Journal
Of the
Oriental Institute
M.S. University of Baroda

ISSN: 0030-5324
UGC CARE Group 1

REVIEW ON PHYSICO-CHEMICAL ANALYSIS OF GROUND WATER IN BHADOHI (U.P.) REGION WITH HEALTH RISK PERSPECTIVE

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Abstract

Groundwater in Bhadohi district (also administratively referred to as Sant Ravidas Nagar) is a vital resource for drinking, domestic and irrigation uses. Over the last decade several studies have assessed its physico-chemical quality and hydro geochemistry; common findings include variable pH, elevated electrical conductivity/TDS in pockets, nitrate pollution linked to agricultural/anthropogenic inputs, and sporadic exceedances of trace metals (Fe, Pb, etc.) above drinking-water limits. This review synthesizes published studies, compares findings against Indian (IS 10500:2012) and WHO drinking-water guidelines, highlights hydrogeochemical controls (rock weathering, ion exchange, anthropogenic inputs) and identifies knowledge gaps and management recommendations for stakeholders. Key references and standards used in this review include peer-reviewed studies on Bhadohi groundwater, BIS IS 10500, WHO Guidelines for Drinking-water Quality and standard laboratory methods (APHA).

Keywords- Ground Water, Bhadohi, Heavy metal, Pollution, Health Risk.

Introduction:

Groundwater is the primary drinking water source for many rural and peri-urban populations in Uttar Pradesh. Bhadohi district, a region with mixed agricultural, small industrial (notably textile and carpet weaving) and urban land use, has attracted hydrogeochemical studies because local geology, irrigation practices and industry can influence groundwater chemistry. Several field surveys and analytical studies (pre- and post-monsoon) have characterized major ions, nutrients and trace metals and assessed suitability for drinking and irrigation. This review collates those findings and situates them in the frame of national and international standards. Clean water serves as a valuable economic asset, fueling industries, supporting businesses, and driving economic growth. Industries rely on water for manufacturing, cooling, and cleaning processes. Additionally, tourism and recreational activities centred around clean water bodies contribute significantly to economies worldwide. We will investigate how clean water influences economies on local, national, and global scales, emphasizing the importance of water as a finite and invaluable resource. While clean water is indispensable for life, it faces an array of challenges that jeopardize its purity and availability. Pollution from industrial, agricultural, and urban sources poses significant risks to water bodies. Over-extraction of ground water and the impacts of climate change further compound the problem. In this chapter, we will delve into these threats, their implications on human life, and the urgent need for collective action to protect and preserve clean water resources. The quest for clean water is not without hope. In this final chapter, we will explore various solutions to safeguard and sustain clean water sources. From innovative technologies to responsible water management practices, we will examine how governments, communities, and individuals can collaborate to secure clean water for the present and future generations. By fostering a deeper understanding of the role of clean water in human life, we aim to inspire a shared commitment to protecting this irreplaceable resource and building a more resilient and thriving world. In conclusion, as we conclude this exploration into the role of clean water in human life, we find ourselves standing at the crossroads of responsibility and possibility. The journey through the pages of this discourse has revealed the intrinsic value of clean water in sustaining life, supporting ecosystems, driving economic progress, and nurturing our collective well-being. Yet, the challenges that lie ahead are undeniable. The threats of pollution, over-extraction, and climate change loom large, casting shadows of uncertainty over the future of this precious resource. It is upon us, as stewards of the planet, to rise above complacency and take decisive action to safeguard clean water for current and future generations.

Study coverage and sampling strategies:

- Multiple studies sampled groundwater across Bhadohi and neighbouring Trans-Varuna / Sant Ravidas Nagar regions using seasonal sampling (pre- and post-monsoon). Sample sizes vary by study (examples: 62 samples in a Trans-Varuna study; 70 samples in another hydrogeochemical assessment; other local studies used 20–43 samples depending

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ISSN: 0030-5324
UGC CARE Group 1

on scope). Seasonal sampling allows assessment of monsoonal dilution/contamination effects.

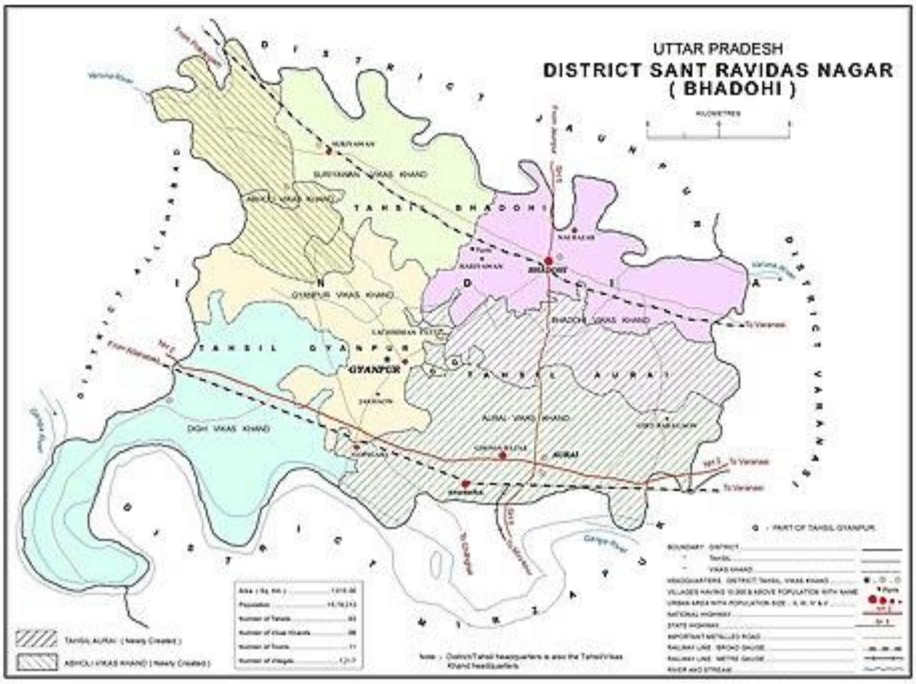

Fig-1 Map of the Bhadohi

Commonly analysed parameters and methods:

- Typical analyses: pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (as $CaCO_3$), major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), major anions (HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, F^{-}), and trace metals (Fe, Mn, Pb, Zn, Cu, Ni, Cd, as where tested).
- Standard laboratory procedures reported are based on APHA / Standard Methods for the Examination of Water and Wastewater and national methods—appropriate titrimetric, colorimetric and AAS/ICP techniques were used for metal analysis.

Main hydrogeochemical findings reported across studies

- Dominant water types: Many studies classify the groundwater facies as bicarbonate or mixed type, with influences of carbonate dissolution and silicate weathering controlling

Ca and Mg. Gibbs plots and ion ratios commonly indicate *rock-dominant* processes, sometimes with anthropogenic overprint.

- TDS / EC: Localized pockets of high EC/TDS exist — often associated with evaporation, shallow water tables or anthropogenic contamination (sewage effluents, textile waste discharge). Some samples exceed desirable BIS limits for TDS in specific locations.

- Nitrate (NO_3^-): Elevated nitrate concentrations are a recurring concern in multiple surveys; percentages of samples above the WHO/IS desirable limit (45 mg/L) vary by study and season, often higher in post-monsoon sampling due to agricultural runoff or leaching from fertilized soils. This raises public-health concerns, especially for infants.

Trace metals: Iron (Fe) is frequently reported above permissible limits in several wells (naturally occurring or due to redox conditions); reports of Pb and other metals above limits exist in some localized studies, indicating either geogenic sources or anthropogenic contamination (industrial effluents, improper waste disposal).

Table 1. Physico-chemical parameters commonly analysed in groundwater studies of Bhadohi district

Parameter Category	Parameter	Importance / Interpretation	Typical Method
Physical	pH	Acidity/alkalinity of water	pH meter
	EC (µS/cm)	Ionic concentration, salinity	Conductivity meter
	TDS (mg/L)	Total dissolved solids; suitability for drinking	Gravimetric / Conductivity
	Temperature (°C)	Physical stability; affects reactions	Thermometer
Chemical – Major Cations	Ca^{2+}	Hardness contributor; rock weathering	EDTA titration
	Mg^{2+}	Hardness contributor	EDTA titration
	Na^{+}	Salinity hazard; irrigation suitability	Flame photometer / AAS
Chemical – Major Cations	K^{+}	Minor nutrient; indicates	Flame photometer

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		contamination in some cases	
Chemical – Major Anions	HCO_3^-	Buffering capacity; carbonate weathering	Titration
	Cl^-	Indicates sewage/industrial contamination	Argentometric titration
	SO_4^{2-}	Industrial/agricultural sources	Turbidimetric
	NO_3^-	Fertilizer, sewage; infant health risk	UV spectrophotometer
	F^-	Dental/health effects	Ion-selective electrode
Chemical – Other Indicators	Hardness (mg/L)	Domestic/industrial suitability	Titration (EDTA)
	Alkalinity (mg/L)	Acid neutralizing capacity	Titration
	DO (mg/L)	Aeration level	Winkler method
	BOD/COD	Organic pollution	3-day BOD test / COD digestion
Trace Metals	Fe, Mn, Pb, Zn, Cu, Cd, As	Health risk; industrial/geogenic sources	AAS / ICP-OES

Comparison with Standards (IS 10500:2012 and WHO GDWQ)

- IS 10500:2012 (BIS) provides desirable and permissible limits for drinking water (pH 6.5–8.5; TDS desirable 500 mg/L; nitrate 45 mg/L; hardness, alkalinity, sulphate, etc.). Studies of Bhadohi frequently compare measured values to these standards when assessing suitability.

WHO Guidelines for Drinking-water Quality (4th ed. + addenda) are used as international reference—particularly for nitrate, heavy metals and risk characterization. Several Bhadohi studies perform risk assessment (Hazard Quotient / Hazard Index) using WHO or USEPA dose models to estimate health risk, often noting higher vulnerability among children.

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Table 2. BIS (IS 10500:2012) and WHO Drinking Water Standards

Parameter	BIS Desirable Limit	BIS Permissible Limit	WHO Guideline
pH	6.5–8.5	No relaxation	6.5–8.5
TDS (mg/L)	500	2000	1000
Hardness (mg/L)	200	600	500
Ca^{2+} (mg/L)	75	200	200
Mg^{2+} (mg/L)	30	100	150
Chloride (mg/L)	250	1000	250
Sulfate (mg/L)	200	400	500
Nitrate (mg/L)	45	No relaxation	50
Fluoride (mg/L)	1.0	1.5	1.5
Iron (mg/L)	0.3	No relaxation	0.3
Lead (mg/L)	0.01	No relaxation	0.01

Hydrogeochemical processes and source attribution

- Rock weathering and carbonate dissolution: many datasets show Ca and HCO_3 dominance indicating carbonate rock dissolution as a major natural control on water chemistry.
- Ion exchange and silicate weathering: cation ratios and saturation indices indicate ion exchange in some locations and contributions from silicate minerals.
- Anthropogenic inputs: elevated NO_3^-, Cl^- and some trace metals in certain zones reflect agricultural runoff, sewage/septic leakage and possible industrial effluent impact (textile-related salts and organics reported historically in the region). Studies using scatter plots (Na/Cl, SO_4/Cl) and multivariate statistics attribute mixed sources.

Health risk assessments reported

Several studies applied non-carcinogenic risk assessment (Hazard Quotient, Hazard Index) for ingestion and dermal exposure to trace metals and nitrate. Results commonly indicate children are at higher risk (higher HQ/HI) than adults. In some studies, HI exceeded safe thresholds in localized areas indicating potential health concerns that warrant mitigation.

Table 3. Typical Range of Groundwater Parameters Reported in Bhadohi District

Parameter	Reported Range	Interpretation
pH	6.8–8.4	Slightly acidic to alkaline
EC (µS/cm)	450–1800	Some locations show high salinity
TDS (mg/L)	300–1200	Exceeds BIS desirable limit in pockets
Hardness (mg/L)	180–650	Hard to very hard water
Ca^{2+} (mg/L)	30–120	Generally, within limit
Mg^{2+} (mg/L)	18–90	May exceed desirable limit
Na^{+} (mg/L)	20–160	Higher near agricultural areas
K^{+} (mg/L)	1–15	Usually low; increases near contamination
HCO_3^- (mg/L)	180–380	Indicates carbonate weathering
Cl^- (mg/L)	50–360	Higher near urban/industrial zones
SO_4^{2-} (mg/L)	20–140	Typically, within limit
NO_3^- (mg/L)	10–90	Exceeds limit in some samples
F^- (mg/L)	0.3–1.6	Some exceedances reported
Fe (mg/L)	0.2–1.2	Often above permissible limit
Pb (mg/L)	0.002–0.04	Exceeds WHO limit in some locations

Table 4. Possible Sources of Major Groundwater Contaminants in Bhadohi

Parameter	Possible Source	Impact
NO_3^- (Nitrate)	Fertilizers, sewage leakage	Infant methemoglobinemia, health risk
Cl^-	Domestic sewage, textile effluents	Salinity increase
TDS/EC	Evaporation, industrial discharge, salts	Drinking unsuitability
Fe, Mn	Natural geogenic dissolution	Staining, taste issues
Pb, Cd	Industrial effluents, plumbing	Toxicity risk
F^-	Natural minerals, over-extraction	Fluorosis in high levels
SO_4^{2-}	Industrial effluents, fertilizers	Taste issues; laxative effect

Table 5. Suitability of Bhadohi Groundwater for Irrigation

Parameter / Index	Acceptable Range	Interpretation
Sodium Adsorption Ratio (SAR)	< 10	Excellent for irrigation
Residual Sodium Carbonate (RSC)	< 1.25 me/L	Safe water
EC (µS/cm)	< 750	Suitable; >2250 = unsuitable
Na%	< 60%	Safe
PI (Permeability Index)	25–75	Good for irrigation

Spatial and seasonal variability:

- Seasonality: Pre- and post-monsoon comparisons in multiple studies show seasonal dilution effects on some parameters (e.g., lower EC/TDS post-monsoon) but also pulses of nitrate after fertilizer application and monsoon-related leaching.
- Spatial heterogeneity: Chemical anomalies are often clustered near urban areas, industrial clusters, or intensive agriculture. GIS mapping in some studies identifies contamination hotspots.

Critical gaps identified in the literature:

1. Long-term trend data scarcity: Few long-term temporal studies exist for Bhadohi to assess trends beyond one or two seasons.
2. Limited microbiological data: Most physico-chemical studies focus on chemical parameters; comprehensive microbiological surveillance (coliforms, pathogens) is limited.
3. Inadequate source tracing for metals: While many studies report elevated metals (Fe, Pb), fewer use isotopic or advanced forensic methods to distinguish geogenic vs anthropogenic origin conclusively.
4. Insufficient integration with health outcomes: Epidemiological linkage between measured contaminants and local health statistics is sparse.
5. Groundwater-surface water interactions and recharge characterization need more study to support management.

Recommendations (management, monitoring, and research)

Monitoring & policy

- Adopt an expanded periodic monitoring program (minimum seasonal sampling at representative wells, handpumps and tubewells) using standardized APHA methods and strict QA/QC.
- Implement regular testing for nitrate and priority trace metals in potable sources, and compare results to IS 10500:2012 desirable/permissible limits with public reporting.

Source control and mitigation

- Promote best agricultural practices (optimized fertilizer application, buffer strips, controlled irrigation) to reduce nitrate leaching.
- Identify and regulate point-source discharges (textile effluents, domestic sewage) with stricter enforcement of effluent standards and local treatment solutions (decentralized treatment for effluents).

Technical & community measures

- Provide targeted water treatment (e.g., iron removal filters, blended supplies, community-scale treatment) in hotspots where contaminants exceed limits.
- Community awareness campaigns on safe water handling, borewell protection, and alternatives for infant feeding (if nitrates are high) are essential.

Conclusions

Published surveys and hydrogeochemical investigations in Bhadohi district consistently show that while much groundwater is suitable for irrigation and many domestic uses, there are recurring and localized problems — notably elevated nitrates and occasional trace-metal exceedances — that warrant targeted monitoring and mitigation. Management must combine seasonal surveillance, pollution source control (agriculture and industry), community engagement, and provision of treated water in affected zones. Strengthening local laboratory capacity and applying standardized methods will improve data quality and support evidence-based policy.

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