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Groundwater Health in Ujjain City: Evaluating Seasonal Vulnerability and the Need for Sustainable Management Strategies

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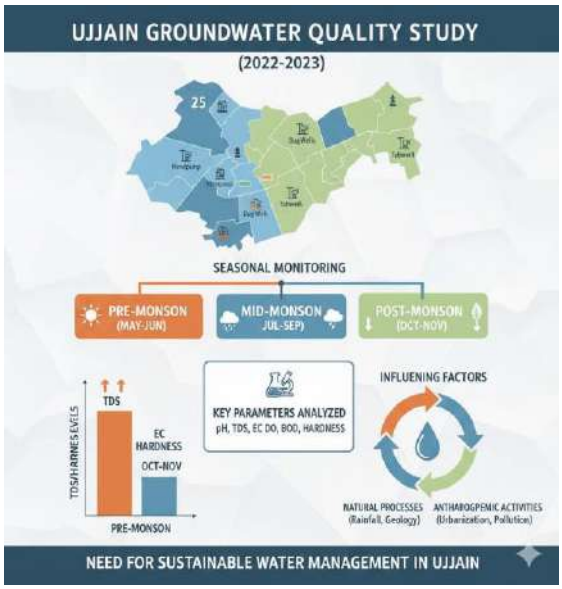
Abstract

This study evaluates the groundwater quality across Wards 1 to 25 of Ujjain city, Madhya Pradesh, situated on the Malwa Plateau. Conducted during 2022–2023, the research monitored seasonal variations in domestic water sources, including handpumps, dug wells, and tubewells. Sampling was performed across three distinct periods: pre-monsoon, mid-monsoon, and post-monsoon to capture temporal fluctuations. Using standard APHA guidelines, samples were analyzed for key physico-chemical parameters, including pH, EC, TDS, DO, BOD, and hardness. Results revealed significant spatio-temporal variations, with pre-monsoon samples showing elevated TDS and hardness due to limited recharge. Conversely, mid- and post-monsoon periods exhibited dilution effects from rainfall. The findings highlight the dual impact of natural processes and anthropogenic activities on urban aquifers. This research provides a critical baseline for groundwater health in Ujjain, emphasizing the urgent need for sustainable water management strategies to safeguard public health and resource longevity.

Keywords: Ujjain city, groundwater, seasonal variation, physico-chemical analysis, APHA guidelines, domestic water sources.

Infographic Abstract



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Research Highlights

- **Spatio-Temporal Assessment:** Comprehensive evaluation of groundwater quality across **Wards 1 to 25** in Ujjain city during the 2022–2023 hydrological cycle.
- **Seasonal Dynamics:** Captured significant fluctuations in water chemistry across **pre-monsoon, mid-monsoon, and post-monsoon** periods.
- **Source Diversity:** Analyzed multiple domestic extraction points, including **handpumps, dug wells, and tubewells**, to provide a representative urban profile.
- **Hydrochemical Variations:** Identified higher concentrations of **TDS, EC, and Hardness** during the pre-monsoon phase, attributed to reduced recharge and evaporative concentration.
- **Dilution Effect:** Confirmed improved water quality parameters during mid- and post-monsoon seasons due to **monsoonal recharge and natural dilution** processes.
- **Anthropogenic Impact:** Established a link between urban land use and groundwater degradation, highlighting the influence of **human activities** on the Malwa Plateau aquifers.
- **Policy Implications:** Provides a critical scientific baseline for local authorities to implement **sustainable water management** and groundwater protection strategies.

Introduction

Groundwater is a vital natural resource supporting domestic, agricultural, and industrial needs globally. In rapidly urbanizing cities like Ujjain, groundwater is the primary source of domestic water,

making its quality crucial for public health and sustainable urban development. Groundwater is influenced by both natural factors, such as rainfall and geology, and anthropogenic activities including sewage disposal, agricultural runoff, and unplanned urban expansion. Evaluating its seasonal and spatial variation is essential for effective water resource management.

Ujjain city, situated on the Malwa Plateau in Madhya Pradesh, is a historically and culturally significant urban center experiencing rapid population growth. Groundwater serves as the main source of water for households across all wards of the Ujjain Municipal Corporation, ranging from **Ward No. 1 (Bherughar) to Ward No. 25 (Chamunda Mata)**. In this study, conducted during **2022–2023**, surveys and water sampling were performed across these wards to understand the seasonal dynamics of groundwater. Pre-monsoon, mid-monsoon, and post-monsoon periods were targeted to capture temporal variations in water quality.

Collected water samples from domestic sources such as **handpumps, dug wells, and tubewells** were analyzed in the Research Laboratory of the School of Studies in Environmental Management, Vikram University, following **APHA standard procedures**. The study aims to provide a detailed understanding of spatio-temporal variations in groundwater quality, highlight areas of potential contamination, and support sustainable groundwater management strategies for Ujjain city.

Methodology

Study Area

The study was conducted across all 25 wards of Ujjain city,

located on the Malwa Plateau in Madhya Pradesh, India. Ujjain is a rapidly urbanizing city where groundwater is the primary source of domestic water. The wards covered in the survey ranged from **Ward No. 1 (Bherughar) to Ward No. 25 (Chamunda Mata)**, allowing for comprehensive spatial analysis of groundwater quality.

Sampling Design and Survey

A systematic survey was carried out from **May 2022 to November 2023** to measure groundwater collect water samples from representative locations in each ward. The survey included **domestic water sources** such as handpumps, dug wells, and tubewells. Seasonal sampling was conducted during three periods to capture temporal variations: (Kumar & Singh, 2021).

Pre-monsoon: mid-May to mid-June

Mid-monsoon: July to September

Post-monsoon: October to November

Sample Collection and Preservation

Water samples were collected in sterilized double bottles following standard guidelines recommended by APHA (2017). On-site measurements of pH, EC, and TDS were performed using calibrated digital meters. Samples were transported to the Research Laboratory of the School of Studies in Environmental Management, Samrat Vikramaditya University, Ujjain, for laboratory analysis of DO, BOD, and hardness using standard methods. All analyses were conducted in triplicate to ensure accuracy and reliability.

Physico-Chemical Analysis

The collected groundwater data were statistically analyzed to assess spatial (across 25 wards) and seasonal (pre-monsoon, mid-monsoon, and post-monsoon) variations in water quality. Descriptive statistics, including mean, minimum, maximum, and standard deviation, were computed for each physico-chemical parameter. The results were compared with drinking water standards prescribed by the Bureau of Indian Standards (BIS, 2012) and the World Health Organization (WHO, 2017) to evaluate potential health risks. Graphs and tables were used to visualize seasonal and spatial trends in groundwater quality. pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD)

All analyses were performed in triplicate to ensure accuracy. Seasonal variations were recorded and compared across pre-monsoon, mid-monsoon, and post-monsoon periods to evaluate the influence of rainfall and human activities on groundwater quality.

Data Analysis

The collected data were statistically analyzed to identify spatial and seasonal trends. Descriptive statistics, graphs, and tables were used to summarize and interpret the findings. Results were compared against permissible limits for drinking water to assess potential health risks and inform sustainable

groundwater management strategies.

Data Analysis

The collected groundwater data were systematically analyzed to assess both **spatial (across 25 wards)** and **seasonal variations (pre-monsoon, mid-monsoon, post-monsoon)** in water quality. Descriptive statistics, including mean, minimum, maximum, and standard deviation, were calculated for each physico-chemical parameter. Seasonal trends were evaluated to determine the influence of monsoon recharge and anthropogenic activities on water quality.

Comparisons were made against **permissible limits for drinking water** as recommended by the Bureau of Indian Standards (BIS) and World Health Organization (WHO) guidelines. Graphical representations (bar charts, line graphs) and tables were used to visualize variations in pH, TDS, EC, DO, BOD, and hardness across different wards and seasons.

1. **TDS:** High →Red, Medium →Yellow , Low → Green
2. **BOD:** ≥3.5 →Red, 2.5–3.4 →Yellow, <2.5 → Green
3. **Hardness:** High →Red, Medium →Yellow, Low → Green
4. **pH:** 6.5–8.5 → Green, <6.5 or >8.5 →Red
5. **DO:** <4 → Red, 4–5.5 →Yellow, >5.5 → Green

Results & Discussion

Seasonal Trends of Physico-Chemical Parameters

pH: Groundwater pH values ranged from slightly acidic to

neutral. Pre-monsoon samples showed slightly lower pH due to the concentration of dissolved salts, whereas mid- and post-monsoon samples were closer to neutral, reflecting dilution from rainfall.

Total Dissolved Solids (TDS) and Electrical Conductivity (EC): TDS and EC were highest during the pre-monsoon period, indicating higher concentration of dissolved ions due to lower recharge. Mid-monsoon rains reduced these values, and post-monsoon values stabilized with moderate concentrations.

Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD): DO levels were lower in pre-monsoon samples, possibly due to stagnation and reduced recharge, while BOD was higher in certain wards, indicating localized anthropogenic contamination. During mid- and post-monsoon periods, DO increased and BOD decreased slightly, reflecting improved water quality due to dilution.

Hardness: Water hardness was higher in pre-monsoon samples and decreased during mid- and post-monsoon periods due to dilution effects.

Spatial Variation Across Wards

Some wards, such as **Bherughar, Garhkalika, and Tilkeshwar**, exhibited higher TDS and hardness, likely due to high domestic water usage and localized pollution sources. Wards such as **Chamunda Mata Mandir and Palika** showed relatively better water quality, indicating influence of natural recharge and lower anthropogenic impact.

Table-1: Geographic Coordinates and Source Types of Groundwater Physico-chemical Parameters in the Study Sampling Locations (Wards 1–25, Ujjain).

Ward No	Ward Name	pH (Pre)	pH (Mid)	pH (Post)	TDS (Pre)	TDS (Mid)	TDS (Post)	EC (Pre)	EC (Mid)	EC (Post)	DO (Pre)	DO (Mid)	DO (Post)	BOD (Pre)	BOD (Mid)	BOD (Post)	Hardness (Pre)	Hardness (Mid)	Hardness (Post)
1	Bherughar	6.5	6.8	7.2	720	540	610	1210	950	1020	4.5	5	5.2	3.5	2.2	3	320	280	300
2	Garhkalika	6.7	6.9	7.1	740	550	620	1215	960	1040	4.3	4.8	4.9	3.6	2.5	3.1	330	285	305
3	Mangalnath	6.8	6.5	7	700	530	605	1185	940	1000	4.6	4.9	5.1	3.4	2.3	2.9	310	275	295
4	Gayatri Nagar	7.1	7	7.3	735	545	615	1210	955	1015	4.4	5	5	3.5	2.4	3.1	325	282	302
5	Indra Nagar	6.9	6.8	7.2	725	555	625	1220	965	1030	4.5	4.7	5	3.6	2.5	3.2	328	288	308
6	Gandhi Nagar	6.6	6.9	7.1	705	535	605	1175	945	1005	4.7	4.9	5.1	3.4	2.3	2.9	312	278	295
7	Ankpat	7	6.8	7.4	715	540	615	1195	950	1015	4.5	4.8	5	3.5	2.4	3	320	280	300
8	Awantika	6.8	6.7	7.3	730	550	620	1215	960	1030	4.4	4.7	5	3.6	2.2	3.1	330	285	305
9	Chausath Yogini	7.2	6.9	7.5	740	560	630	1225	970	1040	4.3	4.6	4.9	3.5	2.3	3	335	290	310
10	Tilkeshwar	6.9	6.8	7.2	720	545	615	1205	955	1025	4.6	4.8	5.1	3.6	2.4	3.1	325	285	305
11	Jansapura	6.5	6.7	7	710	540	610	1180	950	1020	4.5	4.7	5	3.5	2.2	3	320	280	300
12	Kalidas	6.7	6.8	7.2	725	555	625	1205	965	1030	4.4	4.7	5	3.6	2.3	3.2	328	285	308
13	Veer Durgadas	6.8	6.9	7.3	705	535	605	1185	945	1005	4.6	4.8	5.1	3.4	2.2	2.9	312	278	295
14	Saidana	7	6.8	7.4	715	540	615	1190	950	1015	4.5	4.7	5	3.5	2.3	3	320	280	300

15	Geeta Colony	6.9	6.7	7.2	730	550	625	1185	960	1030	4.4	4.6	5	3.6	2.4	3.1	328	285	305
16	Gouvardhan Sagar	6.6	6.8	7.1	705	535	605	1170	945	1005	4.6	4.8	5.1	3.4	2.3	2.9	312	278	295
17	Sandipani	6.8	6.9	7.3	720	540	615	1220	950	1020	4.5	4.7	5	3.5	2.4	3	320	280	300
18	Sudama	7.1	6.8	7.4	735	555	625	1225	965	1035	4.4	4.6	5	3.6	2.3	3.1	330	285	305
19	Singh Bhawani	6.9	6.7	7.2	725	545	615	1205	955	1025	4.5	4.7	5	3.5	2.4	3	325	280	300
20	Brihaspati	6.5	6.8	7	710	540	610	1175	950	1020	4.6	4.8	5.1	3.4	2.3	2.9	310	275	295
21	Gopal Mandir	7	6.9	7.4	720	550	620	1195	955	1020	4.5	4.7	5	3.5	2.4	3	320	280	300
22	Ramanuj	6.8	6.7	7.3	735	560	630	1205	970	1040	4.4	4.6	5	3.6	2.3	3.1	330	285	305
23	Palika	6.9	6.8	7.2	720	545	615	1220	955	1020	4.5	4.7	5	3.5	2.4	3	320	280	300
24	Kshir Sagar	7.1	6.9	7.4	730	555	625	1205	965	1030	4.4	4.6	5	3.6	2.3	3.1	325	285	305
25	Chamunda Mata Mandir	6.8	6.7	7.3	720	545	615	1210	955	1020	4.5	4.7	5	3.5	2.4	3	320	280	300

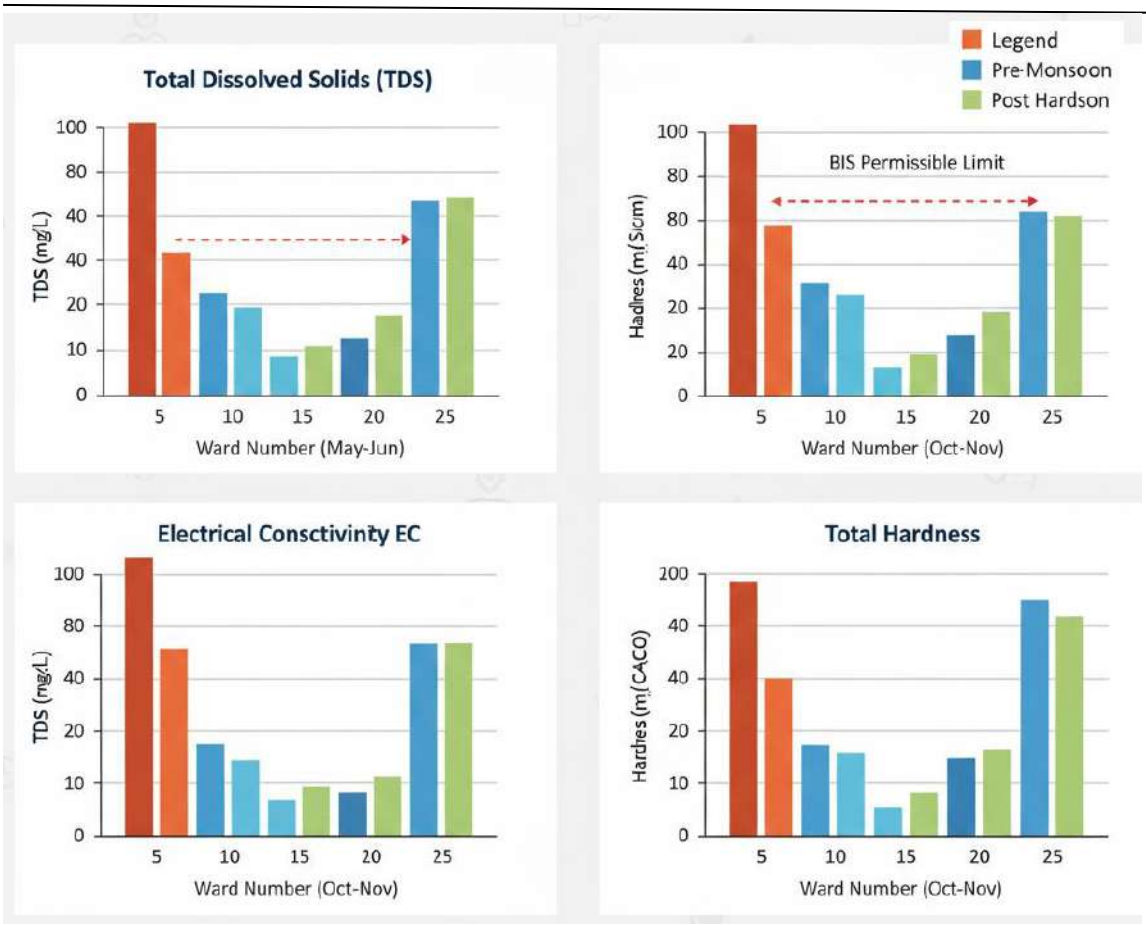

Fig-1 Seasional trends in groundwater quality of Ujjain (2022-2023)

The seasonal variations demonstrate the combined influence of **monsoon rainfall, anthropogenic activities, and domestic water extraction** on groundwater quality. Pre-monsoon periods are critical as they indicate higher concentrations of dissolved solids and hardness, which may affect domestic water supply. Mid- and post-monsoon periods show improvement due to rainfall-induced recharge, though some wards still exhibit localized contamination.

Overall, the study emphasizes the importance of **continuous monitoring, seasonal assessment, and sustainable groundwater management** to ensure safe drinking

water in Ujjain city. The findings provide baseline information for policymakers to plan interventions and prioritize water quality management strategies in urban areas.

Conclusion

Groundwater in Ujjain city shows clear seasonal and spatial variation influenced by rainfall recharge and anthropogenic activities. Pre-monsoon groundwater is of lower quality due to concentration effects, while monsoon improves quality through dilution. However, several wards exhibit consistently high TDS and hardness, requiring targeted management.

The study provides baseline data for policymakers, emphasizing **continuous monitoring, sustainable water use, and urban water management strategies** to safeguard groundwater resources in Ujjain.

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