

## Geographical Patterns of Groundwater Quality in Haryana: Salinity, Fluoride, and Nitrate Contamination and Their Implications for Health and Agriculture

Komal<sup>1\*</sup>, Ajay Kumar<sup>2</sup>

<sup>1</sup>Assistant Professor, Department of Geography, Sakshi Malik Government College Mokhra, Maharishi Dayanand University Rohtak Haryana India

<sup>2</sup>Assistant Professor, Department of Physical Education, Sakshi Malik Government College Mokhra, Maharishi Dayanand University Rohtak Haryana India.

### \*Corresponding Author

Miss. Komal

Email:

monimalikmoni354@gmail.com

### Article History

Received: 07.03.2026

Accepted: 20.05.2026

Published: 16.06.2026

**Abstract:** Haryana has an important source of drinking water, irrigation and industrial supply in ground water. However, the quality of groundwater varies considerably throughout the state because of variations in geology, geomorphology, rainfall, aquifer characteristics, agricultural intensity, urbanization and groundwater extraction. This mini-review compiles the findings of government reports and peer-reviewed studies on the spatial distribution, sources and impacts of salinity, fluoride and nitrate contamination in Haryana. Evidence available suggests that relatively fresh groundwater is generally found in the north-eastern districts and areas affected by river and canal recharge. Saline and sodic groundwater is more common in the arid and semi-arid western, south-western and poorly drained central districts. Parts of Panipat, Bhiwani, Hisar, Jhajjar, Rohtak, Mahendragarh and adjoining areas have reported fluoride enrichment. Nitrate contamination is more spatially diffuse and is mostly associated with fertilizer application, livestock waste, sewage leakage, septic systems and poor sanitation. These contaminants reduce the safety of drinking-water, increase non-carcinogenic health risk and affect agricultural productivity through soil salinization, sodicity and ion toxicity. Children may be especially vulnerable to health risks from fluoride and nitrate. Hence, Haryana requires aquifer-specific monitoring, village-level water-quality mapping, conjunctive use of canal and groundwater, regulation of agrochemical inputs, managed aquifer recharge, and locally appropriate water-treatment systems. The decline in ground water quality in Haryana should be viewed as an integrated problem of geography, environment, agriculture & public health, not just as a water treatment issue.

**Keywords:** groundwater quality, Haryana, geographical distribution, salinity, fluoride, nitrate, irrigation, health risk, GIS.

This work is licensed under a [Creative Commons Attribution-NonCommercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/) (CC BY-NC 4.0)

### Cite this article:

Komal., Kumar, A., (2026). Geographical Patterns of Groundwater Quality in Haryana: Salinity, Fluoride, and Nitrate Contamination and Their Implications for Health and Agriculture. *ISAR Journal of Agriculture and Biology*, 4(6), 18-25.

## 1. Introduction

Ground water is one of the most important natural resources supporting socio-economic development of Haryana. It is used for drinking, irrigation, livestock management, industrial production and urban water supply. Groundwater is a significant source for the state's agricultural economy, in particular for its rice-wheat, cotton-wheat and pearl millet-mustard cropping systems. But, the prolonged withdrawal, intensive agriculture, industrialization, population growth and urban expansion have exerted considerable pressure on quantity and quality of groundwater.

Geographically, Haryana is very diverse. The state has the Shivalik foothills in the northeast; the Yamuna alluvial plain in the east; large older alluvial plains in the center; semi-arid and arid tracts in the west and southwest; and, extensions of the Aravalli hill system in the south. Within these physical divisions, the geological, rainfall, drainage, soil composition, recharge potential and groundwater-flow conditions differ. Hence, groundwater quality pattern is not uniform throughout the state.

The north-eastern districts usually get more rain and recharge from the Shivalik hills and seasonal streams. Conversely, the western and south-western districts have low rainfall, high evapotranspiration, limited natural recharge and higher accumulation of dissolved salts. Groundwater in the vicinity of rivers and major canals may be relatively fresh, but saline or sodic groundwater is common in poorly drained depressions and in areas where the aquifer is flushed infrequently. The groundwater-quality problem of Haryana is thus intimately linked with the physical geography of the state.

Groundwater chemistry is affected by natural and anthropogenic processes. Natural processes include mineral weathering, dissolution, precipitation, ion exchange, evaporation, water-rock interaction and mixing of fresh groundwater with older saline water. Anthropogenic sources include agricultural fertilizers, pesticides, livestock waste, septic tanks, leaking sewer lines, industrial effluents, landfill leachate and irrigation return flow. Malik et al. (2023) reported that the groundwater quality in Haryana is mainly affected by salinity, hardness, fluoride, nitrate and heavy metals, and their distribution is controlled by a combination of geological and anthropogenic factors.

Among the different groundwater contaminants reported in Haryana, salinity, fluoride and nitrate are of particular importance. Salinity affects the acceptability and suitability of drinking-water. High sodium levels can damage soil structure and reduce crop yield. Fluoride is usually of geogenic origin and high consumption above the permissible concentration over long periods can lead to dental and

skeletal fluorosis. Nitrate is largely related to human activity and is especially dangerous to infants, children and other vulnerable populations.

The acceptable concentration of fluoride in drinking water is 1.0 mg/L as per Bureau of Indian Standards (BIS, 2012) and in the absence of an alternate source, the permissible limit is 1.5 mg/L. The permissible level of nitrate is 45 mg/L and should not be exceeded. Water containing higher concentrations of these components may not be suitable for routine human consumption without proper treatment. The present mini-review aims to review the geographical distribution of major groundwater-quality problems in Haryana, identify the natural and anthropogenic factors responsible for salinity, fluoride and nitrate contamination, discuss their health and agricultural implications and suggest geographically appropriate strategies for sustainable groundwater management.

## 2. Review Methodology

A narrative mini-review approach was used. Relevant literature was obtained from peer-reviewed journal articles, Central Ground Water Board publications, government water-quality reports and Indian drinking-water standards. Priority was given to studies conducted in Haryana in particular. This included work on groundwater hydrochemistry, geographical information system mapping, water-quality indices, fluoride and nitrate contamination, salinity, irrigation suitability and human-health risk assessment.

The literature was analyzed to find out geographical patterns in different districts and physiographic regions of Haryana comparatively. However, because of differences among the available studies in sampling periods, sample sizes, well depths, laboratory procedures, sources of groundwater, seasonal conditions, and water quality classification methods, no statistical meta-analysis was attempted. Thus, numerical results from individual studies have been interpreted as local or regional evidence rather than uniform estimates across the whole state.

## 3. Geographical and Hydrogeological Setting of Haryana

The greater part of Haryana is covered by Quaternary alluvium. Hard rock formations occur in the southern and south-western parts. Alluvial aquifers are made of alternating layers of sand, gravel, silt and clay. These materials vary widely in thickness, continuity and hydraulic connectivity. These changes impact the amount of groundwater recharged, its movement, storage and chemical composition.

**3.1 North Eastern Haryana:** The north-eastern region includes Panchkula, Ambala, Yamunanagar and parts of Kurukshetra. It receives comparatively higher rainfall and

recharge from Shivalik foothills, seasonal rivers, streams, canals and irrigated fields. In this area, the groundwater is generally less saline than in western Haryana. However, local contamination can occur from intensive farming, urbanization, industrial discharge and poor sanitation.

Groundwater quality in north-eastern Haryana has been reported as suitable to unsuitable depending on local hydrogeological and land-use conditions. Increased nitrate and dissolved-solids concentrations may result from agricultural return flow. Industrial and urban activities may add other chemical and microbial contaminants.

**3.2 Eastern Yamuna alluvial plain:** The alluvial deposits associated with the Yamuna River have influenced the eastern districts of Karnal, Panipat, Sonapat and Faridabad. Recharge from rivers, canals and irrigation may maintain relatively fresh groundwater zones. However, localized groundwater quality problems have arisen from intensive agriculture, population density, industrial development and urban sprawl.

Panipat is an important instance of intra-district spatial variation. Fluoride concentration was generally higher in western part of Panipat than eastern part (Kaur and Rishi, 2018). This variation indicates that water quality conditions may differ within an administrative district due to proximity to rivers, recharge, groundwater flow, and aquifer chemistry.

**3.3 Central Alluvial Plains:** The central alluvial plain comprises of Rohtak, Kaithal, Jind and Jhajjar. Groundwater quality in this area is very variable. Canal irrigation and irrigation return flow can create shallow freshwater zones, while deeper or poorly flushed aquifers contain saline groundwaters. Poor natural drainage and high evaporation may result in a further concentration of dissolved salts.

In Rohtak and Jhajjar, places are identified where groundwater quality varies significantly over short distances. Differences in aquifer sediments, depth, proximity to canals, recharge, intensity of pumping and drainage may account for this variability. Thus, district-level averages may not accurately reflect the quality of water available in individual villages.

**3.4 Haryana (West and Southwest):** The western and south-western part includes Sirsa, Fatehabad, Hisar and Bhiwani. It has a semi-arid climate, with low rainfall, high evapotranspiration, and limited natural recharge of groundwater. These conditions are conducive to the concentration of dissolved salts and to the increased occurrence of saline and sodic groundwaters.

Groundwater in this area may be characterized by high electrical conductivity, total dissolved solids, sodium, chloride, bicarbonate, and fluoride. In addition, intensive pumping and use of poor quality groundwater for irrigation can further increase salinity of soil and water. Therefore

salinity and sodicity are major constraints for the long-term agricultural sustainability of western Haryana.

**3.5 Southern Haryana and National Capital Region Southern Haryana** comprises Gurugram, Nuh, Rewari and Mahendragarh districts. The region is influenced by the Aravalli hill system, weathered and fractured hard-rock aquifers, rapid urbanization, industrial development and heavy groundwater extraction. Hard-rock aquifers often have limited and heterogeneous storage, leading to considerable spatial variability in groundwater availability and quality.

Groundwater pollution from sewage leakage, industrial waste, landfill leachate, construction activities and unregulated extraction is threatening the fast growing urban centers of Gurugram and Faridabad. Recent assessment of groundwater around Bandhwari landfill shows combined effect of landfill leachate, urbanization and large scale groundwater withdrawal on groundwater quality of Gurugram-Faridabad region (Kumar et al., 2025).

## 4. Major Groundwater-Quality Problems

### 4.1 Salinity and alkalinity

Salinity is the concentration of dissolved salts in water and is usually measured by electrical conductivity and total dissolved solids. Sodicity is the relative abundance of sodium to calcium and magnesium, and is often measured by the sodium adsorption ratio.

A broad geographical gradient in groundwater salinity is observed across Haryana. Relatively fresh groundwater is typically encountered near active river and canal recharge zones, whereas saline and sodic groundwater is more typical of semi-arid (western, south-western and poorly-drained central) regions. The distribution is not completely uniform, with zones of fresh water and saline-water occurring at different depths or in adjacent locations.

Salinity in Haryana is caused by several interacting mechanisms. Low rainfall and high evapotranspiration lead to salt accumulation in soils and shallow groundwater. Drainage is poor, limiting the removal of salt, and prolonged water-rock interaction promotes mineral dissolution. Some saline groundwater may be older water stored in poorly flushed aquifers. Evaporation from shallow water tables can also bring salts up to the soil surface.

Groundwater extraction may result in increased salinity. When too much water is pumped from a freshwater aquifer, hydraulic pressure can be reduced, inducing lateral or vertical migration of saline groundwater toward the pumping well. Irrigation return flow can also carry dissolved salts and agricultural chemicals from soil into shallow ground water. Salinity has been identified as an important groundwater-quality problem in north-western India,

including parts of Haryana, by the Central Ground Water Board (CGWB, 2024).

Saline water causes an osmotic effect which stops the plants taking up water. The crop may still suffer physiological water stress although there is plenty of moisture in the soil. Sodic water is a further problem due to the dispersing effect of sodium on soil clay particles, the decrease in soil aggregation, the reduced infiltration and the surface crusting. Repeated irrigations with sodic water can at times make productive land difficult to till for a period of time.

**Agricultural Implication of Saline and Sodic Groundwater**  
The effect of saline and sodic groundwater depends on soil texture, drainage, rainfall, crop tolerance, irrigation method and the chemical composition of the water. Soils with a coarse texture and good drainage can withstand moderate salinity better than fine-textured and poorly drained soils. Under marginal water-quality conditions salt tolerant crops may also outperform sensitive crops.

**4.2 Contamination of fluoride:** Fluoride is a naturally occurring element that is found in many minerals. It originates from weathering and dissolution of fluoride-bearing minerals into groundwater. Generally, alkaline pH, high concentrations of bicarbonate and sodium, low calcium activity, long groundwater residence times and evaporative concentration are favorable for fluoride mobilization. Fluoride contamination has been reported in alluvial and hard rock aquifers of Haryana. So it cannot be regarded as a hard-rock problem per se. Fluoride enrichment of alluvial regions may be favored by fine-grained sediments, ion-exchange processes, groundwater alkalinity, and long residence times. Kaur and Rishi (2018) analyzed the groundwater fluoride in Panipat district and reported the concentrations in the range of 0.50 to 5.95 mg/L with an average concentration of ~1.60 mg/L. Around 42.9% of the samples analyzed were found to exceed the permissible limit prescribed by World Health Organization and Bureau of Indian Standards. The study also showed a distinct geographical contrast with the western part of Panipat generally having higher fluoride concentrations than the eastern part. The Panipat findings reveal that the quality of water can be varied considerably within a district. The relatively lower fluoride concentrations in the eastern part of Panipat may be due to a fresher recharge from the Yamuna system, while the groundwater in the western part may have a longer residence time and greater interaction with aquifer materials. However, detailed hydrogeochemical investigations are necessary before spatial differences can be attributed to a single process. Increased Fluoride has also been reported in some parts of Jhajjar, Bhiwani, Hisar, Rohtak, Mahendragarh and adjoining districts. Chauhan et al. (2009) investigated the groundwater fluoride and dental fluorosis in schoolchildren of villages of Jhajjar district. Their findings supported an association between exposure to

fluoride in drinking water and the prevalence and severity of dental fluorosis. Fluoride has a very narrow margin between beneficial and toxic exposure. Appropriate levels of fluoride may be beneficial in preventing dental caries. However, long-term consumption of water with high fluoride content can lead to dental fluorosis, which is characterized by changes in the enamel of teeth. Prolonged exposure to far higher concentrations may lead to skeletal fluorosis, joint stiffness, pain, reduced mobility and skeletal deformities. According to Malik et al. (2023) one of the major inorganic contaminants affecting the groundwater in Haryana is fluoride. They stressed that the occurrence of fluoride is controlled by geological conditions, water-rock interaction, aquifer chemistry, climatic factors and groundwater abstraction.

**4.3 Nitrate contamination:** Nitrate is one of the most common groundwater contaminants due to anthropogenic activities in the intensively cultivated and densely populated areas. High nitrate is typically associated with human activities, unlike fluoride which is largely geogenic in origin. Major sources include nitrogenous fertilizers, animal manure, livestock enclosures, septic tanks, leaking sewer lines, open drains, solid waste disposal and irrigation return flow.

Intensive agriculture in Haryana demands heavy application of nitrogen fertilizer. If more fertilizer is applied than the crop can absorb, nitrate may remain in the soil and leach down with rain or irrigation water. Nitrate is highly soluble and can travel through the unsaturated zone and into shallow aquifers. Risk is increased in sandy soils and where excessive irrigation leads to increased deep percolation. Kumar et al. (2023) studied fluoride and nitrate contamination in Haryana and reported that about 11% of the analyzed samples were above the recommended limit for fluoride and about 6% were above the limit for nitrate. These percentages are based on this particular sampling network used in the study, and cannot be considered a uniform prevalence for all districts. Individual villages and groundwater sources have been found to be considerably more contaminated in local studies.

Nitrate contamination can be a serious problem in shallow hand pumps and wells near agricultural fields, septic tanks, drains, animal shelters, or waste-disposal sites. Note that deeper groundwater is not always safe, as poorly constructed wells may allow contaminated water to move vertically up the casing. Nitrate is colorless, odorless and tasteless at concentrations of public-health concern. Therefore, visual inspection or taste cannot be used by households to determine nitrate safety. Laboratory testing is critical. Infants are especially vulnerable to high nitrate exposure because nitrate can be transformed into nitrite in the body and affect the ability of hemoglobin to carry oxygen. This condition is called methemoglobinemia or "blue-baby

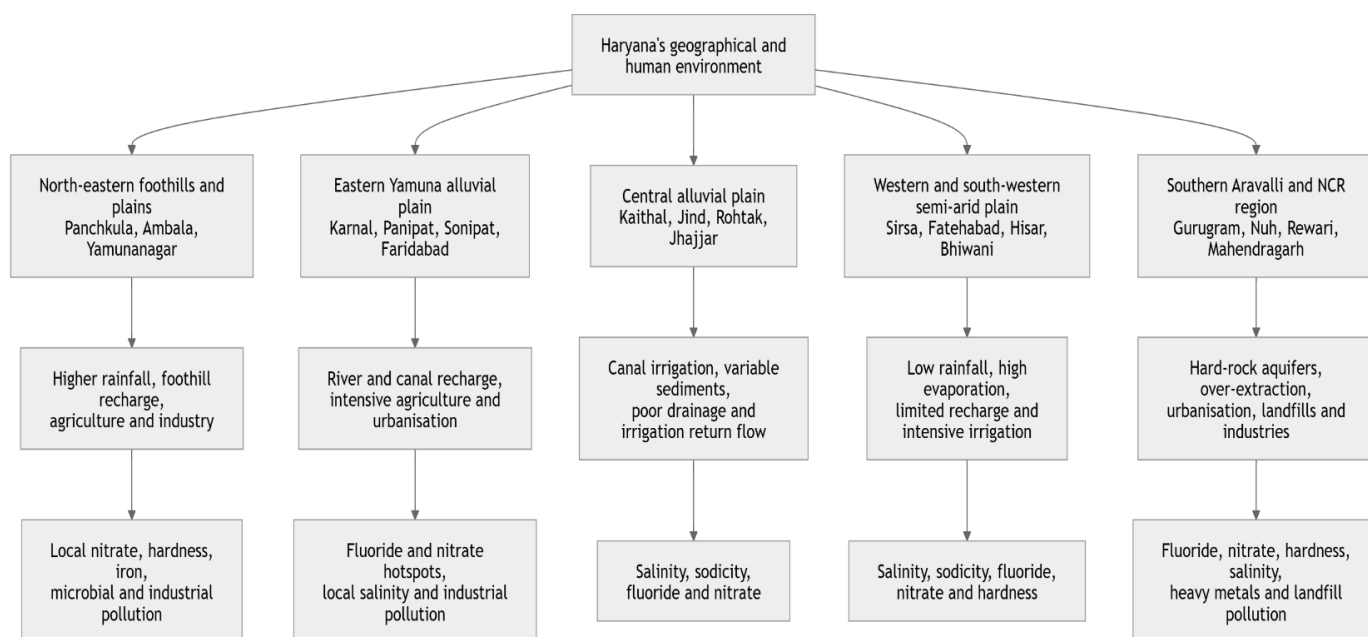
syndrome". Certain health conditions and pregnancy may also make women more vulnerable.

4.4 Urban and industrial pollutants: Salinity, fluoride and nitrate are the main concerns across the state, but urban and industrial areas may have other contaminants in their groundwater. Contaminants such as chloride, ammonium, organic pollutants, trace elements and heavy metals can reach shallow aquifers through industrial effluents, leaking sewers, waste dumps, landfill leachate and polluted drains. As per Malik et al. (2023), heavy metals and other inorganic pollutants in groundwater have been identified as emerging

threats in Haryana. The risk is particularly high in fast-urbanising and industrializing districts such as Gurugram, Faridabad, Panipat, Sonipat and Yamunanagar.

Urban contamination is often localized. A monitoring well several kilometers away from a landfill, drain or industrial site may not reflect the exposure of households close to a pollution source. Hence, the monitoring of urban groundwater should be performed with high-density sampling networks in the vicinity of potential contamination hotspots.

## 5. Geographical Distribution of Groundwater-Quality Problems



**Fig No. 1:** Haryana Geography and its general trends

The regional patterns presented in the fig 1 are general trends rather than fixed boundaries. Groundwater chemistry may vary between neighbouring villages, between wells of different depths, and between pre-monsoon and post-monsoon periods. Therefore, village-level and aquifer-specific mapping is more informative than broad district classification.

## 6. Human-Health Implications

The health effects of contaminated groundwater depend on contaminant concentration, exposure duration, daily water consumption, body weight, age, nutritional status, and simultaneous exposure through food and other water sources.

Kaur et al. (2020) conducted deterministic and probabilistic health-risk assessments for fluoride and nitrate in Panipat district. They found that the combined non-carcinogenic

hazard index exceeded unity in 40.8% of samples for adults and 69.7% of samples for children. These findings indicate that children may be more vulnerable because their water intake is higher relative to their body weight.

The principal health concerns associated with groundwater contamination in Haryana include:

- Dental fluorosis resulting from prolonged fluoride exposure during tooth development.
- Skeletal fluorosis following long-term exposure to high fluoride concentrations.
- Methemoglobinemia among infants exposed to excessive nitrate.
- Possible thyroid and gastrointestinal effects associated with prolonged nitrate exposure.

- Increased sodium intake from saline drinking water.
- Combined health risks where fluoride, nitrate, salinity, and other contaminants occur together.

Chauhan et al. (2009) demonstrated that groundwater fluoride exposure was associated with dental fluorosis among schoolchildren in Jhajjar district. School dental-screening programmes may therefore provide a practical method for identifying communities where drinking-water sources require urgent testing.

Health-risk communication is also important. The physical appearance and taste of water do not reliably indicate fluoride or nitrate safety. Communities should receive understandable information regarding source testing, alternative water availability, treatment requirements, and the limitations of household filtration systems.

## 7. Agricultural and Environmental Implications

The effect of groundwater quality in Haryana extends beyond human consumption. A large proportion of groundwater is used for irrigation, and poor-quality irrigation water may gradually degrade soil and reduce crop productivity.

Salinity produces osmotic stress, reducing the ability of roots to absorb water. Sodicty breaks down soil aggregates, decreases infiltration, increases surface crusting, and restricts root development. Chloride, sodium, and boron may also become toxic to sensitive crops at elevated concentrations.

The sustainability of irrigation with marginal-quality groundwater depends on scientific management. Potential strategies include:

- Blending saline groundwater with canal water.
- Cyclic use of fresh and saline water.
- Applying gypsum where sodicty is the main constraint.
- Improving field and subsurface drainage.
- Using laser land levelling to improve water distribution.
- Employing drip or sprinkler irrigation where technically appropriate.
- Selecting salt-tolerant crop varieties.
- Applying irrigation according to crop requirements.
- Monitoring soil salinity and groundwater quality periodically.

However, these strategies should not be applied uniformly. For example, gypsum may help manage sodic water but may

not solve problems caused mainly by high neutral salinity. Similarly, blending is effective only when adequate quantities of better-quality water are available.

Groundwater quantity and quality are closely related. Continuous over-extraction reduces dilution, changes groundwater-flow direction, and may draw saline or contaminated water towards productive wells. Groundwater-quality management should therefore be integrated with crop diversification, demand reduction, canal-water management, and aquifer recharge.

## 8. Research Gaps

Although numerous studies have examined groundwater quality in Haryana, several research gaps remain.

First, many studies are restricted to one district, block, or season. Such studies are valuable for local assessment but cannot provide a complete statewide picture. Second, sampling depth is not consistently reported, making it difficult to distinguish shallow contamination from deeper aquifer chemistry. Third, differences in sampling season, analytical procedures, and water-quality indices reduce comparability between studies.

Fourth, chemical monitoring is more common than microbiological assessment. Rural drinking-water safety cannot be ensured through chemical analysis alone because bacterial contamination may occur because of poor well construction, sanitation, and water storage practices. Fifth, relatively few studies combine water-quality data with clinical or epidemiological evidence.

Future investigations should focus on:

1. Seasonal and depth-specific groundwater monitoring.
2. Village-level GIS-based contamination maps.
3. Standardised sampling and laboratory protocols.
4. Separate assessment of shallow and deep aquifers.
5. Longitudinal monitoring of fluorosis and nitrate exposure.
6. Source identification through isotope and hydrochemical techniques.
7. Integrated evaluation of groundwater quantity and quality.
8. Monitoring of pesticides, pharmaceuticals, microplastics, uranium, and industrial contaminants.
9. Assessment of the effectiveness and maintenance requirements of treatment systems.
10. Development of publicly accessible groundwater-quality databases.

## 9. Management and Policy Recommendations

District- and village-level irrigation-water-quality maps should guide farmers in crop selection, gypsum application, water blending, drainage, and irrigation scheduling. Agricultural extension services should translate laboratory results into practical field-level recommendations.

9. Recommendations for Management and Policy: In Haryana, the management of groundwater quality should be based on geographical and aquifer specific conditions and not on a single statewide approach.

9.1 Kartierung und Überwachung : “Groundwater drinking sources need to be tested before and after monsoon. Monitoring should include: fluoride, nitrate, electrical conductivity, total dissolved solids, hardness, major ions, heavy metals and microbial indicators. The results should be presented at the village level and explained to the people in simple language.

9.2 Protection of sources of drinking-water : Wells that exceed standards for fluoride, nitrate or salinity should be clearly identified and removed from the drinking-water supply where safer alternatives exist. Drinking water for areas of high impact should be prioritized from high-quality surface water, canal water, rainwater or verified low-contaminant aquifers.

9.3 Treatment of water: Where source substitution is not possible, defluoridation, reverse osmosis, ion exchange and other treatment technologies may be used. But treatment units need regular maintenance, quality testing, trained operators and safe disposal of concentrated waste. Installing without long-term maintenance can create a false sense of security.

9.4 Nutrient management in farming: Soil-test-based fertilizer application, split nitrogen doses, precision farming, improved manure management and synchronization of fertilizer application with crop demand can reduce nitrate contamination. Avoid application of fertilizer immediately before heavy irrigation or rainfall.

9.5 Gestión de residuos y saneamiento : Safe distances should be maintained between septic tanks, drains, animal shelters, manure-storage areas, landfills and waste-disposal sites and the drinking-water wells. Sewer systems and septic tanks should be inspected regularly for leaks. Landfill sites need engineered liners, leachate collection and groundwater monitoring wells.

9.6 Managing aquifer recharge: Rainwater harvesting and managed aquifer recharge can improve groundwater availability and reduce some dissolved constituents. However, recharge structures need to be designed to match the local hydrogeology. Polluted runoff shall not be injected directly into aquifers unless it has undergone pre-treatment.

9.7 Irrigation water management: Farmers should use maps of irrigation water quality at the district and village level to guide their choice of crops, application of gypsum, blending of water, drainage, and irrigation scheduling. Laboratory results have to be translated into practical recommendations for farmers by agricultural extension services.

## 10. Conclusion

The quality of groundwater in Haryana displays a clear spatial pattern governed by climate, geology, aquifer properties, drainage, land use and groundwater draft. Groundwater conditions are generally relatively good in the north-eastern and eastern parts that are actively recharged, although local nitrate and industrial contamination can occur. Salinity and sodicity are more common in the semi-arid western, south-western and poorly drained central plains. Fluoride contamination in both alluvial and hard rock aquifers has been reported where alkaline condition and long-term water-rock interaction promotes the mobilization of fluoride. Nitrate contamination is more associated with intensive agriculture, sanitation, livestock waste, sewage and solid-waste disposal.

The case studies in Panipat and Jhajjar highlight potential health hazards of contaminated groundwater, especially for children. Irrigation water of poor quality is also a threat to soil structure, crop productivity and agricultural sustainability. Average water quality at the district level is not sufficient as quality can vary significantly between neighboring villages and aquifer depths. Haryana requires a holistic framework for groundwater management that brings together hydrogeology, geography, agriculture, public health, urban planning and environmental regulation. The framework should be based on village level monitoring, aquifer specific mapping, safer sources of drinking water, appropriate treatment, nutrient management, waste control, crop diversification and managed recharge. Ensuring quality of groundwater is important not only for safe drinking water but also for long term food security, rural livelihoods and sustainable development of Haryana .

## References

1. Bureau of Indian Standards. (2012). *Indian standard drinking water—Specification (second revision)*, IS 10500:2012. Bureau of Indian Standards.
2. Central Ground Water Board. (2024). *Annual ground water quality report 2024*. Ministry of Jal Shakti, Government of India. <https://www.jalshakti-dowr.gov.in/document/annual-ground-water-quality-report-2024>
3. Chauhan, D., Chauhan, T., Sachdev, V., & Kirtaniya, B. C. (2009). Fluoride distribution in groundwater and survey of dental fluorosis among school children in the villages of Jhajjar district of Haryana, India.

- Environmental Geochemistry and Health*, 31, 431–438.  
<https://pubmed.ncbi.nlm.nih.gov/18651230/>
4. Kaur, L., & Rishi, M. S. (2018). Data on fluoride contamination in potable water in alluvial plains of district Panipat, Haryana, India. *Data in Brief*, 20, 1844–1849. <https://doi.org/10.1016/j.dib.2018.09.031>
  5. Kaur, L., Rishi, M. S., & Siddiqui, A. U. (2020). Deterministic and probabilistic health risk assessment techniques to evaluate non-carcinogenic human health risk due to fluoride and nitrate in groundwater of Panipat, Haryana, India. *Environmental Pollution*, 259, Article 113711. <https://doi.org/10.1016/j.envpol.2019.113711>
  6. Kumar, P., Mahajan, A. K., & Kumar, A. (2023). Fluoride and nitrate in groundwater: A comprehensive analysis and its associated human health risk assessment in Haryana, India. *Environmental Geochemistry and Health*, 45. <https://pubmed.ncbi.nlm.nih.gov/36602646/>
  7. Kumar, S., Sharma, R., Singh, P., & Yadav, A. (2025). Suitability assessment of groundwater quality near Bandhwari landfill, Gurugram, Haryana, India. *Discover Geoscience*. <https://doi.org/10.1007/s43832-025-00312-z>
  8. Malik, A., Katyal, D., Narwal, N., Kataria, N., Ayyamperumal, R., & Khoo, K. S. (2023). Sources, distribution, associated health risks and remedial technologies for inorganic contamination in groundwater: A review in specific context of the state of Haryana, India. *Environmental Research*, 236, Article 116696. <https://doi.org/10.1016/j.envres.2023.116696>