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Assessment of Seasonal Variations in Groundwater Quality Using Physicochemical Analysis and Water Quality Index in Panna, Madhya Pradesh, India: A Review

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Abstract:
Groundwater is one of the most important freshwater resources for domestic, agricultural and institutional requirements, particularly in regions where surface-water availability is seasonal and uneven. In India, increasing dependence on groundwater, rapid urbanization, inadequate drainage and sewage infrastructure, agricultural activities and changing recharge conditions have increased the vulnerability of aquifers to both quantitative and qualitative degradation. Panna District of Madhya Pradesh represents an important area for groundwater-quality assessment because of its varied geological formations, seasonal climatic conditions and increasing dependence on groundwater resources.

The present review synthesizes the available information on seasonal groundwater-quality variation in selected locations of Panna using physicochemical analysis and the Water Quality Index (WQI). The documented investigation covers seven sampling locations, namely Diamond Chauraha, Mohan Nivas Chauraha, Gandhi Chowk, Ajaygarh Chauraha, Kishorji Mandir, Baldevji Mandir and Purana Power House. Seven major physicochemical parameters—chloride, calcium hardness, total hardness, pH, electrical conductivity (EC), temperature and total dissolved solids (TDS)—were considered. Groundwater monitoring was conducted from May to August, representing pre-monsoon, monsoon and post-monsoon conditions.

The reviewed data indicate considerable spatial and seasonal variability in groundwater chemistry. During May, TDS ranged from 134 to 481.41 mg/L, while total hardness varied from 300 to 370 mg/L. The highest TDS was observed at Purana Power House, whereas Ajaygarh Chauraha showed the lowest TDS. The WQI values reported for the selected locations indicate comparatively better groundwater quality at Ajaygarh Chauraha and deterioration at locations subjected to greater urban and anthropogenic pressure. The review also identifies important research gaps, including limited monitoring duration, restricted sampling density and the absence of several important chemical and microbiological parameters. Integration of long-term monitoring, GIS, remote sensing and expanded hydrochemical analysis is recommended for sustainable groundwater management in Panna.

Keywords: Groundwater Quality, Seasonal Variation, Hydrochemistry, Water Quality Index, Physicochemical Parameters, Panna, Madhya Pradesh, Groundwater Management.

1. Introduction

Groundwater is a fundamental component of the hydrological cycle and is stored within the pores, fractures and fissures of subsurface geological formations. It represents an important strategic freshwater reserve because of its widespread availability, natural filtration through geological formations and relative protection from immediate surface-level contamination.

In India, groundwater plays a particularly important role in domestic water supply and agricultural irrigation. Dependence on groundwater is intensified by uneven rainfall distribution, seasonal drought conditions, increasing irrigation requirements and limitations in municipal water-supply infrastructure. Continuous extraction without adequate recharge can result in declining groundwater levels and may also contribute to deterioration of groundwater quality.

Groundwater chemistry develops through the interaction of infiltrating water with geological formations. During subsurface movement, water dissolves and transports minerals and ions from surrounding rocks. Calcium, magnesium, chloride, sulphate and other dissolved constituents may therefore originate from natural water–rock interactions. At the same time, human activities such as sewage disposal, agricultural runoff, solid-waste dumping and uncontrolled wastewater discharge can introduce additional contaminants into aquifer systems.

Panna District of Madhya Pradesh contains diverse geological formations, including granite, sandstone, shale, basalt, limestone and alluvial deposits. Such geological diversity can influence groundwater chemistry through mineral dissolution and water–rock interaction. Groundwater occurs mainly within weathered and fractured formations and alluvial deposits, making its quality dependent on both geological and environmental conditions.

Seasonal variation is another important factor controlling groundwater chemistry. During the pre-monsoon period, high temperature and evaporation combined with limited recharge can increase the concentration of dissolved constituents. During the monsoon, rainfall recharge introduces relatively fresh water into the aquifer and may dilute dissolved ions. The post-monsoon period represents the response of the aquifer after recharge and may therefore show a different hydrochemical condition.

Consequently, assessment of groundwater quality based on a single sampling event may not adequately represent the actual condition of an aquifer. Seasonal monitoring combined with physicochemical analysis and WQI provides a more comprehensive approach to understanding groundwater-quality variation.

1.1 Importance of Groundwater Quality Assessment

Groundwater-quality assessment is essential in regions where communities depend heavily on wells, borewells and handpumps. Unlike surface-water pollution, groundwater contamination may remain hidden for long periods because pollutants can move gradually through soil and geological formations.

Groundwater quality is influenced by both geogenic and anthropogenic processes. Natural processes include mineral dissolution, weathering, ion exchange and water–rock interaction. Anthropogenic influences include urbanization, wastewater discharge, agricultural activities, septic systems and solid-waste disposal.

Regular groundwater-quality assessment is important for the following reasons:

1. Public Health Protection

Groundwater used for drinking must be chemically and microbiologically suitable. Excessive dissolved constituents or contamination may create health risks, making regular monitoring necessary.

2. Domestic Water Use
High hardness, TDS and EC can adversely affect domestic water use by causing scaling in pipes and appliances and reducing the effectiveness of soaps and detergents.
3. Agricultural Sustainability
Groundwater used for irrigation may influence soil salinity and crop productivity. Therefore, continuous assessment of irrigation-water quality is important.
4. Aquifer Protection
Once groundwater becomes contaminated, remediation is generally difficult and costly. Early identification of deterioration therefore supports preventive management.
5. Seasonal Monitoring
Groundwater chemistry changes according to recharge, evaporation and rainfall conditions. Seasonal monitoring helps identify these temporal changes.
6. Water Resource Management
Reliable groundwater-quality information can assist authorities in developing water-supply, treatment, recharge and pollution-control strategies.

1.2 Rationale for Seasonal Groundwater-Quality Assessment

The rationale for seasonal groundwater assessment in Panna is associated with the combined effects of urban development, groundwater dependence, geological conditions and seasonal recharge.

Urban expansion increases the proportion of impervious surfaces and may reduce natural infiltration. Inadequate sewage and drainage systems can allow wastewater to enter the subsurface. Agricultural activities can also contribute dissolved constituents through leaching.

At the same time, geological formations determine the natural background chemistry of groundwater. Therefore, distinguishing between natural hydrochemical characteristics and anthropogenic influences requires both spatial and temporal observations.

The seasonal cycle can broadly be described as:

Pre-monsoon → concentration of dissolved constituents

Monsoon → recharge and dilution

Post-monsoon → hydrochemical adjustment/stabilization

Thus, seasonal investigation provides a better understanding of groundwater behaviour than isolated sampling.

1.3 Need for Seasonal Variation Study

Seasonal groundwater monitoring is particularly important in monsoon-dominated regions such as Panna.

During the pre-monsoon period, elevated temperature and evapotranspiration reduce available water and may concentrate dissolved ions.

During the monsoon period, rainfall recharge can increase groundwater levels and dilute previously accumulated dissolved constituents. However, rainfall runoff may also transport contaminants from agricultural and urban surfaces into recharge zones.

During the post-monsoon period, the groundwater system responds to the preceding recharge event. The resulting chemistry reflects dilution, mineral dissolution and subsequent hydrochemical adjustment.

Therefore, monitoring three seasonal phases provides a more complete understanding of the groundwater-quality cycle.

2. Literature Review

2.1 Introduction

Water Quality Index (WQI) is a widely used approach for converting multiple water-quality parameters into a single numerical value representing the overall quality of water. The method makes complex physicochemical information easier to interpret and compare between locations.

The development and application of water-quality indices have provided researchers and water-resource managers with a practical method for evaluating water quality. WQI has been applied to groundwater, rivers, lakes and reservoirs under different environmental conditions.

2.2 WQI-Related Studies and Their Applications

2.2.1 Application of WQI to Groundwater

Several studies have demonstrated the usefulness of WQI for evaluating groundwater-quality conditions. WQI combines several physicochemical parameters into a single index, thereby allowing comparison between different groundwater locations.

Studies using WQI have shown that groundwater quality may deteriorate in areas affected by domestic wastewater, industrial activities and intensive human settlement.

The application of WQI is particularly useful where several parameters need to be interpreted simultaneously rather than individually.

2.2.2 Application of WQI to Lakes

WQI has also been applied to lakes for evaluating pollution associated with nutrient loading, urbanization and agricultural runoff.

Studies reviewed in the source material indicate that parameters such as nitrate, phosphate, dissolved oxygen and pH can be used to evaluate the influence of agricultural and urban activities on lake water quality.

Seasonal monitoring has also demonstrated that water quality can change substantially between dry and monsoon periods.

* **Kundu et al. (2015):** This study used the WQI to evaluate the water quality of several lakes in India, focusing on nutrient loading from agricultural activities. Parameters such as nitrates, phosphates, DO, and pH were analyzed. The study concluded that eutrophication, caused by excess nutrients from fertilizers, was a major issue, resulting in low DO levels and decreased biodiversity.
* **Kaur and Singh (2018):** In the case of the Sukhna Lake in Chandigarh, India, the authors used WQI to assess the effects of urbanization on water quality. The results revealed that urban sewage and solid waste were the primary sources of contamination, resulting in an increase in microbial load and a decrease in water clarity.
* **Patel et al. (2019):** This study discussed the application of WQI in assessing the water quality of a lake used for drinking water supply in Madhya Pradesh, India. The research established that during the dry season, the water quality in the lake was generally good; however, during the monsoon, the agricultural runoff affected this water quality significantly.

2.2.3 WQI in Urban and Industrial Areas

Urban and industrial areas are often subjected to wastewater discharge, surface runoff and industrial effluent. WQI provides a convenient approach for comparing water-quality conditions across such areas.
* **Sharma et al. (2018):** The WQI was used on sub-surfaces and lakes in urban districts adjacent to industrial zones. The findings indicated that water bodies adjacent to industrial areas had poor water quality, with toxic substances such as heavy metals, chemical contaminants, and low oxygen levels.
* **Ravichandran et al. (2020):** WQI was used in the evaluation of water bodies in a fast-growing city in Tamil Nadu, India. The study showed that urban runoff, sewage discharge, and industrial effluents contributed the most to the degradation of water quality.

2.2.4 Climate and Seasonal Effects on WQI

Climate conditions influence water quality through changes in rainfall, temperature, evaporation and runoff. Increased temperature can enhance evaporation and concentrate dissolved constituents, whereas rainfall can cause either dilution or pollutant flushing depending on the surrounding land-use conditions.
Therefore, WQI-based assessment should preferably consider seasonal variations rather than relying only on one sampling period.

 Suresh et al. (2020): This study analyzed the effect of climate change on sub-surface water quality in Southeast Asia. A modified WQI was applied to predict the effect of shifting weather patterns on future water quality. Increased temperatures and unpredictable rainfall may lead to low DO levels as well as increased contamination due to runoff, especially in agricultural areas.

2.2.5 WQI and Environmental/Public Health

Water-quality indices are also useful for communicating water-quality information in relation to human and ecosystem health. High pollution levels can affect drinking-water safety as well as aquatic ecosystems.
The literature therefore establishes WQI as an effective screening and communication tool for identifying locations requiring further investigation and management.

2.3 Studies Related to Groundwater Quality

Previous studies on groundwater quality have emphasized the influence of urbanization, agricultural activities, industrial development and seasonal changes.
The reviewed literature indicates that groundwater chemistry is controlled by a combination of:
geological conditions,
mineral dissolution,
groundwater recharge,
evaporation,
land use,
sewage infiltration,
agricultural runoff, and
industrial activities.
Seasonal investigations have particularly highlighted the importance of comparing pre-monsoon and post-monsoon groundwater conditions.

Studies dealing with groundwater quality in different parts of India have also demonstrated that parameters such as pH, EC, TDS, chloride, hardness and other dissolved constituents can provide useful indicators of groundwater condition.

2.4 Research Papers on Water Quality of the Sub-Surface

The sub-surface is one of India's oldest and most important water sources in Panna, and various studies have been conducted on its water quality and the effects of pollution.

1. **Sharma et al. (2016):** Conducted an assessment of water quality in the sub-surface of Madhya Pradesh, India, focusing on the Panna area. Parameters included pH, DO, TDS, BOD5, and heavy metals. Researchers discovered that water quality near industrial zones and urban areas was heavily affected, showing organic pollution due to sewage and industrial waste.
2. **Dubey et al. (2017**): Analyzed the sources of pollution affecting the sub-surface in Panna. Researchers identified anthropogenic activities like untreated sewage discharge, industrial effluents, and agricultural runoff as the main contributors to degrading water quality.
3. **Singh et al. (2018):** Studied the impact of seasonal variations on water quality. During the monsoon season, the sub-surface exhibited higher turbidity levels and increased concentrations of nutrients like nitrates and phosphates, primarily due to runoff from agricultural fields.
4. **Patel (2019):** Monitored the water quality of the sub-surface at intervals divided into urban and rural areas within Panna. In the dry season, the sub-surface showed good water quality, but the monsoon season polluted the sub-surface through agricultural runoff (pesticides and fertilizers).
5. **Ravichandran et al. (2020):** Dealt with heavy metal contamination mainly in zones around industrial belts. The results showed the presence of metals such as lead, chromium, and cadmium, which were injurious to aquatic life and human beings.
6. **Kaur et al. (2021**): Analyzed long-term trends in water quality using both chemical and biological parameters. Researchers observed a decline over the years, with an increase in microbial contamination and a decrease in aquatic biodiversity.

2.5 Summary of Literature Review

The literature demonstrates that groundwater quality is controlled by a complex interaction of natural and anthropogenic factors. Geological formations determine the baseline hydrochemical characteristics, whereas land-use activities and wastewater management influence the degree of anthropogenic contamination.

WQI has emerged as a useful method for simplifying multidimensional water-quality datasets into an easily interpretable numerical classification. Its application to different water bodies demonstrates its usefulness for identifying spatial differences and supporting environmental management.

Seasonal studies further show that groundwater quality cannot be considered constant throughout the year. Evaporation during summer, rainfall recharge during monsoon and post-monsoon hydrochemical adjustment can produce measurable changes in physicochemical parameters.

The reviewed literature therefore supports the need for location-specific and season-specific groundwater monitoring in Panna.

2.6 Groundwater Quality in Panna

The documented investigation focuses on selected groundwater locations of Panna District. Seven locations are explicitly identified:

Diamond Chauraha
Mohan Nivas Chauraha
Gandhi Chowk
Ajaygarh Chauraha
Kishorji Mandir
Baldevji Mandir
Purana Power House

These sites represent different urban, residential, institutional and peri-urban conditions.

The geological setting includes granite, sandstone, shale, basalt, limestone and alluvial deposits. Such lithological variation may contribute to differences in groundwater chemistry.

2.7 Seasonal Groundwater-Quality Variation

The investigation covered the period from May to August, with the seasonal classification:

Pre-monsoon: May
Monsoon: June–July
Post-monsoon: August

The parameters considered were:

Chloride
Calcium hardness
Total hardness
pH
Electrical conductivity
Temperature
Total dissolved solids

The monthly data demonstrate that groundwater chemistry varies spatially between sampling locations.

For example, the May dataset shows TDS values ranging from 134 mg/L at Ajaygarh Chauraha to 481.41 mg/L at Purana Power House. Total hardness ranged from 300 to 370 mg/L.

These differences indicate that groundwater quality is not spatially uniform across the investigated area.

2.8 Water Quality Index Assessment

The WQI approach provides an integrated interpretation of the groundwater-quality parameters.

For May 2026, the documented WQI table reports:

Sampling Location

Site	WQI	Status
Diamond Chauraha	40.47	Good Water
Mohan Nivas Chauraha	41.3	Good Water

Gandhi Chowk	47.06	Good Water
Ajaygarh Chauraha	26.62	Good Water
Kishorji mandir	48.47	Good Water
Baldevji mandir	53.29	Poor Water
Purana Power House	59.73	Poor Water

The May results indicate comparatively better water quality at Ajaygarh Chauraha and deterioration at Baldevji Mandir and Purana Power House.

The June 2026 WQI values reported in the supplied material also indicate relatively favourable conditions at the documented sites for which values are provided. The June table reports WQI values of 42.33, 31.92, 35.23 and 33.38 for Diamond Chauraha, Mohan Nivas Chauraha, Gandhi Chowk and Ajaygarh Chauraha, respectively.

The WQI results demonstrate the usefulness of an integrated index for comparing groundwater conditions among different locations.

2.9 Spatial Variation of Groundwater Quality

The spatial differences observed among the sampling locations may be associated with differences in land use, drainage conditions, recharge characteristics and geological setting.

Ajaygarh Chauraha

Ajaygarh Chauraha shows comparatively favourable groundwater characteristics in the supplied dataset. Its relatively low TDS during May indicates lower dissolved-solid concentration compared with several other locations.

Diamond Chauraha

The site represents a semi-urban/residential setting. Groundwater quality may be influenced by domestic wastewater and local drainage conditions.

Mohan Nivas Chauraha

The location represents a densely inhabited urban environment where shallow groundwater may be vulnerable to wastewater infiltration.

Gandhi Chowk

Its location near the Kilkila River provides a potentially important recharge influence. The June dataset shows relatively high alkalinity at this location.

Kishorji Mandir

The site shows relatively high TDS and hardness compared with some locations and may be influenced by dense residential development and stagnant surface-water conditions.

Baldevji Mandir

The site exhibits relatively high TDS and EC in the supplied monthly data, indicating comparatively greater dissolved-ion concentration.

Purana Power House

Purana Power House records the highest May TDS value among the seven locations. The location is described in the supplied material as being exposed to considerable urban/industrial pressure.

3. Research Gap

Although the documented investigation provides useful information on groundwater quality in selected parts of Panna, several research gaps remain.

3.1 Limited Monitoring Period

The investigation covers only May to August. Therefore, it represents a short seasonal cycle and cannot establish long-term interannual groundwater-quality trends.

3.2 Limited Sampling Network

Although some sections of the supplied thesis mention ten stations, only seven locations are explicitly listed with coordinates and corresponding monthly datasets. Hence, broader spatial coverage is required for district-level assessment.

3.3 Limited Physicochemical Parameters

The investigation focuses mainly on chloride, calcium hardness, total hardness, pH, EC, temperature and TDS.

Important parameters such as:

nitrate,

fluoride,

sulphate,

iron,

manganese,

lead,

chromium,

other trace elements,

are not included in the reported dataset.

3.4 Lack of Microbiological Assessment

Parameters such as total coliform and E. coli are not included. Therefore, complete microbiological safety cannot be assessed from the reported physicochemical dataset alone.

3.5 Limited Hydrogeological Investigation

Advanced aquifer parameters such as transmissivity, storativity, hydraulic conductivity and pumping-test characteristics were not incorporated into the reported investigation.

3.6 Need for GIS and Remote Sensing Integration

Spatial analysis using GIS and remote sensing could help identify relationships between groundwater quality, land-use/land-cover patterns, drainage, geology and recharge zones.

3.7 Need for Long-Term Monitoring

Long-term monitoring is required to determine whether observed seasonal changes are temporary variations or indicators of persistent groundwater-quality deterioration.

4. Conclusion

The present review synthesizes the available information concerning seasonal groundwater-quality variation in selected locations of Panna District, Madhya Pradesh. The reviewed investigation demonstrates that groundwater quality is influenced by seasonal recharge, evaporation, geological conditions and local anthropogenic activities.

Seven documented groundwater locations were considered, namely Diamond Chauraha, Mohan Nivas Chauraha, Gandhi Chowk, Ajaygarh Chauraha, Kishorji Mandir, Baldevji Mandir and Purana Power House. Seven physicochemical parameters were evaluated, including chloride, calcium hardness, total hardness, pH, EC, temperature and TDS.

The May 2026 dataset demonstrates substantial spatial variation. TDS ranged from 134 mg/L at Ajaygarh Chauraha to 481.41 mg/L at Purana Power House, while total hardness ranged from 300 to 370 mg/L. These differences indicate that groundwater chemistry varies considerably between locations.

The WQI assessment further demonstrates spatial variation in overall groundwater quality. In the reported May dataset, Ajaygarh Chauraha had the lowest WQI, indicating comparatively better water quality, whereas Baldevji Mandir and Purana Power House were classified as poor.

The review establishes that seasonal groundwater monitoring combined with physicochemical analysis and WQI is an effective framework for understanding groundwater-quality conditions. However, the existing investigation requires expansion through longer monitoring periods, increased sampling density and inclusion of additional chemical and microbiological parameters.

For sustainable groundwater management in Panna, the following measures are recommended:

regular seasonal groundwater monitoring,
protection of groundwater recharge zones,
improvement of sewage and drainage systems,
proper solid-waste management,
rainwater harvesting,
artificial groundwater recharge,
expansion of groundwater sampling locations,
inclusion of trace elements and microbiological parameters, and
integration of GIS, remote sensing and hydrogeochemical analysis.

Overall, the reviewed study provides a useful baseline for understanding groundwater-quality variability in Panna, while future long-term and multidisciplinary investigations can provide a stronger scientific basis for sustainable aquifer management.

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