Hydrogeochemical Assessment of Groundwater Contamination and Human Health Implications in Bathinda, District Punjab

Tanu Taneja [1] and B. S. Bhatia[2]

[1,2]RIMT University, Mandi Gobindgarh, India
tanutaneja3891@gmail.com
bsbhatia@rimt.ac.in

Abstract: This comprehensive review critically examines groundwater contamination in Punjab's Bathinda district, a region heavily dependent on this essential resource for domestic, agricultural, and industrial purposes. The review highlights the widespread presence of contaminants such as fluoride, uranium, arsenic, nitrate, and various heavy metals that frequently exceed international and national safety limits. It explores the complex hydrogeochemical processes—both geogenic, including mineral dissolution, and anthropogenic, such as intensive agriculture, industrial discharge, and improper waste disposal—that collectively control groundwater chemistry. The discussion further emphasizes the serious health implications of prolonged exposure to these contaminants, including fluorosis, skeletal and renal disorders, neurological impairment, and carcinogenic outcomes, alongside the degradation of soil fertility and crop productivity. The review synthesizes findings from previous studies on contamination assessment methods, technological and agricultural mitigation strategies, and policy interventions, proposing a roadmap for sustainable groundwater governance in Bathinda to ensure environmental and public health resilience.

Keywords: Groundwater contamination, Hydrogeochemical assessment, Bathinda district Punjab, Heavy metals and uranium pollution, Human health risk assessment, Sustainable groundwater management

1 Introduction

1.1 Background and Context

Groundwater serves as a fundamental source of life and economic stability across arid and semi-arid regions globally, with India—particularly the state of Punjab—illustrating an extreme dependency on this resource (Akhai & Taneja 2024; Akhai & Taneja 2025; Barik et al., 2017; Bhatia & Singh, 2023). In Bathinda district, groundwater fulfills nearly all domestic and agricultural requirements, sustaining high agricultural productivity that significantly contributes to India's food security (Sidhu et al., 2020a, 2020b). However, this heavy reliance has led to escalating issues of groundwater contamination and depletion, emerging as a major environmental and public health challenge (Barik et al., 2017). The expansion of agriculture under the Green Revolution, combined with industrial growth, rapid urbanization, and population pressure, has strained subsurface aquifers, leading to alarming declines in water quality (Gautam et al., 2021; Gautam & Chand, 2023). The contamination of groundwater in Punjab now represents both a hydrological and socio-economic crisis, calling for urgent scientific attention and policy response.

1.2 Problem Statement

The groundwater in Bathinda district contains multiple pollutants, including fluoride, uranium, arsenic, nitrate, and several heavy metals (Sharma et al., 2021; Verma & Anju, 2018). Concentrations of these substances often surpass the permissible limits defined by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS), suggesting serious risks to water safety (Sharma et al., 2021; Verma & Anju, 2018). Uranium lev-

els have been observed to exceed the WHO limit in a majority of samples, and arsenic and mercury concentrations also remain significantly high across various sites (Sharma et al., 2021). The chronic exposure to such contaminants poses grave health threats to the local population, with potential implications for soil quality and food safety, thus amplifying the urgency for systematic assessment and management.

1.3 Rationale of the Review

Although several isolated studies have analyzed specific aspects of groundwater quality in Bathinda, there remains a lack of an integrated review combining hydrogeochemical, environmental, and human health perspectives. Synthesizing such studies is vital for identifying contamination trends, distinguishing between geogenic and anthropogenic sources, and evaluating the success or limitations of mitigation strategies implemented to date (Schwartz et al., 2020). This review, therefore, seeks to consolidate the existing body of research to provide a coherent understanding of Bathinda's groundwater contamination scenario and guide informed decision-making for sustainable management.

2 Regional Overview of the Study Area

2.1 Location and Physiography

Bathinda district lies in the southwestern part of Punjab between latitudes 29°51′ and 30°20′ N and longitudes 74°42′ and 75°37′ E. The area experiences a semi-arid climate with high temperatures during summer and cold winters. Annual rainfall averages between 200 and 400 mm, with most precipitation occurring during the southwest monsoon. Physiographically, Bathinda forms part of the Indo-Gangetic alluvial plain and is characterized by flat topography interspersed with minor undulations. The predominant soil types are aeolian and alluvial, ranging from sandy to loamy textures, which favor infiltration and thus influence recharge patterns of groundwater aquifers.

2.2 Hydrogeological Setting

The district is underlain by multi-layered aquifer systems composed mainly of unconsolidated sediments. The shallow and intermediate aquifers consist predominantly of fine to medium sand, silt, and clay of alluvial origin, derived from the Ghaggar River system. Groundwater recharge occurs primarily through infiltration of rainfall and irrigation return flow, supplemented by seepage from the canal network. The mineralogical composition of aquifer sediments, rich in silicates, carbonates, and clay minerals, strongly influences groundwater chemistry by facilitating geogenic dissolution of elements such as fluoride, arsenic, and uranium (Gautam et al., 2021; Ullah et al., 2023; Upadhyay et al., 2023). The heterogeneous permeability of these sediments enhances vulnerability to surface contamination, especially from agricultural and industrial activities (Sharma et al., 2016).

2.3 Land Use and Anthropogenic Activities

Bathinda forms part of Punjab's agricultural heartland, where intensive cropping patterns and high-yield practices dominate. The widespread use of nitrogen- and phosphate-based fertilizers, along with organochlorine and organophosphate pesticides, has profoundly impacted groundwater quality (Goyal et al., 2024; Huang et al., 2022). In addition, the district hosts multiple industrial facilities, including thermal power plants, textile manufacturing units, and small-scale chemical industries, which release effluents that frequently find their way into nearby water bodies and aquifers (Verma & Anju, 2018). Inadequate

waste management infrastructure and unregulated solid waste disposal further contribute to leachate generation, facilitating contaminant infiltration (Gautam et al., 2021). These cumulative anthropogenic pressures have intensified the degradation of groundwater across the region.

2.4 Previous Investigations

A number of hydrogeochemical studies in Bathinda have identified the district as a contamination hotspot. Earlier investigations primarily assessed physicochemical parameters and major ions, while more recent studies have employed advanced geochemical and spatial analytical techniques to quantify trace metals and radionuclides (Sharma et al., 2021; Singh et al., 2021). Results from these studies consistently report fluoride, uranium, and arsenic levels exceeding safe drinking water limits. The evolution of groundwater contamination research in Bathinda reflects a growing understanding of the interplay between natural processes and anthropogenic stressors, forming the basis for integrated environmental risk assessment and management.

3 Hydrogeochemical Characteristics of Groundwater

Groundwater quality in Bathinda reflects both natural geochemical interactions and anthropogenic influences. The principal parameters determining its chemistry include pH, electrical conductivity, total dissolved solids, and hardness, which often exceed recommended standards (Sidhu et al., 2020a, 2020b). Elevated electrical conductivity and TDS indicate significant salinity, largely resulting from leaching of fertilizers and irrigation return flows. Chloride and sulfate ions are abundant, while high nitrate concentrations—commonly associated with fertilizer leaching—represent a serious health concern. The major cations and anions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, F^{-}, HCO_3^{-}, SO_4^{2-}, Cl^{-}) reveal that the groundwater typically exhibits mixed hydrochemical facies, ranging from Ca-Mg-HCO_3 type in recharge zones to Na-Cl or Na-HCO_3 types in discharge areas, as shown in Piper and Gibbs diagram interpretations (Sidhu et al., 2020). These transitions suggest processes of ion exchange, rock-water interaction, and evaporation under semi-arid conditions.

Trace element contamination adds another layer of complexity. Uranium, arsenic, mercury, and fluoride are consistently detected at concentrations exceeding WHO limits (Sharma et al., 2021; Singh et al., 2021). Their occurrence varies spatially, forming hotspots that correspond to geological formations and human activities such as industrial discharge and intensive agriculture. Seasonal variations are pronounced, with monsoonal recharge temporarily diluting pollutants but also facilitating contaminant mobilization through leaching (Gautam & Chand, 2023). Post-monsoon periods typically exhibit higher concentrations due to reduced dilution and stronger water-rock interactions.

Recent monitoring by the Central Ground Water Board (CGWB) and associated agencies during 2023–2024 provides quantitative evidence supporting the persistent contamination of Bathinda's aquifers. Table 1 summarizes the major water quality parameters reported for Bathinda district, highlighting the widespread exceedance of permissible limits for nitrate, fluoride, and uranium. These findings confirm the ongoing deterioration of groundwater quality and the combined influence of agricultural, industrial, and geogenic factors.

Table 1. Groundwater Quality Parameters in Bathinda District, Punjab (2023–2024).

Year	Location / Scope	Parameter / Metric	Value / Observation	Notes / Source	URL / Web Link
2023	Bathinda (Shallow Aquifer Study, Punjab)	Electrical Conductivity	> 3000 µS/cm at several wells (high salinity)	Central Ground Water Board (CGWB), *Ground Water Quality in Shallow Aquifer of Punjab (2023)*	https://www.cgwb.gov.in/cgwbpnm/public/uploads/documents/17085970733445501 79file.pdf
2023	Bathinda / Punjab	Fluoride	Hotspot district with values > 1.5 mg/L	CGWB, *Ground Water Quality in Shallow Aquifer of Punjab (2023)*	https://www.cgwb.gov.in/cgwbpnm/public/uploads/documents/17085970733445501 79file.pdf
2023	Bathinda / Punjab	Uranium	Bathinda among districts with U > 30 µg/L	CGWB, *Punjab Groundwater Quality Scenario (2023)*	https://www.cgwb.gov.in/cgwbpnm/public/uploads/documents/17422957324618717 57file.pdf
2024	Bathinda District	Nitrate	46 % of samples exceed BIS limit (45 mg/L)	CGWB, *Annual Ground Water Quality Report (2024)*	https://www.cgwb.gov.in/cgwbpnm/public/uploads/documents/17363727719103932 16file.pdf
2024	Bathinda / Punjab	General contamination status	Multiple exceedances: nitrate, uranium, fluoride	CGWB, *Groundwater Chemical Quality Bulletin – Pre-Monsoon 2024*	https://gwdata.cgwb.gov.in/download/Bulletin/Punjab%20GWQ%20Bulletin%20Pre-monsoon%202024.pdf
—	Bathinda (Punjab)	Uranium (state-level summary)	32.6 % of samples exceed 30 µg/L	Press Information Bureau (PIB), *Punjab Groundwater Contamination Report (2024)*	https://pib.gov.in/PressReleasePage.aspx?PRID=2111857

Note. *Data compiled from secondary publicly available sources (CGWB and government reports). The author does not guarantee the accuracy or completeness of the information, and it is presented solely for academic reference.*

4 Sources and Pathways of Contamination

Groundwater contamination in Bathinda arises from both geogenic and anthropogenic origins, often interacting synergistically. The district's alluvial sediments contain fluoride-bearing minerals and uranium-enriched formations that naturally release contaminants into groundwater (Coyte et al., 2019; Pandit et al., 2022). Average uranium concentrations reach 88 µg L^{-1}, with nearly three-quarters of samples exceeding WHO limits (Sharma et al., 2021). Similarly, arsenic and mercury concentrations average 176 µg L^{-1} and 174 µg L^{-1} respectively, both far above safe thresholds (Sharma et al., 2021). Fluoride contamination primarily results from mineral dissolution within the aquifer (Aryan et al., 2023; Khusulio et al., 2024).

Human activities further amplify natural contamination. Fertilizers and pesticides leach nitrates, phosphates, and heavy metals into aquifers (Sharma et al., 2016; Gautam et al., 2021). Industrial effluents, particularly from thermal power plants and textile units, contribute additional toxic load (Gautam & Chand, 2023). Over-extraction of groundwater for irrigation has lowered water tables, accelerating the concentration of dissolved ions and triggering salinization (Sarkar et al., 2022). The cumulative effect of natural and human factors creates a complex hydrogeochemical environment where contamination becomes self-reinforcing through hydrological feedbacks.

5 Human Health Risk Assessment

Groundwater contamination in Bathinda poses severe public health challenges. The Human Health Risk Assessment (HHRA) framework evaluates these risks through hazard

identification, exposure analysis, dose-response assessment, and risk characterization (Herojeet et al., 2023). The U.S. Environmental Protection Agency model is widely adopted to calculate non-carcinogenic (HQ, HI) and carcinogenic (CR) risks (Rashid et al., 2022; Shetty et al., 2024). Ingestion of contaminated drinking water remains the dominant exposure route, while dermal absorption contributes to secondary exposure (Brindha et al., 2020). Children are more vulnerable than adults because of higher water intake relative to body mass and developing physiological systems (Chaudhry & Sachdeva, 2020; Yadav & Kalkal, 2024).

Empirical studies link Bathinda's water contamination to fluorosis, skeletal deformities, kidney damage, neurological disorders, and cancers (Ali et al., 2023; Yetiş et al., 2024). Arsenic exposure causes hyperkeratosis, melanosis, and vascular disorders (Ullah et al., 2022). Comparative studies in nearby districts report hazard index values exceeding unity, confirming significant non-carcinogenic risks, particularly among children (Kapoor & Kumar, 2024; Yadav & Kalkal, 2024). Despite these findings, longitudinal epidemiological studies directly linking groundwater quality to disease prevalence in Bathinda remain limited, underscoring the need for more integrated hydro-biological and health monitoring research (Aryan et al., 2023). Table 2 summarizes the principal contaminants detected in Bathinda groundwater during 2023–2024, along with associated health effects and regulatory guideline limits.

Table 2: Contaminants in Bathinda Groundwater, Health Effects, and Regulatory Limits (2023–2024)

Contaminant	Major Source(s)	Principal Health Effects	WHO Guideline Limit	BIS (IS 10500:2012) Limit	Key References
Fluoride (F^-)	Natural mineral dissolution; phosphate fertilizers	Dental & skeletal fluorosis, bone deformation	1.5 mg L^{-1}	1.0 mg L^{-1}	Aryan et al. (2023); CGWB (2023)
Uranium (U)	Geogenic origin in alluvial aquifers; thermal-plant effluent	Nephrotoxicity, carcinogenic risk	30 µg L^{-1} (0.03 mg L^{-1})	30 µg L^{-1} (0.03 mg L^{-1})	Sharma et al. (2021); CGWB (2024)
Arsenic (As)	Mineral dissolution under reducing conditions; agro-chemicals	Skin lesions, vascular diseases, cancers	10 µg L^{-1} (0.01 mg L^{-1})	10 µg L^{-1} (0.01 mg L^{-1})	Ullah et al. (2022); CGWB (2023)
Nitrate (NO_3^-)	Excess fertilizer, manure, sewage infiltration	Methemoglobinemia ("blue-baby" syndrome)	50 mg L^{-1}	45 mg L^{-1}	CGWB (2024); BIS (2012)
Lead (Pb)	Industrial effluent, corroded plumbing	Neurotoxicity, anemia, developmental delay	10 µg L^{-1} (0.01 mg L^{-1})	10 µg L^{-1} (0.01 mg L^{-1})	
Mercury (Hg)	Coal combustion, chemical-industry discharge	Renal & nervous-system damage	1 µg L^{-1} (0.001 mg L^{-1})	1 µg L^{-1} (0.001 mg L^{-1})	Sharma et al. (2021)
Chromium (Cr VI)	Electroplating & textile wastewater	Carcinogenicity, skin ulcers, DNA damage	50 µg L^{-1} (0.05 mg L^{-1})	50 µg L^{-1} (0.05 mg L^{-1})	Herojeet et al. (2023); CGWB (2023)

Note. *Data derived from secondary publicly available sources (CGWB, WHO 2022, BIS 2012). The author does not guarantee the accuracy or completeness of these values; they are presented solely for academic and reference purposes.*

6 Hydrogeochemical Modelling and Analytical Tools

Advanced analytical approaches help in understanding groundwater quality trends in Bathinda. Statistical methods such as Principal Component Analysis and Factor Analysis simplify complex datasets and identify pollution sources (Gulgundi & Shetty, 2018; Machiwal & Jha, 2015). Correlation matrices highlight relationships among physicochemical parameters (Khusulio et al., 2024). Geographic Information Systems (GIS) are widely employed to map contaminant dispersion using interpolation methods like Kriging and Inverse Distance Weighting (Thakur et al., 2025). Artificial Intelligence and Machine Learning models—including Support Vector Machines, Random Forests, and Boosted Regression Trees—are increasingly used for predicting groundwater contamination and assessing risk distribution (Awais et al., 2021; Biswas et al., 2025). Water Quality Index frameworks, including the Weighted Arithmetic and Canadian Council models, offer simplified indicators for communication and policy decisions (Naz et al., 2023; Najeeb & Saeed, 2022). Integration of fuzzy logic and GIS enhances predictive accuracy (Chaudhry & Sachdeva, 2021).

7 Environmental and Agricultural Implications

The use of contaminated groundwater for irrigation deteriorates soil quality, leading to salinization, alkalinity, and loss of fertility (Masood et al., 2023). Heavy metal accumulation alters microbial communities and nutrient cycles, reducing crop yield (Devika et al., 2024; Sharafi & Salehi, 2025). Toxic elements absorbed by plants can enter the human food chain, with documented bioaccumulation of nickel and other metals in wheat and rice cultivated in Punjab (Khan et al., 2023; Naz et al., 2022). The ecological impacts extend beyond agriculture, as contaminated runoff degrades aquatic ecosystems, diminishes biodiversity, and alters trophic dynamics (Ahamad et al., 2024; Samaraweera et al., 2024). Such cascading effects highlight the intertwined nature of water quality, soil health, and ecosystem stability.

8 Mitigation and Sustainable Management Strategies

Technological, hydrological, agricultural, and policy-level measures are essential to restore Bathinda's groundwater. Adsorption-based defluoridation, de-uranation using nanomaterials, and membrane filtration technologies have shown promise in removing contaminants (Dhaduti et al., 2025; Dhanya et al., 2022; Vani et al., 2024). Managed Aquifer Recharge and rainwater harvesting can replenish declining water tables (Brar et al., 2019; Raj et al., 2024). Agricultural reforms—such as crop diversification, precision irrigation, and organic farming—reduce fertilizer leaching and water demand (Brar et al., 2021; Jat et al., 2019). Policy interventions must strengthen groundwater regulation, promote efficient pricing mechanisms, and establish real-time monitoring networks (Bhatia & Singh, 2023; Megdal, 2018). Public awareness campaigns and participatory management programs are equally crucial to ensure sustainable community-led water conservation (Chinnasamy & Gupta, 2023; Das, 2024).

9 Research Gaps and Future Directions

Despite extensive research, gaps persist in long-term monitoring, interdisciplinary integration, and field-based implementation. Continuous water quality datasets are scarce, hindering accurate trend analysis (Schwartz et al., 2020). Future studies must integrate hydro-

geochemistry, toxicology, and socio-economic factors (Bhatia & Singh, 2024). Artificial Intelligence-based predictive modeling tailored to Bathinda's complex aquifers could enhance early warning systems (Kerketta et al., 2024; Pranjal et al., 2023). Field-scale pilot projects are required to test recharge and remediation strategies and evaluate their socio-economic feasibility (Ciampi et al., 2022; Shafeeque et al., 2023).

10 Conclusion

Groundwater in Bathinda district is severely contaminated with multiple pollutants, posing significant health, agricultural, and ecological challenges. Both geogenic and anthropogenic processes contribute to this degradation, with contaminant concentrations frequently surpassing WHO and BIS limits. Health risk assessments reveal alarming hazard indices and carcinogenic risk values, particularly among vulnerable populations. The integration of hydrogeochemical analysis with advanced modeling and policy measures is essential for developing sustainable solutions. Effective mitigation will depend on combining technological innovations, managed recharge systems, and agricultural reforms with strong governance and public participation. Ensuring the long-term safety of Bathinda's groundwater requires continuous monitoring, interdisciplinary research, and community engagement to protect this vital resource for future generations.

References

Abraham, M., & Mohan, S. (2015). Effectiveness of Artificial Recharge Structures in Enhancing Groundwater Storage: A Case Study. Indian Journal of Science and Technology, 8(20). https://doi.org/10.17485/ijst/2015/v8i20/81596

Ahamad, M. İ., Yao, Z., Ren, L., Cheng, Z., Li, T., Lu, H., Mehmood, M. S., Rehman, A., Adil, M., Lu, S., & Feng, W. (2024). Impact of heavy metals on aquatic life and human health: a case study of River Ravi Pakistan. Frontiers in Marine Science, 11. https://doi.org/10.3389/fmars.2024.1374835

Akhai, S., & Taneja, T. (2024). Liquid Gold: Safeguarding Our Health Through Pure Drinking Water and Rigorous Water Testing. In Natural Resource Management Issues in Human-Influenced Landscapes (pp. 129-148). IGI Global. https://doi.org/10.4018/978-1-6684-7051-0.ch007

Akhai, S., & Taneja, T. (2025). The Critical Role of Water Quality: Health Impacts, Contaminants, and Sustainable Solutions for Environmental and Human Well-being. In Smart Water Technology for Sustainable Management in Modern Cities (pp. 101-116). IGI Global. https://doi.org/10.4018/979-8-3693-8074-1.ch005

Alam, M. F., Pavelic, P., Sharma, N., & Sikka, A. (2020). Managed Aquifer Recharge of Monsoon Runoff Using Village Ponds: Performance Assessment of a Pilot Trial in the Ramganga Basin, India. Water, 12(4), 1028. https://doi.org/10.3390/w12041028

Ali, S., Agarwal, M. B., Verma, S., Islam, R., Deolia, R. K., Singh, S., Kumar, J., Mohammadi, A. A., Gupta, M. K., Fattahi, M., & Nguyen, P. (2023). Variability of groundwater fluoride and its proportionate risk quantification via Monte Carlo simulation in rural and urban areas of Agra district, India. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-46197-7

Aryan, Y., Pon, T., Panneerselvam, B., & Dikshit, A. K. (2023). A comprehensive review of human health risks of arsenic and fluoride contamination of groundwater in the South Asia region [Review of A comprehensive review of human health risks of arsenic and fluoride contamination of groundwater in the South Asia region]. Journal of Water and Health, 22(2), 235. UWA Publishing. https://doi.org/10.2166/wh.2023.082

Atta, M. I., Zehra, S. S., Dai, D.-Q., Ali, H., Naveed, K., Ali, I., Sarwar, M. K., Ali, B., Iqbal, R., Bawazeer, S., Abdel-Hameed, U. K., & Ali, I. (2023). Amassing of heavy metals in soils, vegeta-

bles and crop plants irrigated with wastewater: Health risk assessment of heavy metals in Dera Ghazi Khan, Punjab, Pakistan. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.1080635

Awais, M., Aslam, B., Maqsoom, A., Khalil, U., Ullah, F., Azam, S., & Imran, M. (2021). Assessing Nitrate Contamination Risks in Groundwater: A Machine Learning Approach. Applied Sciences, 11(21), 10034. https://doi.org/10.3390/app112110034

Barik, B., Ghosh, S., Sahana, A. S., Pathak, A., & Sekhar, M. (2017). Water–food–energy nexus with changing agricultural scenarios in India during recent decades. Hydrology and Earth System Sciences, 21(6), 3041. https://doi.org/10.5194/hess-21-3041-2017

Bhatia, S., & Singh, S. (2023). Can an Incentivized Command-and-Control Approach Improve Groundwater Management? An Analysis of Indian Punjab. Sustainability, 15(22), 15777. https://doi.org/10.3390/su152215777

Bhatia, S., & Singh, S. (2024). Assessing Groundwater Use Efficiency and Productivity across Punjab Agriculture: District and Farm Size Perspectives. Agriculture, 14(8), 1299. https://doi.org/10.3390/agriculture14081299

Bilali, A. E., Taleb, A., & Brouziyne, Y. (2020). Groundwater quality forecasting using machine learning algorithms for irrigation purposes. Agricultural Water Management, 245, 106625. https://doi.org/10.1016/j.agwat.2020.106625

Biswas, S., Chattopadhyay, A., Schilling, K., & Das, A. (2025). Investigating the association between groundwater contaminants and hypertension risk in India: a machine learning-based analysis. Journal of Exposure Science & Environmental Epidemiology. https://doi.org/10.1038/s41370-025-00776-0

Brar, A. S., Kaur, K., Sindhu, V. K., Tsolakis, N., & Srai, J. S. (2021). Sustainable water use through multiple cropping systems and precision irrigation. Journal of Cleaner Production, 333, 130117. https://doi.org/10.1016/j.jclepro.2021.130117

Brar, P. S., Kaur, N., Aggarwal, R., & Kaur, S. (2019). Studies on artificial groundwater recharge through abandoned well. Journal of Pharmacognosy and Phytochemistry, 8, 582. https://www.phytojournal.com/archives/2019/vol8issue1S/PartN/Sp-8-1-143-668.pdf

Brindha, K., Paul, R., Walter, J., Tan, M. L., & Singh, M. K. (2020). Trace metals contamination in groundwater and implications on human health: comprehensive assessment using hydrogeochemical and geostatistical methods. Environmental Geochemistry and Health, 42(11), 3819. https://doi.org/10.1007/s10653-020-00637-9

Bureau of Indian Standards. (2012). IS 10500: Drinking Water Specification (Second Revision). New Delhi: BIS.

https://bis.gov.in/

Central Ground Water Board. (2023). Ground Water Quality in Shallow Aquifer of Punjab. Ministry of Jal Shakti, Government of India.

https://www.cgwb.gov.in

Central Ground Water Board. (2024). Groundwater Chemical Quality Bulletin – Pre-Monsoon 2024. Ministry of Jal Shakti, Government of India.

https://gwdata.cgwb.gov.in

Chaudhari, U., Kumari, D., Tyagi, T., Mittal, S., & Sahoo, P. K. (2024). Geochemical Signature and Risk Assessment of Potential Toxic Elements in Intensively Cultivated Soils of South-West Punjab, India. Minerals, 14(6), 576. https://doi.org/10.3390/min14060576

Chaudhry, A. K., & Sachdeva, P. (2020). Groundwater quality and non-carcinogenic health risk assessment of nitrate in the semi-arid region of Punjab, India. Journal of Water and Health, 18(6), 1073. https://doi.org/10.2166/wh.2020.121

Chaudhry, A. K., & Sachdeva, P. (2021). GIS-based groundwater quality assessment using GQIs and fuzzy-logic approach. Water and Environment Journal, 36(1), 172. https://doi.org/10.1111/wej.12738

Chinnasamy, P., & Gupta, M. (2023). Participatory approaches for water monitoring and harvesting: Case study from India. Cambridge Prisms Water, 2. https://doi.org/10.1017/wat.2023.18

Ciampi, P., Esposito, C., Bartsch, E., Alesi, E. J., Rehner, G., Morettin, P., Pellegrini, M., Olivieri, S., Ranaldo, M., Liali, G., & Papini, M. P. (2022). A data-driven modeling approach for the sustainable remediation of persistent arsenic (As) groundwater contamination in a fractured rock aquifer through a groundwater recirculation well (IEG-GCW®). Environmental Research, 217, 114827. https://doi.org/10.1016/j.envres.2022.114827

Coyte, R., Singh, A., Furst, K. E., Mitch, W. A., & Vengosh, A. (2019). Co-occurrence of geogenic and anthropogenic contaminants in groundwater from Rajasthan, India. The Science of The Total Environment, 688, 1216. https://doi.org/10.1016/j.scitotenv.2019.06.334

Das, S. (2024). Water Management: Community Participation. Journal of the Geological Society of India, 100(4), 463. https://doi.org/10.17491/jgsi/2024/173862

Devika, D., Aulakh, R. K., Sharma, R., & Rani, N. (2024). Analysis of pesticide and heavy metal bioaccumulation in earthworms from Central plain zone of Punjab. Research Square (Research Square). https://doi.org/10.21203/rs.3.rs-4719879/v1

Dhaduti, M. S., Hunashyal, A. M., Rajappa, S. K., Kadabinakatti, S., & Hubballi, S. S. (2025). Activated Charcoal and Natural Soil Granules for Removing Fluoride from Aqueous Solution and Groundwater. Journal of The Institution of Engineers (India) Series A. https://doi.org/10.1007/s40030-025-00880-2

Dhanya, V., Arunraj, B., & Rajesh, N. (2022). Prospective application of phosphorylated carbon nanofibers with a high adsorption capacity for the sequestration of uranium from ground water. RSC Advances, 12(21), 13511. https://doi.org/10.1039/d2ra02031a

García, J., Leiva-Araos, A., Diaz-Saavedra, E., Moraga, P., Pinto, H., & Yepes, V. (2023). Relevance of Machine Learning Techniques in Water Infrastructure Integrity and Quality: A Review Powered by Natural Language Processing [Review of Relevance of Machine Learning Techniques in Water Infrastructure Integrity and Quality: A Review Powered by Natural Language Processing]. Applied Sciences, 13(22), 12497. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/app132212497

Gautam, A., & Chand, S. (2023). Groundwater zoning and sustainable management strategies for groundwater resources in the Bist-Doab region of Punjab, India. Environment Development and Sustainability, 26(4), 8421. https://doi.org/10.1007/s10668-023-03053-y

Gautam, A., Chand, S., & Prakash, S. (2021). Assessment of Groundwater Quality beneath Agriculturally Advanced Region of Northern Alluvial Plain, India. Sustainability, 13(13), 7053. https://doi.org/10.3390/su13137053

Gautam, V. K., Kothari, M., Al-Ramadan, B., Singh, P. K., Upadhyay, H., Pande, C. B., Alshehri, F., & Yaseen, Z. M. (2024). Groundwater quality characterization using an integrated water quality index and multivariate statistical techniques. PLoS ONE, 19(2). https://doi.org/10.1371/journal.pone.0294533

Gorai, A. K., Hasni, S., & Iqbal, J. (2014). Prediction of ground water quality index to assess suitability for drinking purposes using fuzzy rule-based approach. Applied Water Science, 6(4), 393. https://doi.org/10.1007/s13201-014-0241-3

Goyal, D., Haritash, A. K., & Singh, S. (2023). Hydrogeochemical characterisation and geospatial analysis of groundwater for drinking water quality in Ludhiana district of Punjab, India. Environmental Monitoring and Assessment, 195(6). https://doi.org/10.1007/s10661-023-11220-x

Goyal, S., Dave, R., Kumar, R., & Bhatia, U. (2024). Indian interstate trade exacerbates nutrient pollution in food production hubs. Communications Earth & Environment, 5(1). https://doi.org/10.1038/s43247-023-01178-6

Gulgundi, M. S., & Shetty, A. (2018). Groundwater quality assessment of urban Bengaluru using multivariate statistical techniques. Applied Water Science, 8(1). https://doi.org/10.1007/s13201-018-0684-z

Gwira, H. A., Osae, R., Abasiya, C., Peasah, M. Y., Owusu, F., Loh, S. K., Kojo, A., Aidoo, P., & Agyare, E. A. (2024). Hydrogeochemistry and human health risk assessment of heavy metal pollution of groundwater in Tarkwa, a mining community in Ghana. Environmental Advances, 17, 100565. https://doi.org/10.1016/j.envadv.2024.100565

Hahshmi, A. M., Abdullah, Z., Amjad, T., Ali, G., & Iqbal, T. (2024). The Impact of Anthropogenic Activities and Water Pollution on the Fish Diversity and Ecosystem Health of the Chenab River in the Punjab Region of Pakistan. Journal of Health and Rehabilitation Research, 4(1), 554. https://doi.org/10.61919/jhrr.v4i1.437

Hassan, G., Allan, C., Akhtar, S., & Shabir, G. (2021). Community participation for land and water care by improving groundwater management- a case study from Punjab Pakistan. https://researchoutput.csu.edu.au/en/publications/community-participation-for-land-and-water-care-by-improving-grou

Hassan, G., Allan, C., Punthakey, J. F., Baumgartner, L. J., & Ahmad, M. (2023). Groundwater Governance in Pakistan: An Emerging Challenge. In Global issues in water policy (p. 143). Springer Nature (Netherlands). https://doi.org/10.1007/978-3-031-36131-9_6

Hassan, G., Punthakey, J. F., Shabir, G., Yasmeen, F., Sultan, M., Ashraf, H., Sohoo, I., & Majeed, F. (2022). Physicochemical Investigation of Rainfall for Managed Aquifer Recharge in Punjab (Pakistan). Water, 14(14), 2155. https://doi.org/10.3390/w14142155

Herojeet, R., Dewangan, R., Naik, P. K., & Verma, J. R. (2023). Probabilistic modelling is superior to deterministic approaches in the human health risk assessment: an example from a tribal stretch in central India. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-45622-1

Huang, T., Ma, J., Song, S., Ling, Z., Macdonald, R. W., Gao, H., Tao, S., Shen, H., Zhao, Y., Liu, X., Tian, C., Li, Y.-F., Jia, H., Lian, L., & Mao, X. (2022). Health and environmental consequences of crop residue burning correlated with increasing crop yields midst India's Green Revolution. Npj Climate and Atmospheric Science, 5(1). https://doi.org/10.1038/s41612-022-00306-x

Jat, H. S., Sharma, P. C., Datta, A., Choudhary, M., Kakraliya, S. K., Yadvinder-Singh, Sidhu, H. S., Gérard, B., & Jat, M. L. (2019). Re-designing irrigated intensive cereal systems through bundling precision agronomic innovations for transitioning towards agricultural sustainability in North-West India. Scientific Reports, 9(1). https://doi.org/10.1038/s41598-019-54086-1

Kang, T., Shin, Y., Shin, M.-H., Lee, D.-J., Lim, K. J., & Kim, J. (2024). Evaluation of the Effect of Agricultural Return Flow on Water Quality, Water Quantity and Aquatic Ecology in Downstream Rivers. Water, 16(11), 1604. https://doi.org/10.3390/w16111604

Kapoor, K., & Kumar, S. (2024). Carcinogenic and Non- Carcinogenic Health Risk Assessment of Heavy Metals in Groundwater Sources, Punjab State, North India. https://doi.org/10.2139/ssrn.4743323

Kaur, N., Kaur, S., Tsolakis, N., Mishra, N., & Srai, J. S. (2022). Managing groundwater demand through surface water and reuse strategies in an overexploited aquifer of Indian Punjab. Modeling Earth Systems and Environment, 9(2), 2009. https://doi.org/10.1007/s40808-022-01602-4

Kerketta, A., Kapoor, H. S., & Sahoo, P. K. (2024). Groundwater fluoride prediction modeling using physicochemical parameters in Punjab, India: a machine-learning approach. Frontiers in Soil Science, 4. https://doi.org/10.3389/fsoil.2024.1407502

Khan, Z. I., Ahmad, K., Ahmad, T., Zafar, A., Alrefaei, A. F., Ashfaq, A., Akhtar, S., Mahpara, S., Mehmood, N., & Uğulu, İ. (2023). Evaluation of nickel toxicity and potential health implications of agriculturally diversely irrigated wheat crop varieties. Arabian Journal of Chemistry, 16(8), 104934. https://doi.org/10.1016/j.arabjc.2023.104934

Khusulio, K., Sharma, N. R., Kumar, R., Das, I. C., & Setia, R. (2024). Hydrochemical Assessment of Groundwater in Ludhiana and Amritsar Districts of Punjab and Identification of Fluoride Hotspots using GIS. Geomatics and Environmental Engineering, 18(5), 41. https://doi.org/10.7494/geom.2024.18.5.41

Koli, M., & Singh, S. P. (2023). Surface-modified ultrafiltration and nanofiltration membranes for the selective removal of heavy metals and inorganic groundwater contaminants: a review [Review

of Surface-modified ultrafiltration and nanofiltration membranes for the selective removal of heavy metals and inorganic groundwater contaminants: a review]. Environmental Science Water Research & Technology, 9(11), 2803. Royal Society of Chemistry. https://doi.org/10.1039/d3ew00266g

Krishan, G., Lapworth, D., MacDonald, A., & Rao, M. S. (2023). Groundwater recharge sources and processes in northwest India: Evidence from high frequency water isotope observations. Journal of Hydrology Regional Studies, 50, 101570. https://doi.org/10.1016/j.ejrh.2023.101570

Kumari, S., & Khan, S. (2017). Defluoridation technology for drinking water and tea by green synthesized Fe3O4/Al2O3 nanoparticles coated polyurethane foams for rural communities. Scientific Reports, 7(1). https://doi.org/10.1038/s41598-017-08594-7

Kushwaha, N. L., Sahoo, M., & Biwalkar, N. (2025). Machine Learning Approaches for Assessing Groundwater Quality and Its Implications for Water Conservation in the Sub-tropical Capital Region of India. Water Conservation Science and Engineering, 10(1). https://doi.org/10.1007/s41101-025-00348-1

Machiwal, D., & Jha, M. K. (2015). Identifying sources of groundwater contamination in a hard-rock aquifer system using multivariate statistical analyses and GIS-based geostatistical modeling techniques. Journal of Hydrology Regional Studies, 4, 80. https://doi.org/10.1016/j.ejrh.2014.11.005

Mahfooz, Y., Yasar, A., Liu, G., Islam, Q. U., Akhtar, A. B. T., Rasheed, R., Irshad, S., & Naeem, U. (2020). Critical risk analysis of metals toxicity in wastewater irrigated soil and crops: a study of a semi-arid developing region. Scientific Reports, 10(1). https://doi.org/10.1038/s41598-020-69815-0

Maji, P., & Selin, N. E. (2024). A Systems Analysis of Sustainability Impacts of Agricultural Policies in India. Earth s Future, 12(1). https://doi.org/10.1029/2023ef003667

Malard, A., Dörfliger, N., Jeannin, P., & Laube, S. (2022). Contribution of the dynamic visualization of a 3D hydrogeological conceptual model to the participatory management of groundwater resources. Comptes Rendus Géoscience, 355, 231. https://doi.org/10.5802/crgeos.152

Masood, N., Hudson-Edwards, K. A., Zafar, T., & Farooqi, A. (2023). Natural carbon mineralization and its control on the geochemical evolution of coal-based aquifers in the Salt Range, Punjab, Pakistan. Environmental Geochemistry and Health, 45(10), 7033. https://doi.org/10.1007/s10653-023-01621-9

Megdal, S. B. (2018). Invisible water: the importance of good groundwater governance and management. Npj Clean Water, 1(1). https://doi.org/10.1038/s41545-018-0015-9

Mutileni, N., Mudau, M., & Edokpayi, J. N. (2023). Water quality, geochemistry and human health risk of groundwater in the Vyeboom region, Limpopo province, South Africa. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-46386-4

Najeeb, R. R., & Saeed, I. O. (2022). Evaluating Groundwater Quality in Al-Hamdaniya District For Drinking Purpose Using the Canadian Water Quality Index Model (CCME WQI). Egyptian Journal of Aquatic Biology and Fisheries, 26(6), 243. https://doi.org/10.21608/ejabf.2022.271938

Naus, F. L., Schot, P. P., Breukelen, B. M. van, Ahmed, K. M., & Griffioen, J. (2020). Potential for managed aquifer recharge in southwestern Bangladesh based on social necessity and technical suitability. Hydrogeology Journal, 29(2), 607. https://doi.org/10.1007/s10040-020-02264-1

Naz, I., Ahmad, I., Aslam, R. W., Quddoos, A., & Yaseen, A. (2023). Integrated Assessment and Geostatistical Evaluation of Groundwater Quality through Water Quality Indices. Water, 16(1), 63. https://doi.org/10.3390/w16010063

Naz, S., Fazio, F., Habib, S. S., Nawaz, G., Attaullah, S., Ullah, M., Hayat, A., & Ahmed, I. (2022). Incidence of Heavy Metals in the Application of Fertilizers to Crops (Wheat and Rice), a Fish (Common carp) Pond and a Human Health Risk Assessment. Sustainability, 14(20), 13441. https://doi.org/10.3390/su142013441

Pandit, P., Saini, A., Chidambaram, S., Kumar, V., Panda, B., Ramanathan, A. L., Sahu, N., Singh, A. K., & Mehra, R. (2022). Tracing geochemical sources and health risk assessment of uranium in

groundwater of arid zone of India. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-05770-2

Parween, F., Kumari, P., & Singh, A. (2020). Irrigation water pricing policies and water resources management. Water Policy, 23(1), 130. https://doi.org/10.2166/wp.2020.147

Pranjal, P., Kumar, D., Soni, A., & Chatterjee, R. S. (2023). Investigating Spatio-temporal behaviour for Groundwater in North-West India: A Deep Learning Approach. Research Square (Research Square). https://doi.org/10.21203/rs.3.rs-3638857/v1

Raheja, H., Goel, A., & Pal, M. (2022). An evaluation of groundwater quality and its suitability for drinking and irrigation uses under the GIS framework. Water Practice & Technology, 17(11), 2259. https://doi.org/10.2166/wpt.2022.134

Raj, A., Yadav, B., Patidar, N., Krishan, G., Deka, B. J., Jeong, S., Pandey, A., Matsuno, Y., & Singh, R. (2024). Artificial recharge initiatives in India: Challenges and future scope. APN Science Bulletin, 14(1), 93. https://doi.org/10.30852/sb.2024.2568

Rashid, A., Ayub, M., Khan, S., Ullah, Z., Ali, L., Gao, X., Li, C., El-Serehy, H. A., Kaushik, P., & Rasool, A. (2022). Hydrogeochemical modeling evaluating carcinogenic and noncarcinogenic health risk of potentially toxic elements, integrating groundwater pollution indexing: Insights of GIS-based and geostatistical approaches. Research Square (Research Square). https://doi.org/10.21203/rs.3.rs-1286132/v1

Rashid, A., Ayub, M., Ullah, Z., Ali, A., Khattak, S. A., Ali, L., Gao, X., Li, C., Khan, S., El-Serehy, H. A., & Kaushik, P. (2022). Geochemical Modeling Source Provenance, Public Health Exposure, and Evaluating Potentially Harmful Elements in Groundwater: Statistical and Human Health Risk Assessment (HHRA). International Journal of Environmental Research and Public Health, 19(11), 6472. https://doi.org/10.3390/ijerph19116472

Raychoudhury, T., & Prajapat, V. (2024). Fluoride Removal from Contaminated Groundwater by a Wide Range of Nanoparticles: Identification of Best Performing Nanoparticle and Major Impacting Water Quality Parameters. https://doi.org/10.2139/ssrn.4739549

Rehman, K. U., Bukhari, S. M., Andleeb, S., Mahmood, A., Erinle, K. O., Naeem, M. M., & Qaiser, I. (2019). Ecological risk assessment of heavy metals in vegetables irrigated with groundwater and wastewater: The particular case of Sahiwal district in Pakistan. Agricultural Water Management, 226, 105816. https://doi.org/10.1016/j.agwat.2019.105816

Samaraweera, S. A. P. T., Najim, M., Alotaibi, B. A., & Traoré, A. (2024). Impacts of a partially connected wastewater treatment plant on the water quality of stormwater drains used as an irrigation source. Frontiers in Environmental Science, 12. https://doi.org/10.3389/fenvs.2024.1412717

Sarkar, I., Karforma, S., Bose, R., & Roy, S. (2022). Ubiquitous on-demand Water Reservoir Tracking System for Smart Village. Universal Journal of Agricultural Research, 10(3), 193. https://doi.org/10.13189/ujar.2022.100302

Schwartz, F. W., Liu, G., & Yu, Z. (2020). HESS Opinions: The myth of groundwater sustainability in Asia. Hydrology and Earth System Sciences, 24(1), 489. https://doi.org/10.5194/hess-24-489-2020

Shafeeque, M., Hafeez, M., Sarwar, A., Arshad, A., Khurshid, T., Asim, M. I., Ali, S., & Dilawar, A. (2023). Quantifying future water-saving potential under climate change and groundwater recharge scenarios in Lower Chenab Canal, Indus River Basin. Theoretical and Applied Climatology, 155(1), 187. https://doi.org/10.1007/s00704-023-04621-y

Shahzad, H., Farid, H. U., Khan, Z. M., Anjum, M. N., Ahmad, I., Chen, X., Sakindar, P., Mubeen, M., Ahmad, M., & Gulakhmadov, A. (2020). An Integrated Use of GIS, Geostatistical and Map Overlay Techniques for Spatio-Temporal Variability Analysis of Groundwater Quality and Level in the Punjab Province of Pakistan, South Asia. Water, 12(12), 3555. https://doi.org/10.3390/w12123555

Shaikh, M., & Birajdar, F. (2024). Artificial intelligence in groundwater management: Innovations, challenges, and future prospects. International Journal of Science and Research Archive, 11(1), 502. https://doi.org/10.30574/ijsra.2024.11.1.0105

Sharafi, S., & Salehi, F. (2025). Comprehensive assessment of heavy metal (HMs) contamination and associated health risks in agricultural soils and groundwater proximal to industrial sites. Scientific Reports, 15(1). https://doi.org/10.1038/s41598-025-91453-7

Sharma, D. A., Rishi, M. S., & Keesari, T. (2016). Evaluation of groundwater quality and suitability for irrigation and drinking purposes in southwest Punjab, India using hydrochemical approach. Applied Water Science, 7(6), 3137. https://doi.org/10.1007/s13201-016-0456-6

Sharma, P., Kaur, L., Mittal, R., Kaur, S., & Kaur, S. (2018). Social marketing approach to bring change in water use behaviour of rural people of Punjab, India. Journal of Water and Climate Change, 10(4), 968. https://doi.org/10.2166/wcc.2018.150

Sharma, T., Bajwa, B. S., & Kaur, I. (2021). Contamination of groundwater by potentially toxic elements in groundwater and potential risk to groundwater users in the Bathinda and Faridkot districts of Punjab, India. Environmental Earth Sciences, 80(7). https://doi.org/10.1007/s12665-021-09560-3

Shetty, B. R., Pai, J. B., Salmataj, S. A., & Naik, N. (2024). Assessment of Carcinogenic and Non-Carcinogenic Risk Indices of Heavy Metal Exposure in Different Age Groups using Monte Carlo Simulation Approach. Research Square (Research Square). https://doi.org/10.21203/rs.3.rs-5037859/v1

Sidhu, B., Sharda, R., & Singh, S. (2020a). Spatio-temporal assessment of groundwater depletion in Punjab, India. Groundwater for Sustainable Development, 12, 100498. https://doi.org/10.1016/j.gsd.2020.100498

Sidhu, B., Sharda, R., & Singh, S. (2020b). A Study of Availability and Utilization of Water Resources in Punjab. Current World Environment, 15(3), 544. https://doi.org/10.12944/cwe.15.3.18

Singh, G., Rishi, M. S., Herojeet, R., Kaur, L., Garg, P., & Sharma, K. (2019). Multivariate analysis and geochemical signatures of groundwater in the agricultural dominated taluks of Jalandhar district, Punjab, India. Journal of Geochemical Exploration, 208, 106395. https://doi.org/10.1016/j.gexplo.2019.106395

Singh, K., Pandey, G., & Singh, R. (2021). Carcinogenic trace metals in ground water of Bathinda district, Punjab, India. International Journal of Engineering Science and Technology, 13(1), 105. https://doi.org/10.4314/ijest.v13i1.16s

Singh, L., Kumar, R., Kumar, S., Bajwa, B. S., & Singh, S. (2012). Health risk assessments due to uranium contamination of drinking water in Bathinda region, Punjab state, India. Radioprotection, 48(2), 191. https://doi.org/10.1051/radiopro/2012042

Tamanna, & Gupta, N. C. (2023). A study and evaluation of groundwater quality and heavy metal contamination in Bathinda district of Punjab, India. Ecology, Environment and Conservation, 29(4), 1847–1856. https://doi.org/10.53550/EEC.2023.v29i04.065

Thakur, B. K., Kaur, S., Verma, V. K., & Biswas, A. (2025). Geostatistical evaluation and network optimization for precision groundwater resource mapping and management in Punjab State, India. Hydrogeology Journal. https://doi.org/10.1007/s10040-025-02878-3

Tsolakis, N., Harrington, T. S., & Srai, J. S. (2022). Leveraging Automation and Data-driven Logistics for Sustainable Farming of High-value Crops in Emerging Economies. Smart Agricultural Technology, 4, 100139. https://doi.org/10.1016/j.atech.2022.100139

Ullah, Z., Rashid, A., Ghani, J., Nawab, J., Zeng, X., Shah, M., Alrefaei, A. F., Kamel, M., Aleya, L., Abdel-Daim, M. M., & Iqbal, J. (2022). Groundwater contamination through potentially harmful metals and its implications in groundwater management. Frontiers in Environmental Science, 10. https://doi.org/10.3389/fenvs.2022.1021596

Ullah, Z., Zeng, X., Rashid, A., Ghani, J., Ali, A., Shah, M., Zainab, R., Almutairi, M. H., Sayed, A. A., & Aleya, L. (2023). Integrated approach to hydrogeochemical appraisal of groundwater quality concerning arsenic contamination and its suitability analysis for drinking purposes using water quality index. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-40105-9

Upadhyay, R. K., Tripathi, G., Đurin, B., Šamanović, S., Cetl, V., Kishore, N., Sharma, M., Singh, S. K., Kanga, S., Wasim, Md., Kumar, P., & Bhardwaj, V. (2023). Groundwater Potential Zone

Mapping in the Ghaggar River Basin, North-West India, Using Integrated Remote Sensing and GIS Techniques. Water, 15(5), 961. https://doi.org/10.3390/w15050961

Vani, B., Hymavathi, M., Kalyani, S., Sahu, N., & Sridhar, S. (2024). Effective removal of fluoride and arsenic from groundwater via integrated biosorption and membrane ultrafiltration. Water Science and Engineering. https://doi.org/10.1016/j.wse.2024.04.001

Verma, S., & Anju, A. (2018). Assessment of water quality around coal-fired thermal power plant, Bathinda (Punjab), India. Journal of Applied and Natural Science, 10(3), 915. https://doi.org/10.31018/jans.v10i3.1809

World Health Organization. (2022). Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda. Geneva: World Health Organization.
https://www.who.int/publications/i/item/9789240045064

Yadav, S., & Kalkal, S. (2024). Health risk assessment using Monte-Carlo simulations due to arsenic contamination in groundwater in Punjab. Journal of Water and Health, 22(12), 2304. https://doi.org/10.2166/wh.2024.188

Yetiş, A. D., İlhan, N., & Kara, H. (2024). Integrating deep learning and regression models for accurate prediction of groundwater fluoride contamination in old city in Bitlis province, Eastern Anatolia Region, Türkiye. Environmental Science and Pollution Research, 31(34), 47201. https://doi.org/10.1007/s11356-024-34194-w