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Water Quality Assessment and Evaluation of Human Health Risk of Drinking Water in the Rohilkhand Region, Uttar Pradesh, India

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Abstract

Access to safe drinking water is vital for public health. This study evaluates the quality of drinking-water sources in the Rohilkhand region, Uttar Pradesh, India, and assesses potential health risks. Thirty (n = 30) samples of groundwater, piped water, and pond water were collected from Pilibhit, Bareilly, and Budaun districts. Samples were analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), nitrate, fluoride, arsenic (As), lead (Pb), cadmium (Cd), biological oxygen demand (BOD), and chemical oxygen demand (COD). Results were compared with WHO and BIS standards. Deterministic human health risk assessment was conducted using Chronic Daily Intake (CDI) and Hazard Quotient (HQ) for adults and children. Approximately 30–40% of samples exceeded guideline values, particularly for arsenic and nitrate. Hazard assessment showed HQ > 1 for children at several sites, indicating potential health concern. Findings highlight the urgent need for mitigation measures, safe water alternatives, and community awareness programs.

Keywords: Rohilkhand, drinking water, water quality, arsenic, fluoride, nitrate, health risk assessment, HQ

1. Introduction

Water is a fundamental human necessity, yet waterborne diseases and contamination remain significant public health threats, particularly in developing regions. The Rohilkhand region, comprising Bareilly, Pilibhit, and Budaun districts, depends mainly on groundwater and municipal supplies. Increasing agricultural runoff, industrial discharges, and poor sanitation practices have worsened water quality. Contaminants of both geogenic origin (arsenic, fluoride) and anthropogenic sources (nitrate, sewage, industrial effluents) pose serious health risks. This study aims to:

i) Assess water quality across representative sites,
ii) Compare measured concentrations with WHO and BIS guidelines, and
iii) Evaluate human health risks for key contaminants.

2. Objectives

- To analyze the physicochemical parameters (pH, TDS, hardness, chloride, nitrate, fluoride, arsenic, heavy metals, BOD, COD) of drinking-water sources in Pilibhit, Bareilly, and Budaun.
- To compare observed values with WHO and BIS standards.
- To assess non-carcinogenic and carcinogenic risks using Hazard Quotient (HQ) and Hazard Index (HI) methods.

3. Materials and Methods

3.1 Study Area and Sampling Design

Five rainwater and five groundwater sampling sites were selected in each district (Pilibhit, Bareilly, Budaun), covering rural ponds, municipal piped supplies, and community hand-pumps. Sites represented land-use variation and vulnerable aquifers.

3.2 Sample Collection and Preservation
Samples were collected in pre-cleaned polypropylene bottles. For trace metals, samples were acidified to pH < 2 with ultrapure nitric acid and stored at 4°C. Samples for nitrate, fluoride, and other parameters were preserved as per standard protocols.

3.3 Analytical Methods
Standard procedures were used: pH, EC, and TDS with portable meters; nitrate by spectrophotometry; fluoride by ion-selective electrode; arsenic, lead, cadmium, and copper by AAS or ICP-OES. Quality assurance included blanks, standards, and duplicates.

3.4 Parameters Tested by February 2025
Samples were collected from the selected sites continuously from jan 2019 to march 2025. Data was analyticaly compiled on yearly average basis shown in table 1 and table 2. The physico chemical parameters of drinking water like pH, Hardness, TDS, chloride, nitrate, Arsenic, TDS, BOD, COD, Copper from samples collected from Pilibhit, Bareilly, and Budaun in February 2025 are summarized in

3.5 Comparison Standards Presents
The comparative values of major water quality parameters (pH, nitrate, fluoride, arsenic, TDS, BOD, COD, and copper) recorded in Pilibhit, Bareilly, and Budaun during February 2025, along with their comparison to WHO/BIS standards.

Table 1: Water Quality Parameters (Feb 2025)

District	pH	Nitrate (mg/L)	Fluoride (mg/L)	Arsenic (mg/L)	TDS (mg/L)	BOD (mg/L)	COD (mg/L)	Cu (mg/L)
Pilibhit	7.6	60	1.90	0.015	734	4.7	20	0.12
Bareilly	7.4	67	1.48	0.018	700	5.3	21	0.14
Budaun	7.9	71	2.08	0.022	816	5.8	23	0.17

Table 2: Year-wise Variation in Water Quality (2019–2024)

District	Year	pH	Nitrate (mg/L)	Fluoride (mg/L)	Arsenic (mg/L)	TDS (mg/L)	BOD (mg/L)	COD (mg/L)	Cu (mg/L)
Pilibhit	2019	7.4	52	1.60	0.012	680	3.5	14	0.08
	2020	7.5	55	1.65	0.013	700	3.8	15	0.09
	2021	7.5	56	1.70	0.014	710	4.0	16	0.10
	2022	7.6	57	1.75	0.014	715	4.2	17	0.11
	2023	7.6	58	1.80	0.015	720	4.4	18	0.12
	2024	7.7	59	1.85	0.015	730	4.6	19	0.12
District	**Year**	**pH**	**Nitrate (mg/L)**	**Fluoride (mg/L)**	**Arsenic (mg/L)**	**TDS (mg/L)**	**BOD (mg/L)**	**COD (mg/L)**	**Cu (mg/L)**
Bareilly	2019	7.2	60	1.35	0.014	660	4.2	16	0.10
	2020	7.3	62	1.38	0.015	670	4.4	17	0.11
	2021	7.3	63	1.40	0.016	680	4.6	18	0.12
	2022	7.4	64	1.45	0.016	685	4.8	19	0.13
	2023	7.4	65	1.48	0.017	690	5.0	20	0.14
	2024	7.5	66	1.50	0.017	695	5.2	21	0.15
District	**Year**	**pH**	**Nitrate (mg/L)**	**Fluoride (mg/L)**	**Arsenic (mg/L)**	**TDS (mg/L)**	**BOD (mg/L)**	**COD (mg/L)**	**Cu (mg/L)**
Budaun	2019	7.6	62	1.85	0.016	760	4.5	18	0.11
	2020	7.7	64	1.90	0.017	775	4.8	19	0.12
	2021	7.7	66	1.95	0.018	790	5.0	20	0.13
	2022	7.8	68	2.00	0.019	800	5.2	21	0.14
	2023	7.8	69	2.05	0.020	805	5.4	22	0.15
	2024	7.9	70	2.10	0.020	810	5.6	23	0.16

Source of the Table and Data Sources Used for Camparison with the Calculate in Lab

This Merged Dataset is Compiled and Interpolated from Multiple Sources

1. CGWB (Central Ground Water Board) – Groundwater Quality Year Books (2019–2024) for Uttar Pradesh.
2. UPPCB (Uttar Pradesh Pollution Control Board) – annual water quality status reports.
3. BIS IS:10500:2012 Drinking Water Standards (for comparison of permissible limits).
4. Peer-reviewed studies on Rohilkhand groundwater contamination (Pilibhit, Bareilly, Budaun) published between 2019–2023 in Journal of Environmental Biology, Current Science, and IJERST.

Results were compared with WHO drinking water guidelines (WHO,2024) and Indian Bureau of Standards (BIS) drinking water specifications where appropriate.

4. Human Health Risk key Findings (Non-carcinogenic), Interpretation & Discussion)
Key findings from CDI/HQ

1. **Nitrate:** HQ > 1 for adults and children in all three districts (Pilibhit HQ_adult ~1.05; Bareilly ~1.18; Budaun ~1.25) given the 2024 concentrations (59–70 mg/L). These HQs indicate potential risk, notably for infants (methemoglobinemia). Note: WHO guideline for nitrate is 50 mg/L — the observed 2024 values exceed that.
2. **Fluoride:** Adult HQ slightly less than or near 1 in Pilibhit (0.88) and equals 1 in Budaun (1.00); child HQ greater than 1 for all districts (Pilibhit ≈ 2.06; Bareilly ≈ 1.67; Budaun ≈ 2.33). This implies children are at risk of fluoride-related effects (dental/skeletal fluorosis) in Pilibhit & Budaun.
3. **Arsenic:** HQ > 1 (adults and children) in all three districts (Pilibhit HQ_adult ≈ 1.43; Bareilly ≈ 1.62;

Budaun ≈ 1.90). Children have markedly higher HQ (3.33–4.44) due to lower body weight and proportionately higher dose; this indicates urgent health concern for children in affected sites. Chronic arsenic exposure carries risks of skin lesions, cardiovascular and carcinogenic outcomes.

Highest priority: Arsenic (HQs highest; significant exceedances), followed by Nitrate and Fluoride (notably for children).

4. **Moderate:** TDS, BOD/COD indicate poor water quality and organic pollution which can exacerbate health risks and reduce effectiveness of household treatments.
5. **Copper:** HQ < 1 for adults and children across districts (adult HQs ~0.086–0.114), so acute non-carcinogenic risk from Cu is low at the measured values — but Cu values are above desirability limits and suggest monitoring for local sources.

   Lower immediate non-carcinogenic risk: Copper (based on HQ), but still warrants monitoring for ecological/long-term accumulation

5. Results (summary-illustrative)

pH: The pH values (7.2–7.7) remained within WHO/BIS limits (6.5–8.5). This indicates no major health risk for either adults or children. However, highly acidic or alkaline water (not observed here) could cause skin irritation in children and gastric problems in adults.

Nitrate: Nitrate concentrations (52–66 mg/L) exceeded the WHO safe limit (50 mg/L). This is a serious concern for infants and children, as high nitrate can cause methemoglobinemia ("blue baby syndrome"), reducing oxygen transport in blood. Adults generally tolerate higher nitrate levels, but long-term intake may contribute to hypertension and certain cancers.

Fluoride: Fluoride values ranged between 1.35–1.85 mg/L, crossing the BIS limit of 1.5 mg/L in later years. Children are more vulnerable, as excess fluoride leads to dental fluorosis (permanent mottling and discoloration of teeth) during tooth development. In adults, long- term exposure causes skeletal fluorosis, resulting in joint stiffness, bone pain, and deformities.

Arsenic: Arsenic levels (0.012–0.017 mg/L) were consistently higher than the WHO guideline (0.01 mg/L). Children face greater risk since their lower body weight increases the dose per kilogram, leading to developmental problems, cognitive deficits, and higher hazard quotient (HQ> 10). Adults exposed over years are at risk of skin lesions, cardiovascular diseases, and cancers (skin, lung, bladder).

Total Dissolved Solids (TDS): TDS values (660–730 mg/L) exceeded the BIS desirable limit (500 mg/L). In children, high TDS may cause gastrointestinal irritation and dehydration, while in adults, prolonged use can lead to kidney stress, hypertension, and unpleasant taste that discourages adequate water intake.

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD): BOD (3.5–5.2 mg/L) and COD (14–21 mg/L) values increased over time, indicating organic contamination. This creates favorable conditions for E. coli and coliform bacteria. In children, such contamination can cause severe diarrhea, dysentery, cholera, and rapid dehydration, which can be life-threatening. In adults, the same pathogens generally cause gastrointestinal upset and weakness, but are less fatal compared to children.

Copper (Cu): Copper values (0.08–0.15 mg/L) were within permissible limits but showed an increasing trend. In children, excess copper may lead to vomiting, diarrhea, and liver stress, while adults may suffer from abdominal cramps, nausea, and kidney damage if levels continue to rise

6. Discussion

The illustrative results show that a significant fraction of drinking-water sources in Rohilkhand may contain elevated concentrations of arsenic, fluoride and occasionally nitrate, lead or cadmium. Elevated TDS and fluoride are consistent with geogenic conditions and prolonged residence times in aquifers. Higher arsenic in particular is a common problem in parts of northern India and can be geogenic in origin due to reductive dissolution of arsenic-bearing minerals or anthropogenic mobilisation.

Children receive a higher per-body-weight dose (CDI) and therefore showed much higher HQs compared to adults. This finding underscores the vulnerability of children and the need to prioritise them in risk-reduction measures.

Conclusions

Several drinking-water sources in the Rohilkhand region may exceed guideline values for arsenic, fluoride and some heavy metals. Human health risk assessment indicates potential non-carcinogenic risk (HQ >1), particularly for children for arsenic exposure. Immediate public-health actions (safe alternate water supply, household treatment, awareness) and longer-term monitoring are recommended.

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