	1560
TDS (mg/L)	678.6	185.5	452	985
Total Hardness (mg/L)	375	111.1	240	560
Calcium (mg/L)	84.8	25.7	52	128
Magnesium (mg/L)	37.3	13	21	58
Chloride (mg/L)	156.1	68.5	76	268
Sulphate (mg/L)	76.6	38.6	34	138
Nitrate (mg/L)	39.3	23.4	12	74
Fluoride (mg/L)	0.98	0.66	0.3	2.1
Iron (mg/L)	0.7	0.51	0.18	1.58
Alkalinity (mg/L)	305.5	78.2	205	428

Table 6. Descriptive Statistics of Physico-Chemical Parameters ($n = 10$)

The coefficient of variation was greatest for iron and fluoride (over 70%), pointing to marked spatial variability, most likely driven by local geological differences and variation in well depth, whereas pH varied the least (CV of roughly 5.8%), suggesting a fairly well-buffered carbonate system across the block [28].

Parameter	% Stations Exceeding BIS Limit	Remarks
pH	0%	All stations within desirable range
TDS	80%	8 of 10 stations exceed 500 mg/L limit
Total Hardness	100%	All stations exceed 200 mg/L; water is hard to very hard
Calcium	60%	Elevated at 6 stations
Magnesium	60%	Elevated at 6 stations
Chloride	10%	Only Kharaon exceeds 250 mg/L
Sulphate	0%	Within permissible limit at all stations
Nitrate	40%	4 stations exceed 45 mg/L — possible sewage/fertilizer influence
Fluoride	40%	4 stations exceed 1.0 mg/L desirable limit
Iron	70%	7 stations exceed 0.3 mg/L — major concern in the study area
Alkalinity	100%	All stations exceed 200 mg/L

Table 7. Percentage of Sampling Stations Exceeding BIS (2012) Desirable Limits

3.3 Water Quality Index (WQI)

WQI values across the ten stations ranged from 52.00 at Fatehpur to 438.80 at Kharaon, with a block-wide average of 175.98. Under the classification scheme used, four stations (40%) fell into the "Good" category, two (20%) were rated "Poor," one (10%) "Very Poor," and three (30%) were classified "Unfit for drinking" without treatment. Iron was the leading contributor to elevated WQI values at almost every station, owing to its very high unit weight ($W_i = 0.734$) stemming from its strict BIS standard, with fluoride ($W_i = 0.220$) a distant second.

Sampling Station	WQI Value	Water Quality Category
Sherghati Town	118.95	Poor
Amethi	238.51	Very Poor
Barachatti	79.14	Good
Imamganj	314.10	Unfit for drinking
Dumaria	63.57	Good
Banspahari	375.49	Unfit for drinking
Fatehpur	52.00	Good
Nimchak Bathani	189.87	Poor
Kharaon	438.80	Unfit for drinking
Rampur-Sherghati	89.32	Good

Table 8. Computed WQI and Water Quality Classification of Sampling Stations

Figure 2. Water Quality Index (WQI) of Groundwater Samples with Classification Thresholds

Figure 3. Percentage Distribution of Sampling Stations by WQI Category

Figure 4. Spatial Trend of pH and Electrical Conductivity across Sampling Stations

The spatial pattern shown in Figure 2 indicates that the worst-affected stations — Kharaon, Banspahari and Imamganj — lie in the more intensively farmed and densely populated outer parts of the block, while comparatively better water quality is found at Fatehpur, Dumaria, Barachatti and Rampur-Sherghati, all closer to the Morhar riverbed, where stronger recharge and shallower, better-flushed aquifers may help dilute naturally occurring contaminants [29]. A similar link between land use, aquifer depth and water quality has been documented in comparable hard-rock and alluvial transition zones elsewhere in eastern India [30].

UNESCO's World Water Development reports have repeatedly stressed that access to safe, affordable drinking water is fundamental to human health, dignity and development. Declining groundwater quality in aquifers that communities depend on directly threatens this goal — underscoring why a block-level assessment of Sherghati's groundwater is both timely and necessary.

4. Findings

- Groundwater across Sherghati block is mildly alkaline (pH 7.1–8.4) and moderately to highly mineralized (EC 720–1560 $\mu\text{S}/\text{cm}$).
- All sampled stations exceed the BIS desirable limit for total hardness and total alkalinity, meaning the entire block's groundwater is uniformly hard.

- Iron stands out as the most serious contaminant, exceeding the permissible limit at 70% of stations and contributing the most to the computed Water Quality Index.
- Fluoride exceeds the desirable limit at 40% of stations, with Kharaon and Banspahari also crossing the BIS permissible ceiling of 1.5 mg/L, raising concern over long-term dental or skeletal fluorosis.
- Nitrate exceeds the desirable limit at 40% of stations, suggesting agricultural and/or sanitary sources of contamination near shallow wells.
- Based on the computed WQI, 30% of the sampled sources (Imamganj, Banspahari, Kharaon) are unfit for drinking without treatment, while 40% fall in the "Good" category.
- Chloride and sulphate remain within safe limits almost everywhere, indicating these are not immediate concerns in the study area.
- Stations closer to the Morhar River, with shallower and better-flushed aquifers, tend to show comparatively better water quality.

5. Conclusion

This physico-chemical assessment of groundwater in Sherghati block, Gaya district, Bihar, shows that while the water remains broadly usable for domestic purposes in many locations, close to a third of the sampled stations yield groundwater unsuitable for direct drinking, based on the computed Water Quality Index. Elevated iron and fluoride, most likely of geogenic origin tied to weathering of the underlying crystalline and lateritic rock, together with locally raised nitrate levels probably linked to human activity, emerge as the principal factors lowering water quality. Consistently high hardness and alkalinity further limit the water's practical and aesthetic usability for domestic purposes. These findings support long-standing concerns voiced by local residents about taste, staining and scaling, and provide the first systematic, station-wise quantitative baseline for the block. The weighted arithmetic WQI method proved to be a useful, easily communicable way of turning complex, multi-parameter chemical data into a classification that planners, the Public Health Engineering Department and the local community can act on.

6. Suggestions and Recommendations

6. Iron removal units (aeration-cum-filtration systems or manganese greensand filters) should be installed at hand pumps in Kharaon, Banspahari, Imamganj and Sherghati Town, where iron concentrations are highest.
7. Community-level defluoridation units (using activated alumina or the Nalgonda technique) should be set up at Kharaon and Banspahari to reduce fluorosis risk, alongside periodic dental and skeletal health screening of residents.
8. Nitrate-affected sources should be checked for proximity to soak-pits, septic tanks and fertilizer-intensive fields; sanitary setback distances recommended by PHED/CGWB should be enforced for new wells.
9. Regular water quality monitoring — at minimum twice a year, before and after the monsoon — should be institutionalised by the Gaya district PHED in coordination with the Central Ground Water Board.
10. Rainwater harvesting and managed aquifer recharge structures should be promoted, particularly in the poorer-quality outer zones, to dilute geogenic contaminants through enhanced recharge.
11. Community awareness programmes should be conducted in Hindi or the local dialect, covering safe water handling, boiling/filtration practices, and the health significance of hardness, iron and fluoride.

12. Alternative or blended water supply schemes — such as piped surface-water-based schemes under the Jal Jeevan Mission — should be prioritised for villages classified as "Unfit for drinking" in this study.
13. Future studies should extend sampling to include microbiological testing, trace metals (including arsenic), and post-monsoon seasonal variation, for a more complete water-safety assessment of Sherghati block.

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