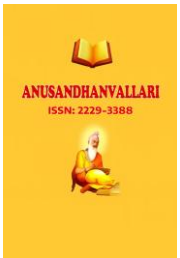

Anusandhanvallari
Vol 2024, No.1
December 2024
ISSN 2229-3388

Spatial Analysis of Groundwater Contamination in Sanganer Area (Jaipur City, Rajasthan): Assessment of Chloride, Fluoride, Nitrate and TDS-Implications for Treatment and Management

Kusum Maan[1], Prof. (Dr.) Menka Bhasin[2]

Abstract

Groundwater is the principal source of domestic and agricultural water supply in much of Rajasthan, including the Sanganer area of Jaipur. Over recent decades, increasing extraction, rapid urbanization, expansion of textile and allied industries, and inadequate wastewater management have altered hydro chemical regimes and elevated concentrations of major ionic contaminants notably fluoride, chloride, nitrate and total dissolved solids (TDS). This paper presents a comprehensive assessment of groundwater quality in Sanganer with emphasis on these parameters: it synthesizes historical monitoring, recent field studies, and regional hydrogeological reports to describe spatial patterns, probable sources, health and agronomic risks, and feasible treatment and management options. The study shows that fluoride and nitrate remain persistent concerns in many sampling locations, while elevated TDS and chloride reflect both natural mineralization in semi-arid aquifers and anthropogenic inputs from domestic and industrial effluents. Drawing on national standards (BIS IS 10500) and WHO guidelines, the paper discusses household and community-scale treatment technologies (adsorption, reverse osmosis, ion exchange, biological denitrification) and evaluates their suitability for Sanganer's socio-economic and hydrogeologic context. The conclusion recommends an integrated approach combining targeted monitoring, demand-side management, decentralized treatment where necessary, industry effluent controls, and community recharge and conservation initiatives to protect groundwater quality and public health. (Keywords: groundwater quality, fluoride, nitrate, chloride, TDS, Sanganer, Jaipur, defluoridation, treatment, BIS, CGWB).

Keywords: Groundwater quality, Sanganer, Jaipur, fluoride, nitrate, chloride, TDS, defluoridation, water treatment, BIS 10500, Central Ground Water Board

Introduction

Groundwater in semi-arid regions of India is both a lifeline and a vulnerability. In the Jaipur district and its Sanganer tehsil, groundwater historically provided reliable water for drinking, domestic use, and irrigation, exploiting alluvial and weathered hard-rock aquifers that receive variable monsoon recharge. Over the past few decades, however, pressures of urban expansion, population growth and industrialization especially the growth of textile and dyeing activities in and around Sanganer have intensified both groundwater extraction and contamination risks. The region's characteristic hot, dry climate and variable recharge combine with long groundwater residence times to concentrate dissolved solids and mobilise geogenic contaminants such as fluoride, while anthropogenic sources (septic systems, agricultural fertilizers, industrial effluents) contribute nitrates, chloride and other dissolved constituents. National and regional monitoring by the Central Ground Water Board (CGWB) and Central Pollution Control Board (CPCB) show that Rajasthan and several areas within Jaipur district

[1] Research Scholar, Department of Chemistry, Vivekananda Global University, Jaipur (Rajasthan)-303012
[2] Supervisor, Department of Chemistry, Vivekananda Global University, Jaipur (Rajasthan)-303012

have experienced increasing instances of groundwater samples that do not meet drinking-water standards for one or more parameters, with fluoride and nitrate commonly exceeding the Bureau of Indian Standards' permissible limits in local pockets. These trends provide the immediate context for a focused assessment of Sanganer.

Hydrogeochemical surveys in Sanganer carried out by university researchers and regional investigators over the last two decades document a variable but concerning picture. Multiple field studies have reported fluoride concentrations above 1.5 mg/L (BIS/WHO guideline threshold for fluorosis risk) in many locations across Sanganer tehsil. Investigations using standard physicochemical analyses and correlation studies indicate that high fluoride commonly correlates with alkaline pH, elevated bicarbonate and calcium/magnesium relationships that promote fluoride release from fluoride-bearing minerals under groundwater geochemical conditions typical of Rajasthan's weathered granitoid and alluvial gravels. Another recurrent observation is elevated TDS and chloride in peri-urban and low-lying areas, suggesting a combination of natural mineral dissolution (evaporative concentration in a semi-arid environment) and saline or sewage influence in shallow aquifers. These geogenic and anthropogenic mixing processes create a spatial mosaic where public health risk (dental and skeletal fluorosis, methemoglobinemia from nitrate excess) and agronomic impacts (soil salinization risks from high chloride/TDS) co-exist.

Nitrate pollution, while traditionally associated with intensive agriculture in many parts of India, is also increasingly linked to on-site sanitation failures (septic leachate), leaking sewer networks, and unregulated waste discharges from small industries and dairies in urbanizing belts like Sanganer. Nitrate concentrations in drinking water above 45 mg/L (as NO3–) raise acute health concerns for infants (blue-baby syndrome) and may indicate broader sanitation and nutrient-management failures. Studies in Sanganer villages and urban peripheries have reported elevated nitrate in a subset of samples, highlighting the need for both point-source control (sewerage, industrial effluents) and diffuse-source strategies (fertilizer management, sanitation improvements). Concurrently, the textile dyeing cluster around Sanganer has been implicated in local wastewater loadings that can raise chloride, organic load, and certain heavy metals in receiving waters, improper disposal of dyeing effluents can also indirectly alter groundwater chemistry via surface-to-subsurface infiltration, especially where wastewater treatment capacity is limited. These combined pressures create not only treatment challenges but also governance imperatives for integrated groundwater management in Sanganer.

Historically, traditional water management systems in Rajasthan stepwells, johads and tank recharge structures buffered communities against both scarcity and localized contamination by maintaining shallow surface reservoirs and enhancing seasonal recharge. However, rapid urban growth and land-use change around Jaipur have impaired many traditional recharge landscapes and reduced the buffering capacity of the natural system. The Public Health Engineering Department (PHED) and state water projects (for example, Bisalpur pipeline initiatives) have supplemented urban supply, but many residents and peri-urban settlements continue to rely on borewells and handpumps drawing from local aquifers, their water quality therefore reflects both basin-scale processes and very local contamination. The CGWB's recent monitoring (2023–2024) identifies regions in Rajasthan, including parts of Jaipur district, where fluoride and nitrate exceedances remain prevalent underscoring the importance of local assessments such as this one to target remedial and preventive action.

From a methodological standpoint, groundwater quality assessment in Sanganer has typically combined (a) field sampling across networked handpumps and borewells, (b) laboratory analyses for pH, EC/TDS, major cations and anions including chloride, fluoride and nitrate, and (c) hydrochemical plotting (Piper, Stiff diagrams), spatial interpolation (GIS), water quality index (WQI) computations, and health-risk screening against BIS IS 10500 and WHO guideline values. These approaches allow the mapping of contamination hotspots, identification of dominant water types, and inferential source apportionment. Recent local studies used between 30 and 115 samples depending on scale results consistently point to a non-homogeneous distribution of contaminants: pockets of high fluoride or nitrate adjacent to locations where water quality meets drinking limits. This heterogeneity is critical for management because it means that blanket assumptions (e.g., “Sanganer groundwater is uniformly unsafe” or “safe”) are misleading interventions must be spatially targeted.

Geochemical mechanisms controlling fluoride in the aquifer deserve specific emphasis because they influence suitable treatment choices. In Sanganer, fluoride largely originates from the dissolution of fluoride-bearing minerals (e.g., fluorapatite, fluorite) in primary and secondary minerals of the weathered bedrock and alluvium. Alkaline pH and high bicarbonate facilitate fluoride desorption into groundwater, prolonged residence times in low-permeability zones allow accumulation. In contrast, chloride and TDS increase from both mineral dissolution and anthropogenic inputs — wastewater, septic leachates, and industrial process waters carry salts that raise conductivity and TDS. Elevated TDS also concentrates under conditions of heavy pumping and low recharge. Nitrate behaves differently: it is conservative in groundwater (does not sorb much) and integrates recent anthropogenic inputs: fertilizer usage, sewage infiltration, and manure management practices. Therefore, understanding the co-variation of pH, EC/TDS, bicarbonate and major ions is essential to interpret why fluoride and chloride/TDS vary differently across the block.

Public health and agronomic implications in Sanganer are nontrivial. Fluoride concentrations beyond safe thresholds lead over time to dental and skeletal fluorosis, with socio-economic consequences for affected households. Nitrate contamination presents acute health risks for infants and chronic risks in combination with other agricultural and chemical exposures. High chloride and TDS impact taste, corrode distribution networks, and when used for irrigation can exacerbate soil salinity, adversely affecting crop yields in fertile peri-urban fields. Beyond health, there are economic and equity dimensions: lower-income communities often depend on the least-protected sources (unmonitored handpumps) and have limited access to appropriate household treatment. Thus, addressing groundwater contamination is as much a public-policy and social-justice challenge as a hydrogeochemical one.

Treatment and mitigation pathways must be chosen with local realities in mind. For fluoride, community and household options range from adsorption on activated alumina or bone char, to coagulation-precipitation, membrane processes (reverse osmosis), and ion-exchange techniques. Each has trade-offs in cost, waste generation, maintenance requirements, and conformity with local water chemistry (e.g., competing anions can reduce adsorption efficiency). For nitrate, biological denitrification and ion exchange are effective at community scale, while point-of-use reverse osmosis also removes nitrate but at a high cost and with brine disposal concerns. Where chloride and TDS are high due to mineralization, blending with lower-TDS sources, controlled abstraction from deeper/less mineralized zones, and desalination technologies are options, though costs limit large-scale use. Critically, source control improving wastewater collection/treatment for textile units, preventing septic leaks, and managing fertilizers reduces long-term burden and should run parallel to technical treatment. International reviews underscore that technology selection must weigh local hydrochemistry, socio-economic capacity, waste disposal, and institutional capacity for operation & maintenance.

Finally, integrated groundwater governance combining systematic monitoring (consistent sampling networks aligned with CGWB/CPCB protocols), GIS-based hotspot mapping, community engagement, demand management (rainwater harvesting, recharge structures), and regulatory enforcement for industrial effluents provides the only sustainable pathway to protect Sanganer’s aquifers. Recent government initiatives (pipeline augmentation, water conservation programs) and CGWB monitoring bulletins highlight both the severity of contamination pockets and the scope for remedial actions, but sustained local planning, transparent data, and financing for decentralized treatment remain essential. This paper synthesizes the available evidence and presents a pragmatic, locally-sensitive approach for monitoring, treatment selection and governance in Sanganer.

International Perspectives

Groundwater contamination by fluoride and nitrate is a global concern, especially in semi-arid regions where evaporative concentration, rock chemistry and anthropogenic inputs intersect. Large meta-analyses and global diagnostics show widespread nitrate pollution in many regions linked to agricultural intensification and inadequate sanitation, and they emphasize that engineered solutions (catalytic reduction, biological denitrification, ion exchange, membrane separation) must be coupled with source-control measures and monitoring programs for effectiveness. Similarly, global reviews of defluoridation techniques point to adsorption (activated alumina, bone char), electrocoagulation, and reverse osmosis as proven methods but they also underline the need to adapt technologies to local water chemistry, affordability, and waste handling capacity. International best practices highlight decentralized, low-cost community systems with local maintenance training in comparable socio-economic settings, pilot schemes combining point-of-use options with centralized monitoring often yield the best trade-off between cost and health protection. Lessons from elsewhere from controlled pilot testing, community ownership models, and hybrid technical-policy responses are directly applicable to Sanganer's context.

Conclusion

Sanganer's groundwater quality reflects the interplay of natural hydrogeology and human activities. Fluoride and nitrate persist as priority contaminants in multiple locales, while elevated chloride and TDS point toward combined geogenic mineralization and anthropogenic salinization. Addressing these issues requires (i) systematic, spatially-representative monitoring linked to CGWB/CPCB protocols, (ii) targeted technical interventions (household and community treatment where necessary) selected based on hydrochemistry and socio-economic feasibility, (iii) robust source control industrial effluent treatment, sewage network improvements and fertilizer management, and (iv) demand-side and recharge interventions (recharge structures, rainwater harvesting) to reduce concentration effects. Success will depend not just on technology but on institutional coordination, financing and sustained community engagement.

Future Scope & Recommendations

1. Establish a formal, high-resolution groundwater monitoring network in Sanganer (Seasonal sampling, GIS mapping).
2. Conduct targeted epidemiological screening in communities showing high fluoride/nitrate to quantify health burden and prioritise remediation.
3. Pilot low-cost community defluoridation units (adsorptive) and decentralized biological denitrification units with local O&M training, evaluate long-term performance and waste disposal.
4. Require full treatment and zero-discharge or secure reuse for textile dyeing effluents, incentivize common effluent treatment plants with strict monitoring.
5. Integrate groundwater quality into urban water supply planning where municipal supply is available, promote safe connection programmes and reduce reliance on unmonitored borewells.
6. Develop community awareness campaigns on sanitation, fertilizer use, and safe water storage, provide technical & financial pathways for household filtration where needed.

References

[1] Bureau of Indian Standards. (2012). *IS 10500:2012 Drinking water Specification* (Second revision). Bureau of Indian Standards. (Law Resource)

[2] World Health Organization. (2017). *Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda.* WHO Press. (World Health Organization)

[3] Central Pollution Control Board (CPCB). (2021). *National Water Quality Monitoring Programme — Water quality data (NWMP 2021).* CPCB. (Central Pollution Control Board)

[4] Joshi, A., & Shrivastava, A. (2012). *Geochemical/physicochemical studies and textile effluent impacts in Sanganer region.* (regional journal/assessment). (ScienceDirect)

[5] Orient Journal of Chemistry. (Year). *Geochemical study of fluoride in ground water of Sanganer Tehsil of Jaipur district of Rajasthan.* Oriental Journal of Chemistry. (Orient Journal of Chemistry)

[6] (Local research / thesis). (2021). *Groundwater quality assessment of different villages of Sanganer block in Jaipur district of Rajasthan.* Journal of Soil Salinity and Water Quality / ResearchGate posting. (ResearchGate)

[7] Shahnawaz, H., et al. (2021). *Investigation & assessment on groundwater water quality of the Sanganer area of Jaipur city.* (ScienceDirect / regional journal). (ScienceDirect)

[8] IJTSRD / IJERT article. (2020). *Sanganer textile and dye industry impacts on groundwater and environment.* IJTSRD. (Trend Research Journal)

[9] G. Sharma (2022). *Status of groundwater fluoride in some areas of Sanganer.* Gyanvihar University proceedings / conference paper. (Suresh Gyan Vihar University)

[10] Central Ground Water Board (CGWB), Jaipur/Western Region. (2024). *Groundwater Chemical Quality Bulletin — Pre-monsoon 2024 (Rajasthan).* CGWB. (CGWB)

[11] Abascal, E., et al. (2022). Global diagnosis of nitrate pollution in groundwater and implications for treatment. *Science of the Total Environment*, (review). (ScienceDirect)

[12] Jamwal, K. D., & co-authors. (2021). *A review of defluoridation techniques of global and Indian prominence.* Clean Water Engineering Journal (review). (cwejournal.org)

[13] Times of India. (2024). *PHED initiates new Bisalpur pipeline project for enhanced water supply.* (news about pipeline impacts on supply & Sanganer storage). (The Times of India)

[14] Times of India. (2024). *Groundwater quality in most parts of India is good but Rajasthan, Haryana and AP face widespread contamination: Report.* (coverage of CGWB findings). (The Times of India)

[15] CGWB. (2024). *Ground Water Level Bulletin — Rajasthan (Post-monsoon/Pre-monsoon 2024).* CGWB monitoring bulletins (hydrograph & regime context). (CGWB)

[16] ResearchGate / case study compendium. (2022). *Correlation study for the assessment of groundwater quality of Sanganer Tehsil, Jaipur City.* (dataset & correlation analysis). (ResearchGate)

[17] Additional regional hydrogeochemical studies and reviews cited in the text (various institutional/peer-reviewed reports and conference papers focusing on hydrochemistry, treatment options and policy measures for Rajasthan groundwater). (ScienceDirect)