

Groundwater Quality Assessment and Seasonal Variation in Bharatpur District, Rajasthan, India

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Abstract

In semi-arid regions like Rajasthan, groundwater is the largest freshwater source available to the population; because surface water is often limited and seasonal, most households will rely on their groundwater resources for various purposes: domestic, agriculture, and industry. The increasing population, application of fertilizers, growth of urban areas, and natural geochemical processes negatively affect the quality of groundwater in Bharatpur District. Our study evaluates the groundwater quality of Bharatpur District and variation in this quality by seasonally assessing several hydrologic factors: pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness, fluoride concentration, and nitrate concentration. We evaluated the differences in the hydrologic factors among the three identified seasons: pre-monsoon (dry), monsoon (wet), and post-monsoon (dry) seasons. Our results indicate significant differences in the quality (i.e., hydrologic factors) of groundwater across the spatial and temporal scales evaluated; while monsoon rainfall temporarily percolates through to recharge groundwater supplies, the effect is short-lived. Once the monsoon rains cease, and as a result of pollutant mobilization, groundwater quality is significantly reduced in the post-monsoon seasons. Moreover, fluoride and nitrate concentrations will frequently exceed the WHO and BIS permissible limits; when ingested, this can elevate the risk of health issues (fluorosis and methemoglobinemia). Our findings support the ongoing need to monitor and manage future groundwater supplies sustainably.

Keywords: Groundwater, Electrical Conductivity, TDS, WHO, Hydrologic Factors.

Introduction

Importance of Groundwater

The hydrological cycle includes groundwater, which is essential for drinking, irrigation, and agriculture for the world's population. Groundwater makes up approximately 60% of the irrigation needs and approximately 85% of all rural drinking water in India.

Rajasthan is a state in northern India that has developed as an arid or semi-arid climate. Due to little or no rainfall and no permanent rivers in Rajasthan, groundwater becomes a required resource to meet human and agricultural needs in the Bharatpur district of eastern Rajasthan.

Increasing Groundwater Stress in Rajasthan

According to recent data published by the CGWB, Rajasthan is one of the states in India that is experiencing the most stresses on its groundwater supply. There are many examples of groundwater quality problems found throughout Rajasthan. The latest data indicates:

- Approximately 20% of groundwater has levels of nitrate contamination above what is considered a safe level.

- Approximately 9% of groundwater has levels of fluoride contamination that exceed what is considered safe.

- There is a high degree of variability in groundwater quality among districts.

The factors that are primarily responsible for the degradation of groundwater quality found within Rajasthan are:

- Excessive use of fertilizers
- Discharge of industrial wastewater
- Infiltration of raw sewage
- Interaction between water and the natural rock formations
- Widespread over-extraction of groundwater

Seasonal Variation in Groundwater

Seasonal Fluctuations in Groundwater Chemistry:

- **During the pre-monsoon period**—high evaporation rates cause higher TDS, EC, and hardness in groundwater.
- **During the monsoon**—rainfall recharges and dilutes groundwater quality; and
- **After the monsoon**—agricultural pollutants leach into the groundwater supply.

Research conducted regarding the quality of groundwater in semi-arid India has confirmed that there is a significant seasonal difference between the levels of nitrate and fluoride in groundwater as measured from recharge events.

Bharatpur Hydrogeological Context

Bharatpur is situated within the Yamuna River basin and contains both alluvial and hard rock aquifers. Groundwater extraction from:

- hand pumps
- bore wells
- dug wells

Hydrochemical research indicates that the vast majority of groundwater available in the area has hardness and total dissolved solids concentrations greater than or equal to allowable limits; treatment must occur before use or ingestion.

Study Objectives

- Assess the quality of groundwater within Bharatpur District.
- Evaluate the seasonal variability of selected physiochemical parameters.
- Compare findings with World Health Organization and Bureau of Indian Standards.
- Locate areas impacted by fluoride and nitrate contamination.
- Propose methods for sustainable management of groundwater resources.

Literature Review

Groundwater quality analysis by way of literature review has consistently illustrated a number of contamination concerns throughout the state of Rajasthan:

• Nitrate Contamination

The Central Ground Water Board (CGWB) has identified approximately 20% (or 1 in every 5) of Indian groundwater samples as containing nitrate pollution as a consequence of agricultural runoff and sewage infiltration; nitrate pollution is generally highly seasonal in occurrence and most prevalent during post-monsoon recharge.

• Fluoride Contamination

Rajasthan is home to geogenic fluoride contamination (natural occurrence) as a result of rocks containing fluoride-containing minerals; fluoride contamination can lead to dental fluorosis (fluoride toxicity) and skeletal fluorosis following years of continued consumption.

- **Seasonal Studies on Water Sources**

Research has produced evidence to support the following:

- Highest concentration of most physiochemical parameters during the pre-monsoon period;
- Dilution of the concentration of most physiochemical parameters during the monsoon;
- The occurrence of different contamination levels during the post-monsoon period;

- **Groundwater-Surface Water Interaction**

Research has indicated significant interaction between surface water and groundwater system; for example, this interaction can significantly alter electrical conductivity, nitrate residuals, and total dissolved solids in semi-arid regions.

Methodology

- **Study Region**

The Bharatpur district of Rajasthan is situated on India's eastern fringe and belongs to the Braj cultural area. The geographic extent of Bharatpur is 26°49'N latitude and 77°30'E longitude. The district is characterized as semi-arid, with a hot summer, moderate monsoons, and cool winters. The yearly average precipitation is low and inconsistent, so people rely on groundwater for domestic, agricultural, and industrial purposes.

Hydrogeologically, Bharatpur consists of predominantly alluvial lowlands and consolidated rock types; both of which dictate how groundwater is stored and exists beneath the surface. The aquifer system is comprised of mostly shallow to moderate depth aquifers, so there is a high likelihood of groundwater contamination by surface activities. Irrigation and the use of fertilizers have caused an increased quantity of nitrate in groundwater and reduced water quality due to depletion of aquifer recharge due to over-pumping of wells.

Evaporation rates in the district are high because of the hot summer weather, therefore causing an increase in the mineral content of groundwater. Consequently, groundwater quality parameters, such as total dissolved solids (TDS), hardness, fluoride, and nitrate, are frequently above the acceptable limits established by World Health Organisation (WHO) and United States Environmental Protection Agency (EPA). The role of the seasonal precipitation in the aquifer recharge process makes the area extremely sensitive to changes in quality of groundwater over seasons.

- **Sampling Strategy**

An investigation of groundwater quality in several locations throughout Bharatpur District was carried out using a sampling strategy that included examining both spatial and seasonal variability in groundwater quality throughout Bharatpur District. Multiple samples from representative locations were taken to provide a comprehensive assessment of water quality.

Sources of the sampled water

Groundwater samples were collected from three major extraction sources:

- **Hand pumps** - Extract shallow groundwater and are very susceptible to surface contamination
- **Bore wells** - Extract from deeper aquifer conditions and provide relative stability of extracted water quality
- **Open wells** - Interconnected with surface and subsurface water systems

All three sources are commonly utilized for drinking and irrigation purposes in rural and semi-urban areas of Bharatpur.

Seasonal Sampling Design

In order to assess temporal variations, samples were obtained during three different hydro-climatic seasons:

- **Pre-monsoon (March through June)** - High evaporation rates produce maximum pumping of groundwater. This period includes the greatest accumulation of dissolved ions, due to a lack of recharge.

- Monsoon (July through September) - Represented by the primary period of groundwater recharge after precipitation; during this period groundwater recharge occurs through the dilution of contaminant levels in groundwater and supplementing aquifers with water.
- Post-monsoon (October through December) - Represented as the period of stability; during this time of year it is common for chemicals used in agriculture and pollution found on surfaces to leach into the groundwater.

The aforementioned classification of seasons enables an in-depth evaluation of how different climatic conditions during each season are affecting the groundwater quality in Bharatpur District.

▪ **Sampling Procedure**

In order to ensure the precision and accuracy of the results, standard sampling protocols were used. Water samples were collected in polyethylene bottles that had been pre-washed with the sample water prior to collection, labelled by location and season, stored in low temperatures until tested to prevent chemical changes, and field measured (pH, EC) using portable meters immediately upon collection.

• **Parameters Analyzed**

An evaluation of groundwater quality was done using a set of physical, chemical and toxicological parameters.

▪ **Physical Parameters**

Physical parameters provide a general level of water quality and usability.

- **pH** - Indicates the acid-base character of the water and has an effect on the water's chemistry as well as the solubility of minerals.
- **Electrical Conductivity (EC)** - Measurement of the amount of ions present in the water and therefore provides an indication of the salinity.
- **Total Dissolved Solids (TDS)** - Represents the total concentration of dissolved entities in the water to include salts and minerals.

These three parameters are useful to determine total mineralization and salinity of groundwater.

▪ **Chemical Parameters**

Chemical parameters provide an indication of how "hard" the water is and whether or not it is suitable for consumption.

- **Total Hardness** - The hardness of the water is primarily caused by the presence of calcium and magnesium ions in the water. The hardness of the water will impact the amount of soap used and scaling.
- **Calcium (Ca^{2+})** - An essential element in water; however, excessive levels will contribute to the hardness of the water.
- **Magnesium (Mg^{2+})** - Contributes to the taste and hardness of water, whereas optimal levels are generally acceptable; however, excessive concentrations may have health implications.

These parameters are significant for analyzing irrigation suitability and household usability.

▪ **Toxicology Parameters**

There are a number of parameters related to toxicity which can be utilized to evaluate the health risk associated with drinking water.

- **Fluoride (F^-)**: Natural element; excessive ingestion can lead to both dental and skeletal fluorosis.
- **Nitrate (NO_3^-)**: Mainly found in agricultural fertilisers and sewage; elevated levels can cause methemoglobinemia.
- **Chloride (Cl^-)**: An indication of salinity and an indicator of sewage or industrial pollution potential.

All three of these parameters are extremely important in assessing the safety of drinking water.

• **Standards Used in this Study**

Groundwater quality was assessed using both internationally and nationally acceptable drinking water quality standards in order to provide reliable and comparable results with respect to water quality.

WHO Drinking Water Quality Guidelines 2017

The World Health Organization publishes international drinking water quality standards worldwide to provide quality assurance for the safety of drinking water. In addition to specifying the acceptable limit for the following drinking water quality parameters:

- pH: 6.5 - 8.5
- TDS = 500 mg/L (acceptable upper limit)
- Fluoride $\leq$ 1.5 mg/L
- Nitrate $\leq$ 45 mg/L

These standards are used as a measure of public health protection and for performing assessments of risk to human health.

Bureau of Indian Standards IS 10500:2015 (India)

The Bureau of Indian Standards (BIS) specifies drinking water quality standards for India which takes into consideration the various climatic and geological conditions experienced across India and establishes both:

- Desirable limits for drinking water quality
 - Permissible level for drinking water quality without an alternative source
- BIS standards are particularly relevant for rural water supply evaluation in Rajasthan.

CGWB Monitoring Reports (India)

The Central Ground Water Board (CGWB) provides national-level groundwater monitoring data and hydrochemical assessments. CGWB reports are used to:

- Compare regional groundwater quality trends
- Identify contamination hotspots
- Understand long-term hydrogeological changes

These reports provide a scientific baseline for evaluating groundwater conditions in Bharatpur district.

Results and Discussion

- **Seasonal Variation of Groundwater Quality**

Table 1: Seasonal Trend of Parameters

Parameter	Pre-Monsoon	Monsoon	Post-Monsoon
pH	7.2–8.5	6.8–7.8	7.3–8.4
TDS	High (800–1800 mg/L)	Reduced	Moderate
EC	Very high	Moderate	High
Hardness	High	Reduced	Moderate
Nitrate	Very high	Diluted	Increased
Fluoride	High	Slight reduction	Persistent

- **Water Quality Status**

Table 2: Comparison with WHO Standards

Parameter	Range Observed	WHO Limit	Status
pH	7.0–8.5	6.5–8.5	Acceptable
TDS	600–1800 mg/L	500 mg/L	Exceeded
Fluoride	0.8–3.5 mg/L	1.5 mg/L	High
Nitrate	45–250 mg/L	45 mg/L	Critical

- **Nitrate Contamination**

Sources of nitrate contamination consist mainly of:

- Use of agricultural fertilizers
- Discharge of sewage
- Decomposition of organic waste

The Central Ground Water Board (CGWB) estimates that nitrate is one of the most common contaminants found in India with ~20% of the samples tested exceeding the allowed levels.

- **Fluoride Contamination**

Fluoride contamination in Bharatpur is primarily due to geogenic causes:

- Interaction between rocks and water
- High rate of evaporation
- Low rate of recharge of groundwater

- **Seasonal Mechanism Table**

Table 3: Hydrochemical Mechanism

Season	Process	Effect
Pre-monsoon	Evaporation	Concentration increase
Monsoon	Recharge	Dilution
Post-monsoon	Leaching	Pollution increase

- **Health Impact**

- Fluoride is associated with dental and skeletal fluorosis
- Nitrate is associated with methemoglobinemia
- High TDS is associated with kidney and gastrointestinal problems

Conclusion

The study indicates that groundwater quality in the Bharatpur district is substantially affected by both seasonal and human-induced factors. Although monsoon precipitation temporarily improves water quality through dilution, post-monsoon groundwater recharge generally worsens water quality through leaching. Long-lasting fluoride and nitrate contamination present considerable risks to public health. Most groundwater sources exceed WHO and BIS standards and must be treated prior to use. Sustainable management of groundwater, managed agricultural practices and ongoing monitoring are critical.

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