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Groundwater Quality and Drinking Water Safety in Bareilly District, Uttar Pradesh, India: A Critical Review and Integrated Monitoring

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Abstract

Groundwater is an important source of domestic and agricultural water in the Bareilly region of Uttar Pradesh, but the safety of an individual drinking-water source cannot be inferred from appearance or from a single screening parameter. This paper reviews selected official groundwater information and develops a practical framework for a more complete assessment of water quality across urban, peri-urban and rural settings. The Central Ground Water Board (CGWB) reports specific electrical conductance of approximately 350–1,610 µS/cm at 25°C for shallow groundwater in its Bareilly district profile, with 63% of analysed samples reported below 750 µS/cm. These figures provide regional context; they are not a substitute for recent, site-specific testing of chemical and microbiological hazards. The paper identifies a priority parameter set comprising pH, electrical conductivity, total dissolved solids, hardness, alkalinity, chloride, nitrate, fluoride, iron, selected toxic elements and faecal indicator bacteria. It proposes stratified seasonal sampling, documented quality assurance, comparison with the applicable amendments to BIS IS 10500, and transparent statistical reporting. A sourced graph presents the published EC range, while additional figures illustrate a proposed sampling design and analytical workflow. The central conclusion is that a defensible assessment of drinking-water safety in Bareilly requires updated, georeferenced and quality-controlled measurements, rather than extrapolation from historical district summaries.

Keywords: Bareilly; groundwater; drinking-water safety; electrical conductivity; nitrate; fluoride; seasonal monitoring; BIS IS 10500; quality assurance

1. Introduction

Reliable drinking water is not defined by clarity, taste or odour alone. Water may appear acceptable while containing dissolved constituents or microorganisms that require laboratory detection. For this reason, water-quality assessment should combine field observations, chemical analysis, microbiological testing and knowledge of the local environment. The World Health Organization (WHO) recommends a preventive approach that links health-based targets, risk management from source to consumer, and independent surveillance [4,5].

In Bareilly district, groundwater supports household use and economic activity. The CGWB's district aquifer-management material identifies growing water demand associated with urbanisation, industrial

activity and agriculture, while the district groundwater brochure describes spatial variation in groundwater-development conditions [1,2]. Such regional context justifies careful monitoring, but it does not establish that any specific locality or source is contaminated. Potential influences—including fertiliser use, leakage from sanitation systems, poorly protected wells and wastewater discharge—must be tested as hypotheses rather than stated as proven causes.

Electrical conductivity (EC) is useful as a rapid indicator of the concentration of dissolved ions. However, EC cannot identify the ions responsible for a reading and does not directly establish microbiological safety. A sound assessment must therefore use a multi-parameter approach and report the limits of the available evidence.

2. Research gap, aim and objectives

The key information gap is not the absence of any district-level groundwater information; it is the lack of a complete, current, publicly retrievable site-by-site dataset in the reviewed summary that covers the full range of chemical and microbiological indicators needed to judge drinking-water safety. Without those observations, district-wide compliance percentages or claims about current unsafe sources cannot be calculated responsibly.

Aim: To develop a transparent, field-ready framework for assessing groundwater and drinking-water quality in Bareilly district.

- To summarise the relevant official groundwater context without overstating what the data show.
- To define a reproducible sampling and laboratory-analysis strategy for urban, peri-urban and rural locations.
- To identify appropriate statistical summaries and standards-based interpretation procedures.
- To recommend practical monitoring and communication measures that can be implemented by local agencies and research teams.

3. Study area and available evidence

The proposed study area is Bareilly district, Uttar Pradesh, including the municipal area and selected peri-urban and rural blocks. A stratified design is preferable to treating the district as a single uniform unit because groundwater development, source construction, land use and sanitation conditions can differ between locations. The CGWB district brochure reports that shallow groundwater is generally colourless and odourless and slightly alkaline. It gives an EC range of 350–1,610 µS/cm at 25°C and reports that 63% of analysed samples had EC below 750 µS/cm [2].

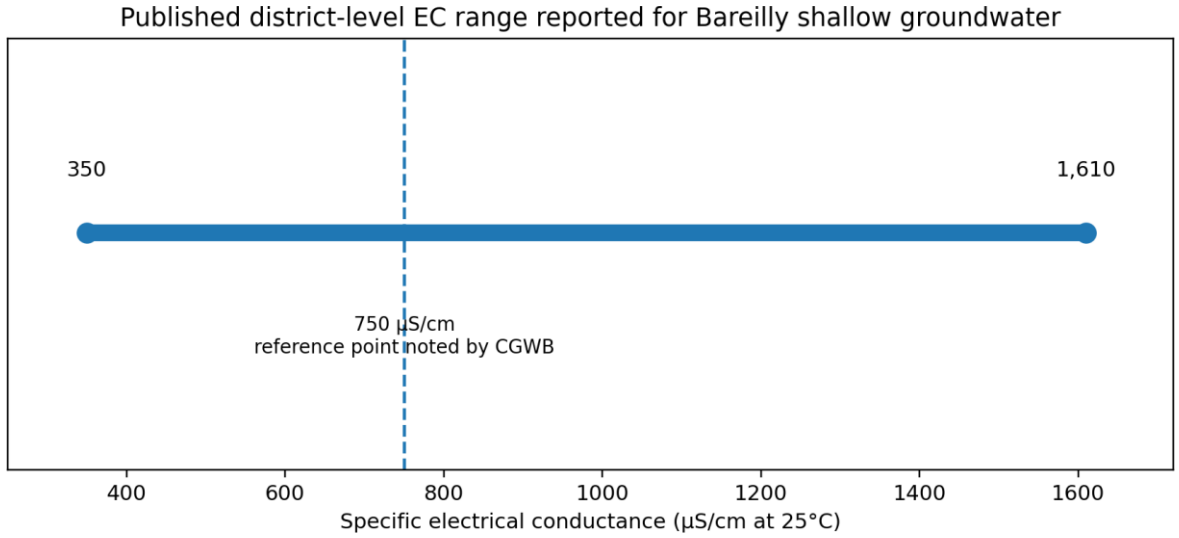

Figure 1. District-level EC range as reported in the CGWB Bareilly groundwater brochure. The plotted range is published regional context, not a new measurement campaign. The 750 µS/cm marker is included only to show the reference point mentioned in that source; it is not presented as a drinking-water compliance limit.

4. Materials and methods: proposed field protocol

4.1 Sampling design

A practical initial survey could include 24–36 sampling points distributed across urban, peri-urban and rural settings. The final sample size should be refined according to the research question, expected variability, available resources and statistical power. Where feasible, the same locations should be revisited before and after the monsoon. Sampling should include public supply taps, handpumps and borewells, with source type and treatment status recorded for every sample.

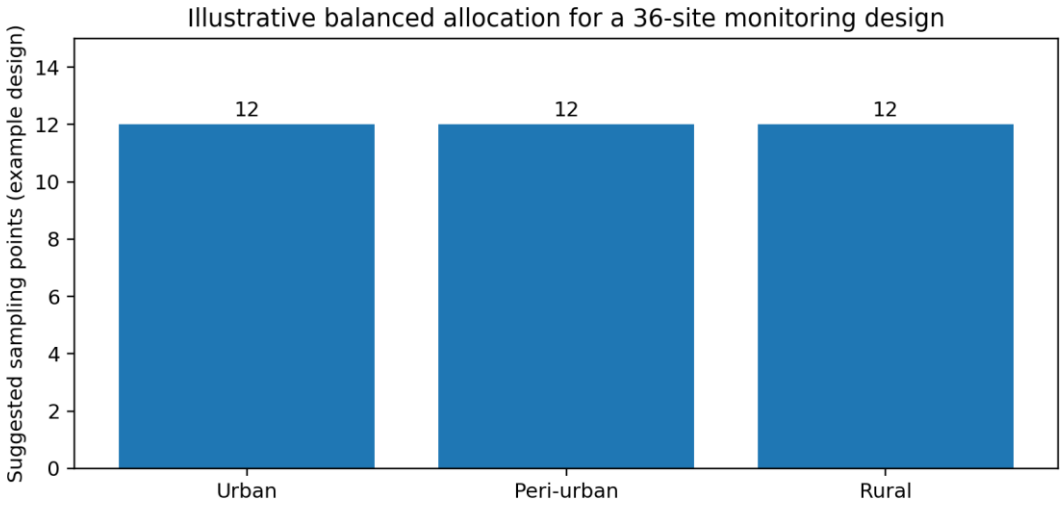

Figure 2. Example of a balanced 36-site allocation (12 sites per stratum). This is a proposed design illustration, not a record of samples collected. A field study may use a different allocation where population, source density or risk-based priorities justify it.

For each site, record a unique sample code, date and time, GPS coordinates, source type, well depth where known, recent rainfall, nearby drains or septic systems, land use, treatment status and sanitary-inspection observations. Sampling points should be selected systematically within each stratum rather than solely for convenience.

4.2 Collection, preservation and quality assurance

Use clean, parameter-appropriate containers and sterile bottles for microbiological samples. Follow the chosen analytical method for preservation, holding time, filtration and transport. Measure field-sensitive parameters such as pH, temperature and EC promptly using calibrated instruments. Maintain a chain-of-custody record. Include field blanks where appropriate, duplicate samples, calibration checks and laboratory control samples. Report the laboratory, analytical method, detection limit, sample holding time, and any deviations from protocol. Standard Methods for the Examination of Water and Wastewater provides established procedures for physical, chemical and microbiological analysis [6].

4.3 Priority parameters and methods

Parameter / group	Suggested method or instrument	Purpose and interpretive note
pH, temperature, EC	Calibrated field meters	Basic field characterisation; EC is a screening indicator of dissolved ionic content.
TDS	Validated TDS meter or gravimetric method	Estimates dissolved-solids burden; should be interpreted alongside major ions.
Total hardness, alkalinity, chloride	Validated titrimetric methods	Helps describe mineralisation, scaling potential and ionic composition.
Nitrate	Validated colorimetry, UV method or ion chromatography	Priority chemical indicator where agricultural or sanitation pathways are plausible.
Fluoride	Ion-selective electrode or validated colorimetric method	Important for health-based assessment at elevated concentrations.
Iron and other trace elements	AAS or ICP-based method with appropriate QA/QC	Select elements based on hydrogeological and local risk evidence; include arsenic and lead where justified.
E. coli / thermotolerant coliforms	Validated membrane filtration or equivalent method	Assesses faecal contamination; chemical testing cannot replace microbiological analysis.

4.4 Standards and interpretation

Compare results against the applicable version and amendments of BIS IS 10500:2012, Drinking Water—Specification. The BIS catalogue identifies IS 10500:2012 as reviewed in 2023 and lists amendments; investigators should verify the complete current text and relevant clauses before final compliance reporting [3]. WHO's 2026 fourth edition incorporating the first, second and third addenda is a current international reference for risk-management principles and health-based guidance [4]. Indian regulatory interpretation should nevertheless use the applicable Indian standard.

For each parameter, report the observed value, unit, applicable acceptable limit, permissible limit where the standard provides one, analytical method and compliance interpretation. Do not describe water as safe solely because one or two routine parameters fall within limits. Microbiological results and risk assessment are essential, and a failure for a health-relevant parameter should trigger confirmation and appropriate public-health action.

5. Statistical analysis plan

For each parameter, report the number of valid observations, missing observations, mean, median, standard deviation, minimum, maximum and interquartile range. For compliance reporting, state the numerator and denominator explicitly: percentage exceeding a threshold = (number of valid samples exceeding the threshold / total valid samples tested for that parameter) × 100. Do not use a single denominator when parameters have different missing-data patterns.

Compare urban, peri-urban and rural groups using ANOVA only when its assumptions are reasonably supported; otherwise consider the Kruskal–Wallis test. If the same sites are sampled in two seasons, use paired methods appropriate to the data distribution. Correlation analysis may help identify co-variation—for example, between EC and TDS—but correlation alone does not prove a common source. If sufficient spatially referenced data are available, mapping can identify areas for follow-up, but maps should display sample counts, sampling dates and uncertainty where possible.

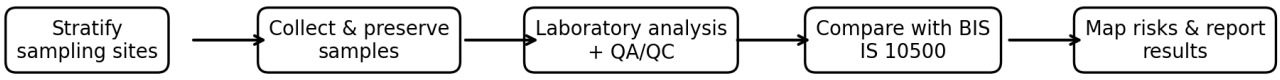

Figure 3. Proposed monitoring-to-reporting workflow for a future field study.

6. Results: what the available evidence supports

The reviewed CGWB summary supports two limited statements: (i) shallow groundwater in the district was described as generally colourless, odourless and slightly alkaline; and (ii) the brochure reports EC values spanning 350–1,610 µS/cm at 25°C, with 63% of analysed samples below 750 µS/cm [2]. These are source-reported findings and should be interpreted in the context of the report's sampling period and coverage.

The material reviewed for this manuscript does not provide a complete, current site-level dataset for pH, TDS, hardness, nitrate, fluoride, trace metals and microbial indicators. Accordingly, this paper does not

calculate new district-wide means, compliance rates or spatial contamination patterns. Those analyses require verified observations. This distinction is important because historical district summaries and illustrative examples cannot establish the current safety of an individual handpump, borewell or public supply.

7. Discussion

The available regional information suggests that water-quality assessment in Bareilly should be designed to capture spatial variation, rather than assuming uniform conditions across the district. EC is valuable for screening and for identifying samples that merit additional ionic analysis, but it cannot determine whether elevated conductivity is caused by naturally occurring minerals, anthropogenic inputs or a combination of factors. Similarly, an acceptable pH does not establish the absence of nitrate, toxic elements or pathogens.

The proposed multi-parameter and seasonal approach is consistent with the preventive risk-management principles set out by WHO and with established analytical practice [4–6]. It also makes the study more useful for local decision-makers: results can be linked to individual sources, the time of sampling, laboratory methods and corrective actions. Where contamination is suspected, source attribution should integrate laboratory data with sanitary inspection, hydrogeological setting, land-use information and repeat sampling.

A further strength of this framework is that it separates observation from interpretation. For example, proximity to a drain may justify prioritising a well for testing, but it does not by itself prove that the drain caused a measured contaminant concentration. This evidence-led approach helps avoid unsupported claims and improves the reproducibility of future work.

8. Practical recommendations

- Develop a georeferenced inventory of drinking-water sources and document source type, depth where known, protection measures and treatment status.
- Sample in pre-monsoon and post-monsoon periods, retaining consistent site identifiers so seasonal comparisons are possible.
- Prioritise microbiological indicators and core physicochemical parameters; add nitrate, fluoride, iron, arsenic, lead and other analytes according to local risk assessment.
- Use accredited or otherwise demonstrably competent laboratories and publish methods, detection limits, quality-control results and missing-data counts.
- Communicate sample-specific results to relevant authorities and communities in plain language, with clear instructions for confirmation testing and alternative safe supplies where a health-based criterion is exceeded.
- Select treatment only after identifying the contaminant; treatment performance should be verified by testing treated water. Boiling does not remove dissolved salts, nitrate, fluoride or metals.
- Consider groundwater recharge and rainwater harvesting only after assessing local hydrogeology and ensuring that recharge practices will not introduce contaminants.

9. Limitations

This manuscript is a review-based assessment framework, not a completed field survey. The district-level CGWB figures are drawn from published material and may not represent present-day conditions at individual sources. No original samples were collected for this paper, and no site-specific contaminant concentrations have been generated. The suggested sample size, balanced allocation and workflow are planning tools, not empirical findings. A field-based research article will require raw data, laboratory records, quality-control documentation and a clear description of the sampling campaign.

10. Conclusion

A defensible assessment of drinking-water quality in Bareilly requires updated measurements from identifiable sources, reliable laboratory procedures and comparison with the applicable Indian drinking-water standard. CGWB's published district summary provides useful context on shallow-groundwater character and EC variation, but it cannot replace current, multi-parameter testing. The framework presented here offers a practical route toward a stronger empirical study through stratified seasonal sampling, quality assurance, transparent statistics and risk-based communication. The next research step is to obtain official station-level records or conduct a documented field campaign; only then should the manuscript report new compliance percentages, contamination hotspots or source-attribution conclusions.

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Appendix A. Minimum dataset template for the empirical phase

Field	Required information
Sample identity	Unique sample ID; locality; block; GPS coordinates
Sampling context	Date/time; season; source type; well depth if known; treatment status
Field readings	Temperature; pH; EC; field observations
Laboratory results	TDS; hardness; alkalinity; chloride; nitrate; fluoride; iron; selected trace elements; E. coli/coliforms
Analytical metadata	Method; laboratory; units; detection limit; preservation; holding time
Quality assurance	Calibration records; blanks; duplicates; control results; deviations
Interpretation	Applicable BIS clause/limit; exceedance status; confirmatory action