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SCHOOL DRINKING-WATER QUALITY IN AN URBAN INDIAN SETTING: MULTI-PARAMETER ASSESSMENT OF PHYSICOCHEMICAL AND CHEMICAL CHARACTERISTICS ACROSS SELECTED SCHOOLS OF BHOPAL

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ABSTRACT

Background: Safe drinking water in schools is a core component of a healthy learning environment. Chemical contaminants may remain undetected by routine visual inspection, making systematic laboratory surveillance important. This study assessed drinking-water quality at selected schools in Bhopal, Madhya Pradesh, using a multi-parameter approach. Methods: A laboratory assessment was conducted in 10 selected schools during February 2025. Samples were obtained from tap-water and refrigerated drinking-water points. The analytical panel comprised pH, total dissolved solids (TDS), turbidity, nitrate, total hardness, electrical conductivity, fluoride, chloride, total alkalinity, calcium, potassium, sodium, sulphate, iron, copper and selected trace metals. Qualitative microbiological screening was also reported. Analytical procedures followed the laboratory procedures supplied with the study records and results were interpreted with reference to BIS IS 10500:2012 and WHO guidance. Results: pH ranged from 7.75–8.47 and TDS from 119.7–357.9 mg/L. Nitrate ranged from 45–75 mg/L, with nine of 10 samples exceeding the BIS acceptable value of 45 mg/L; the same nine samples exceeded the WHO guideline of 50 mg/L. Hardness ranged from 112–276 mg/L, with four samples above 200 mg/L. Turbidity ranged from 0.42–2.77 NTU and fluoride from 0.10–1.10 mg/L. Chloride, sulphate, sodium and iron were comparatively low. Iron ranged from 0.025–0.150 mg/L and copper from 0.010–0.047 mg/L. Cobalt, chromium, cadmium and lead were reported below the detection limit. Qualitative bacterial testing was also negative in all samples. Conclusions: The principal water-quality concern identified was nitrate, which requires analytical confirmation, seasonal surveillance and source-specific investigation. The study should be regarded as a baseline school-level surveillance assessment rather than evidence of city-wide contamination. Larger, repeated and probabilistically sampled investigations are warranted.

Key words: School Drinking Water; Nitrate; Water Quality; Physicochemical Parameters; Heavy Metals; Environmental Health.

1 INTRODUCTION

Safe drinking water is essential for health, hydration and participation in school activities. Schools are distinctive water-use environments because children may repeatedly consume water from common sources during the school day. Recent evidence from low- and middle-income settings indicates that school water, sanitation and hygiene (WASH) conditions are relevant to health and educational outcomes, although intervention effects are context-dependent[1–4]. Chemical contamination is an important component of drinking-water safety because many contaminants are not apparent from colour, odour or taste. Nitrate is particularly relevant because it is highly mobile in water and may enter drinking-water systems through nitrogenous fertilizers, wastewater, sewage leakage, septic systems and other anthropogenic pathways [5–8].

The health relevance of nitrate has traditionally centred on infant methaemoglobinaemia. More recent epidemiological studies have examined possible associations with reproductive outcomes and chronic disease. A 2023 systematic review and meta-analysis reported associations between drinking-water nitrate and preterm birth and some congenital outcomes. Reviews of cancer evidence have identified potential associations but also substantial uncertainty and heterogeneity in exposure assessment [9–11]. Accordingly, exceedance of a guideline value should be treated as a water-quality management signal and not as evidence of disease in exposed individuals.

The present study was undertaken to characterize drinking-water quality at 10 selected schools in Bhopal using the available laboratory dataset. The study specifically aimed to identify parameters requiring corrective or confirmatory investigation and to provide a scientifically defensible baseline for future school-level water-quality surveillance[12].

2. MATERIAL AND METHODS

2.1 Study design and setting

A laboratory-based water-quality assessment was conducted in selected schools of Bhopal, Madhya Pradesh, India. Ten schools from different urban localities were included. The study was conducted during February 2025. Descriptive statistics were calculated for each parameter as minimum, maximum, mean, standard deviation and median.

2.2 Sampling sites and water sources

Samples were designated S1–S10. Water was collected from either school taps or refrigerated drinking-water systems. The school-wise sampling frame is presented in Table 1.

2.3 Analytical procedures

2.3.1 pH

pH was measured using a digital pH meter (Hanna HI3512). The instrument was calibrated with pH 4, 7 and 9 buffer solutions before sample measurement. The electrode was immersed in the sample and the stabilized value was recorded.

2.3.2 Total dissolved solids and electrical conductivity

TDS and electrical conductivity were measured using the Hanna HI3512 meter. TDS values were recorded in ppm (numerically equivalent to mg/L for dilute aqueous samples).

2.3.3 Turbidity

Turbidity was measured using a Systronics µC Turbidity Meter-135 and reported in nephelometric turbidity units (NTU).

2.3.4 Nitrate, sulphate and fluoride

Nitrate and sulphate were assessed using field-test kits (Aquasol, Rakiro Biotech System, India). Fluoride was determined using a fluoride test kit and colour-comparison procedure (Aquasol, Rakiro Biotech System, India).

Table 1. Selected schools and drinking-water sources.

Sample	School	Source
S1	Government Naveen Girls Higher Secondary School, Tulsi Nagar	Tap
S2	Kopal High School, Nehru Nagar	Refrigerated drinking water
S3	Kamla Nehru Higher Secondary School, Kotra Sultanabad	Refrigerated drinking water
S4	Government High School, Kotra Sultanabad	Refrigerated drinking water
S5	Mother Teresa School (Nirmala Shishu Bhavan), Nehru Nagar	Tap
S6	AVM School (Senior Secondary and Boarding School), Nehru Nagar	Refrigerated drinking water
S7	Deepshikha School, TT Nagar	Refrigerated drinking water
S8	Government Kasturba Girls Higher Secondary School, TT Nagar	Refrigerated drinking water
S9	Government Higher Secondary School Vidya Vihar, Professor Colony	Tap
S10	Rose Mary Higher Secondary School, Harshwardhan Nagar	Tap

2.3.5 Total hardness

Total hardness was determined by the EDTA titrimetric method. The laboratory manual specifies a measured water aliquot treated with ammonia buffer and Eriochrome Black T indicator, followed by titration with standardized EDTA to the blue endpoint. Results were expressed as mg/L as $CaCO_3$.

2.3.6 Chloride

Chloride was determined by argentometric titration. The sample was titrated with silver nitrate in the presence of potassium chromate indicator, with the brick-red silver chromate endpoint used for calculation.

2.3.7 Total alkalinity

Total alkalinity was determined by acid titration using the laboratory procedure with phenolphthalein and methyl-orange endpoints. Results were expressed as mg/L as $CaCO_3$.

2.3.8 Calcium, potassium and sodium

Calcium, potassium and sodium were measured using a flame photometer (Systronics 1027, India). The study record states that standards ranging from 1–100 ppm were prepared for instrument calibration before analysis of the school-water samples.

2.3.9 Iron, copper and trace metals

The iron, copper, cadmium, chromium, cobalt and lead were investigated by atomic absorption spectroscopy using an ECIL-4141 instrument, with calibration standards prepared over a 1–5 ppm range at the relevant analytical wavelengths.

2.3.10 Microbiological assessment

The bacterial contamination was assessed by a qualitative method (H_2S Vial) and that all samples were negative.

2.3.11 Water Quality Index (WQI) assessment

Water Quality Index (WQI) was calculated using the weighted arithmetic index method originally proposed by Brown et al. (1972)(12). The parameters included in the present WQI assessment were pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium, iron, fluoride and turbidity. BIS drinking-water standards were used as the standard permissible values (\(S_n\)), while the ideal value (Vo) was considered as 7.0 for pH and zero for the remaining parameters. Electrical conductivity values were converted to µS/cm before WQI calculation. The proportionality constant was calculated as $K=1/\Sigma(1/Sn))$, followed by parameter-specific unit weights $Wi=K/Sn$. The quality rating for each parameter was calculated as $qn=|Vn-Vo|/(Sn-Vo) \times 100)$, and the overall WQI was obtained as $WQI= \Sigma (Wiqn)$. Water quality was classified as excellent (0–25), good (26–50), poor (51–75), very poor (76–100), and unsuitable for consumption (>100), as per the Brown et al. classification.

3. RESULTS AND DISCUSSION

The complete school-wise analytical dataset is presented in Table 2 & Table 3.

3.1 pH

pH ranged from 7.75 (S4) to 8.47 (S9 and S10), with a mean of 8.26. All 10 samples were within the BIS acceptable pH range of 6.5–8.5. The dataset therefore indicates mildly alkaline water rather than pH non-compliance.

3.2 TDS and electrical conductivity

TDS ranged from 119.7 to 357.9 mg/L, with a mean of 206.07 mg/L. Four samples (S2, S3, S4 and S6) exceeded 200 mg/L; however, none exceeded the BIS acceptable TDS value of 500 mg/L. The 200 mg/L threshold should therefore be treated as a descriptive study threshold, not as a BIS failure criterion.

3.3 Turbidity

Turbidity ranged from 0.42 to 2.77 NTU. Eight samples exceeded 1 NTU, while all remained below 5 NTU. This distinction is relevant because IS 10500:2012 uses a lower acceptable value and a higher permissible limit under specified conditions. Turbidity should therefore be considered an operational-quality parameter requiring attention in several schools.

3.4 Nitrate

Nitrate was the principal parameter of concern. Concentrations ranged from 45 to 75 mg/L, with a mean of 65.90 mg/L and median of 70 mg/L. S1 was 45 mg/L, whereas S2–S10 ranged from 55–75 mg/L. Nine of 10 samples (90%) exceeded the BIS acceptable value of 45 mg/L and nine of 10 samples (90%) exceeded the WHO guideline value of 50 mg/L as nitrate ion. The result is therefore a priority signal for confirmatory testing and source investigation.

3.5 Hardness

Total hardness ranged from 112 to 276 mg/L as $CaCO_3$, with a mean of 180.80 mg/L. Four samples—S2, S3, S4 and S6, exceeded 200 mg/L. The values indicate moderate to relatively high hardness in selected schools but do not by themselves indicate toxic contamination.

3.6 Fluoride, chloride, alkalinity and sulphate

Fluoride ranged from 0.10 to 1.10 mg/L. S4 (1.10 mg/L) exceeded the BIS acceptable value of 1.0 mg/L but remained below the permissible limit of 1.5 mg/L; S3 was exactly 1.0 mg/L. Chloride ranged from 16.99 to 75.97 mg/L and sulphate from 20 to 70 mg/L, remaining below their applicable BIS acceptable values. Total alkalinity ranged from 20 to 46 mg/L as CaCO3.

3.7 Calcium, potassium and sodium

Calcium ranged from 4.74 to 59.53 mg/L, potassium from 0.09 to 0.39 mg/L and sodium from 4.53 to 41.16 mg/L. The highest sodium concentration was observed in S4. These major-ion measurements are useful for describing mineral characteristics but should not be interpreted as evidence of a specific hydrogeochemical source from the present sample size.

3.8 Iron, copper and selected trace metals & Microbiological findings

Iron ranged from 0.025 to 0.150 mg/L and copper from 0.010 to 0.047 mg/L. All iron values were below the BIS acceptable concentration of 0.3 mg/L. The supplied record reports cobalt, chromium, cadmium and lead as below the laboratory detection/reporting threshold. Because detection limits were not provided, these findings should be reported as non-detects rather than absolute absence. The study recorded negative qualitative bacterial-contamination results in all 10 samples.

3.9 Water Quality Index

The comprehensive WQI values ranged from 23.41 to 89.88 across the ten sampled schools. Two samples (S8 and S10; 20%) were classified as having excellent water quality, three samples (S2, S5 and S7; 30%) as good, four samples (S1, S3, S6 and S9; 40%) as poor, and one sample (S4; 10%) as very poor. The highest WQI was recorded for S4 (89.88), followed by S3 (68.31), S1 (58.42), S9 (58.33) and S6 (55.00). S8 showed the lowest WQI (23.41), followed by S10 (24.85). Thus, 70% of the sampled schools fell within the good-to-excellent categories, whereas 40% were classified as poor and 10% as very poor under the applied WQI classification. These results demonstrate appreciable inter-school variability in integrated physicochemical water quality.

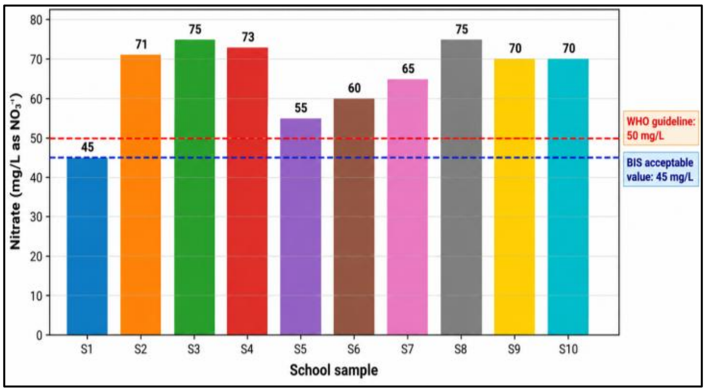

Figure 1. School-wise nitrate concentrations compared with BIS and WHO reference values.

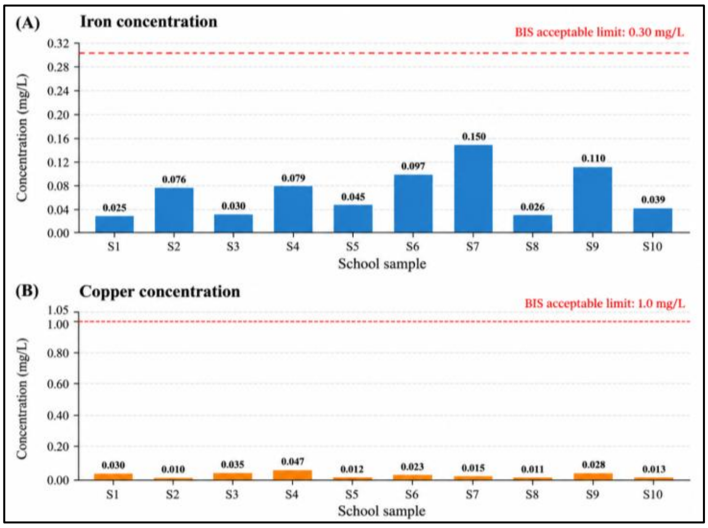

Figure 2. Iron and copper concentrations across the 10 school samples.

Table 2. School-wise physicochemical and chemical characteristics of drinking-water samples.

Sample	pH	TDS	Turbidity	Nitrate	Hardness	EC	Fluoride	Chloride	Alkalinity	Ca	K	Na	SO4
S1	8.35	119.8	1.94	45	112	0.245	0.55	16.99	20	16.09	0.09	4.59	30
S2	8.43	282.2	2.10	71	270	0.574	0.60	40.98	40	40.89	0.26	23.38	40
S3	8.05	305.8	1.95	75	262	0.616	1.00	60.98	46	44.57	0.21	31.50	30
S4	7.75	357.9	2.03	73	276	0.713	1.10	75.97	42	59.53	0.25	41.16	70
S5	8.39	136.8	2.23	55	130	0.267	0.45	22.99	24	12.77	0.27	7.07	30
S6	8.00	295.2	2.77	60	222	0.588	0.85	55.98	46	59.09	0.39	37.31	30
S7	8.32	178.8	2.10	65	174	0.349	0.25	23.99	30	17.16	0.36	10.02	30
S8	8.37	119.7	1.03	75	120	0.238	0.10	20.99	20	4.74	0.31	4.88	30
S9	8.47	144.6	2.00	70	122	0.287	0.30	20.99	22	16.31	0.38	7.01	20
S10	8.47	119.9	0.42	70	120	0.237	0.15	21.99	20	4.85	0.33	4.53	30

Table 3. Descriptive statistics for measured water-quality parameters.

Parameter	Mini	Max	Mean	SD	Median
pH	7.75	8.47	8.26	0.24	8.36
TDS (mg/L)	119.70	357.90	206.07	93.33	161.70
Turbidity (NTU)	0.42	2.77	1.86	0.66	2.01
Nitrate (mg/L as NO3-)	45.00	75.00	65.90	9.81	70.00
Hardness (mg/L as CaCO3)	112.00	276.00	180.80	69.54	152.00
Conductivity (mS/cm)	0.24	0.71	0.41	0.19	0.32
Fluoride (mg/L)	0.10	1.10	0.54	0.35	0.50
Chloride (mg/L)	16.99	75.97	36.19	20.99	23.49
Alkalinity (mg/L as CaCO3)	20.00	46.00	31.00	11.28	27.00
Calcium (mg/L)	4.74	59.53	27.60	21.36	16.73
Potassium (mg/L)	0.09	0.39	0.29	0.09	0.29
Sodium (mg/L)	4.53	41.16	17.14	14.72	8.54
Sulfate (mg/L)	20.00	70.00	34.00	13.50	30.00

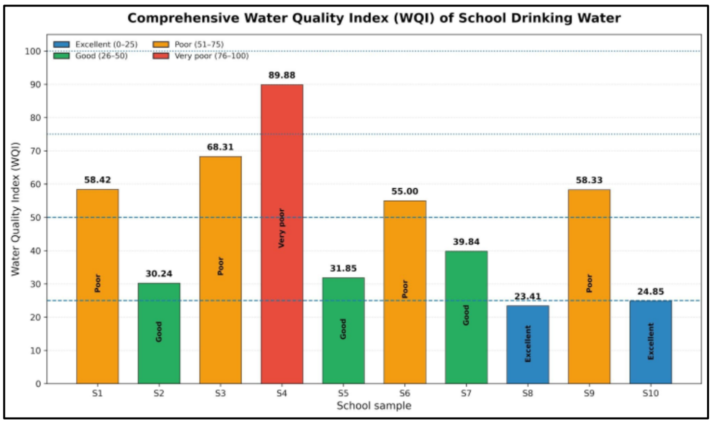

Figure 3. Distribution of Water Quality Index across the school samples.

4. DISCUSSION

The present study assessed the physicochemical, chemical and microbiological quality of drinking water collected from 10 selected schools in Bhopal, Madhya Pradesh. Overall, most measured parameters were within the applicable reference limits; however, nitrate emerged as the major water-quality concern, while turbidity showed recurrent elevation and fluoride presented a localized borderline value. These findings highlight the importance of periodic, multi-parameter monitoring of drinking water in schools rather than relying solely on microbiological assessment. Nitrate was the most notable finding, ranging from 45 to 75 mg/L. Nine of the ten samples exceeded both the BIS acceptable concentration of 45 mg/L and the WHO guideline value of 50 mg/L as nitrate ion, whereas S1 was at the BIS acceptable value. The repeated detection of 75 mg/L in nine samples suggests that elevated nitrate was not restricted to a single sampling location and warrants confirmatory investigation. Nitrate contamination of drinking water is frequently associated with agricultural activities, wastewater, sewage, septic systems and other anthropogenic nitrogen sources. Recent Indian studies have reported substantial spatial variation in groundwater nitrate and identified agricultural and sanitation-related inputs as important contributors [13–16]. Raheja et al. reported nitrate concentrations of up to 85 mg/L in groundwater and found that almost half of the investigated samples exceeded the BIS limit. Aju et al. similarly reported extensive nitrate contamination in groundwater in Kerala, with children representing a relatively higher-risk population in their exposure assessment. Recent basin-scale research in southern India has also demonstrated widespread nitrate exceedance and highlighted the importance of source apportionment for identifying dominant contamination pathways.

The health relevance of elevated nitrate is well established, particularly for methaemoglobinaemia in susceptible populations. Recent epidemiological research has additionally investigated associations between drinking-water nitrate exposure and adverse reproductive outcomes and cancer, although considerable heterogeneity and uncertainty remain in the available evidence [17,9]. Therefore, the present findings should not be interpreted as evidence of nitrate-related disease among schoolchildren. Rather, they identify nitrate as a priority parameter for confirmatory testing and water-safety surveillance. Because the present study was cross-sectional and involved only 10 schools, the source of nitrate cannot be determined. Future investigations should therefore include source-to-point-of-use sampling and seasonal monitoring to establish whether elevated nitrate originates from the source water, groundwater influence, storage systems or other environmental pathways.

The pH values ranged from 7.75 to 8.47, remaining within the BIS acceptable range of 6.5–8.5. TDS ranged from 119.7 to 357.9 mg/L and although four samples exceeded 200 mg/L, all remained below the BIS acceptable value of 500 mg/L. Thus, TDS values above 200 mg/L should not be classified as regulatory non-compliance. The observed variation indicates differences in dissolved mineral content among the sampled schools.

Total hardness ranged from 112 to 276 mg/L as $CaCO_3$, with higher values occurring at selected sites. Such hardness is primarily related to calcium and magnesium and is more relevant to scaling and water-use characteristics than to acute toxicity. Chloride, sulphate, sodium, calcium, potassium and alkalinity were comparatively low, suggesting that generalized mineral enrichment was not a dominant feature of the sampled waters.

Turbidity ranged approximately from 0.42 to 2.77 NTU, with eight of ten samples exceeding 1 NTU. Although the measured values remained below 5 NTU, the repeated elevation above the lower benchmark may indicate variability in source water, storage-tank condition, filtration efficiency or distribution infrastructure. Low turbidity is also important for effective disinfection because suspended particles can interfere with microbial inactivation [18]. Repeated sampling combined with sanitary inspection of storage tanks and point-of-use equipment would help determine whether this represents a persistent problem.

Fluoride concentrations ranged from 0.10 to 1.10 mg/L. The highest value, observed at S4, was slightly above the BIS acceptable concentration of 1.0 mg/L but below the permissible limit of 1.5 mg/L. This represents a localized finding rather than evidence of widespread fluoride contamination. Nevertheless, continued monitoring is justified because fluoride concentrations in Indian groundwater can vary substantially according to hydrogeological conditions [19].

Iron concentrations ranged from 0.025 to 0.150 mg/L, remaining below the BIS acceptable concentration of 0.30 mg/L. Copper concentrations were also substantially below the applicable reference value. Cobalt, chromium, cadmium and lead were also observed below the detectable limit. Qualitative bacterial screening was negative in all 10 samples. Chemical and microbiological monitoring should therefore be considered complementary components of school-water surveillance. Recent school-WASH research emphasizes the importance of reliable and safe water services as part of a healthy educational environment [20].

The comprehensive WQI provides an integrated perspective on the drinking-water quality of the sampled schools and demonstrates substantial inter-school variability. Although S8 and S10 showed excellent integrated quality and S2, S5 and S7 were classified as good, four samples were classified as poor and S4 as very poor. The relatively high WQI values at S4, S3, S1, S9 and S6 indicate that multiple measured parameters collectively contributed to deterioration of the composite index. Importantly, the WQI findings complement rather than replace the parameter-specific assessment. In particular, nitrate concentrations were elevated in most samples, ranging from 45 to 75 mg/L, with nine samples exceeding the BIS acceptable concentration of 45 mg/L. Therefore, a favourable WQI at an individual school should not be interpreted as absence of a specific contaminant concern [20]. Conversely, the poor WQI classification should not be interpreted as evidence of a specific health outcome. WQI is most appropriately used in this study as a comparative screening tool for identifying schools requiring further investigation, while individual health-based parameters particularly nitrate should remain the basis for targeted risk management.

The findings support a risk-based school drinking-water surveillance strategy. The immediate priority is to confirm the elevated nitrate concentrations using a validated quantitative laboratory method. If confirmed, source tracing and seasonal monitoring should be undertaken before selecting an appropriate intervention. Depending on the source, potential measures may include source substitution, blending with a verified low-nitrate source, appropriate treatment or provision of an alternative drinking-water supply.

LIMITATIONS

The study provides a useful preliminary baseline but has limitations. Only 10 selected schools were investigated, limiting generalizability to all schools in Bhopal. In addition, student-level exposure and health outcomes were not evaluated. These limitations should be considered when interpreting the results.

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