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International Journal of Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281

The Spatio-Temporal Behaviour of Groundwater in The West Singhbhum District, Jharkhand

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ABSTRACT

This study examines the spatio-temporal behaviour of groundwater in the West Singhbhum district of Jharkhand, a hard-rock and mining-dominated region where groundwater is the primary source of drinking, domestic, agricultural, and industrial supply. Using seasonal groundwater-level records, physicochemical data and GIS-based spatial analysis, the study evaluates how groundwater quantity and quality vary across locations and between pre- and post-monsoon periods. Findings show clear seasonal fluctuations, with significant pre-monsoon decline in mining and densely populated zones, while forested uplands display comparatively stable water levels. Groundwater quality is largely moderate to good, but pockets of poor quality appear near mining belts due to elevated iron, manganese, nitrate, fluoride, hardness, and TDS. Spatial clustering of contamination highlights the influence of land use, lithology, and anthropogenic activities. The study provides a comprehensive district-level understanding of groundwater dynamics and offers a scientific basis for targeted recharge planning, pollution mitigation, and sustainable groundwater management in West Singhbhum.

Keywords: *Groundwater, Spatio-Temporal Variation, West Singhbhum, Mining Impact, Water Quality, GIS Analysis.*

I. Introduction

Groundwater is one of the most dependable and extensively utilized freshwater resources for drinking, domestic, agricultural, mining, and industrial activities, especially in hard-rock terrains and rain-fed regions such as Jharkhand. In such physiographic environments, limited surface-water storage, erratic monsoon rainfall, and weak water-supply infrastructure make aquifers the primary foundation of water security for both rural and urban communities (Pramanik et al., 2021; Mali et al., 2020). However, rapid population growth, unplanned urbanisation, expansion of mining activities, intensive agricultural pumping, and emerging hydro-climatic variability have increasingly disrupted the balance between groundwater recharge and extraction. These pressures have altered both the quantity and quality of groundwater in Jharkhand, raising significant concerns about long-term sustainability (Mishra & Lal, 2023; Singh et al., 2018).

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Recent hydrogeochemical studies reveal that Jharkhand faces a critical dual challenge—groundwater depletion and water-quality deterioration. At the state level, Gupta and Maiti (2025) documented widespread groundwater contamination arising from both geogenic factors (such as mineral dissolution, rock-weathering, lithology) and anthropogenic activities (including agriculture, industrial effluents, and mining). Using an Integrated Water Quality Index (IWQI) based on expert judgement and entropy-weighting of 545 samples, they found that although nearly half of the samples fell in the "excellent" category and a substantial portion in the "good" range, a concerning fraction ranged from moderate to extremely poor quality. Elevated fluoride, nitrate, and sulphate emerged as the most critical contaminants, posing risks of fluorosis, skeletal deformities and methemoglobinaemia. Fluoride enrichment was most pronounced in Palamu, Garhwa, Ranchi, Giridih, Bokaro, and parts of Dhanbad and Jamtara, driven by gypsum dissolution, evaporite weathering, and halite pollution (Gupta & Maiti, 2025).

Parallel research on rainfall-groundwater interactions demonstrates that spatio-temporal variability in precipitation strongly governs groundwater behaviour. Analysing rainfall and groundwater levels across 11 districts for the period 2001–2020, Kumar et al. (2025) reported significant spatial variability in monsoon rainfall, ranging from 650–1250 mm, and pre-monsoon rainfall between 25–175 mm. Higher precipitation was observed in Simdega, Lohardaga and Latehar, whereas Garhwa and Palamu remained persistently low-rainfall zones. Their trend analysis using the Mann–Kendall test and Sen's slope revealed negative rainfall trends in seven districts (up to –6.8 mm/year). This was accompanied by declining pre-monsoon groundwater levels in Palamu, East Singhbhum and Khunti, whereas Simdega, Ranchi and parts of West Singhbhum exhibited improving groundwater trends. These results highlight the heterogeneous nature of groundwater behaviour in Jharkhand and underline the need for district-specific evaluations (Kumar et al., 2025; Swain et al., 2022).

Groundwater contamination associated with mining activities adds further complexity to this issue. Several studies conducted in the coal, iron and mica mining belts of Jharkhand have shown that dissolved solids, major ions, and heavy metals frequently exceed drinking-water standards (Giri et al., 2023; Kumar et al., 2023). In mica-mining regions, Giri et al. (2025) found that nitrate, fluoride, calcium, magnesium, and total hardness exceeded BIS limits in many samples. Although a portion of the samples fell within "good" WQI ranges, nearly 29% were classified as "poor." Metal contamination studies further indicate that aluminium (Al), iron (Fe) and manganese (Mn) often surpass safe limits, with Hazard Index (HI) values for children exceeding 1 in certain seasons, signalling significant non-carcinogenic risks (Giri et al., 2023). Industrial belts such as Bokaro and Ramgarh also report elevated hardness, fluoride, chloride, bicarbonate, and heavy metals, although some areas remain suitable for domestic and irrigation use due to natural dilution and recharge processes (Yadav et al., 2024; Kumar et al., 2022).

Alongside contamination studies, geospatial analyses have enhanced understanding of groundwater potential and quality. Murmu et al. (2019) delineated groundwater potential zones in Dumka using an integrated remote sensing–GIS–AHP approach, identifying 11% of the district as "very good," with moderate-to-good zones covering nearly 80% of the area. Kumari and Krishna (2025) applied machine-learning models Random Forest (RF), Support Vector Machine (SVM), and Generalized Linear Model (GLM) and found RF to achieve the highest predictive accuracy (96%) for groundwater potential zoning

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in Ranchi district. These studies emphasise the strength of geospatial and data-driven tools in analysing complex hydrogeological variables such as slope, drainage density, lithology, soil type, land use/land cover (LU/LC) and lineament density. Comparable studies in Dumka, Hazaribag and Bokaro demonstrate that 70–80% of samples in some areas fail to meet drinking-water standards without treatment due to high levels of TDS, hardness, heavy metals, or arsenic (Srivastava & Srivastava, 2025; Kumar & Srivastava, 2024; Verma et al., 2020; Kumar & Pati, 2022).

Nitrate and fluoride contamination remain persistent challenges in various districts of Jharkhand. Gautam et al. (2021) observed nitrate concentrations as high as 250–260 mg/L along the Subarnarekha River, with nearly 44% of sites falling into unsafe zones. In Gharbar, Thapa et al. (2019) reported fluoride reaching ~18.5 mg/L and nitrate up to 319 mg/L—levels far exceeding permissible limits. Studies in Chandwara and other blocks show that 60–70% of samples exceed permissible limits for iron and hardness, with Monte Carlo–based health-risk assessments indicating significant non-carcinogenic risks from fluoride and iron ingestion (Pramanik & Chatterjee, 2021; Pramanik et al., 2021).

Despite Jharkhand possessing substantial groundwater resources—estimated at 4.29 BCM—only about 15% of this resource is developed, leaving nearly 85% underutilized (Mali et al., 2020). However, this apparent availability masks local-level crises. Long-term groundwater-level assessments in Ranchi, Purbi Singhbhum and Saraikela reveal significant increases in depth-to-groundwater (i.e., water-table decline) over the past 20 years, especially during pre-monsoon seasons (Swain et al., 2022; Pratik & Patel, 2023). These findings reinforce the need for granular, district-level spatio-temporal assessments to design appropriate recharge, regulation, and conservation strategies.

Although a substantial body of hydrogeochemical and modelling research has been conducted in Jharkhand, a major research gap persists regarding the detailed spatio-temporal assessment of groundwater behaviour in the West Singhbhum district. Most studies focused on Ranchi, Dumka, Bokaro, Hazaribag, Dhanbad, Koderma and East Singhbhum do not adequately capture the hydrogeological complexities of West Singhbhum, which is characterised by extensive mining, forested uplands, tribal settlements, high geomorphological diversity and varied lithological formations (Giri et al., 2021; Singh et al., 2018; Murmu et al., 2019; Mishra & Lal, 2023). While limited evidence suggests improving post-monsoon groundwater trends in some parts of West Singhbhum (Kumar et al., 2025), a systematic spatio-temporal groundwater evaluation at the district level remains absent.

II. Reviews Study and Findings

Author & Year	Study Focus	Parameters	Findings	Implications
Gupta & Maiti (2025)	Statewide groundwater contamination; IWQI	545 samples; Fluoride, nitrate, sulfate; Ca, EC, TH	~50% “Excellent”, large share “Good”; some moderate–extremely poor. • High fluoride in Palamu, Garhwa, Ranchi, Giridih, Bokaro, Dhanbad, Jamtara. Fluoride controlled by evaporite & gypsum dissolution, carbonate weathering.	Need for defluoridation, monitoring, and fluoride-risk mitigation.

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Kumar et al. (2025)	Rainfall–groundwater trends (11 districts, 2001–2020)	Rainfall ranges: Pre-monsoon 25–175 mm; Monsoon 650–1250 mm. GW levels: 2–18 m. Sen's slope: –6.8 mm/year.	Negative rainfall trends in 7 districts. Declining GW levels in Palamu, East Singhbhum, Khunti. Improving GW in Simdega, Ranchi, West Singhbhum, Latehar.	Region-specific recharge strategies needed; promote RWH & efficient irrigation.
Giri et al. (2025)	Mica mining region hydrochemistry	pH, EC, TDS, Ca, Mg, Na, K, NO_3^-, F^-	High nitrate, fluoride, Ca, Mg, TH beyond BIS limits at many sites. ~29% samples "Poor". PCA: Rock weathering dominant; mining/agriculture secondary.	Regular monitoring needed; risk of nitrate/fluoride health impacts.
Kumari & Krishna (2025)	ML-based Groundwater Potential Zonation (Ranchi)	ML Models: GLM, SVM, RF; Accuracy: 76%–96%	RF highest accuracy (96%). Key variables: slope, drainage density, lithology, LU/LC, rainfall, lineaments.	ML outperforms traditional MCDM; useful for hard-rock aquifer planning.
Srivastava & Srivastava (2025)	Hydro-geo-chemistry in Dumka	61 samples; TDS ~182 ppm; EC ~366–358 µS/cm; pH 6.9	Ca–Mg–Cl_2 facies dominant. Carbonate weathering & ion exchange major drivers. Poor WQI in Jarmundi, Shikaripara, Jamua.	Water quality degradation increasing; urgent need for treatment measures.
Yadav et al. (2024)	Bokaro industrial belt water quality	pH 6.15–7.73; EC 230–1676 µS/cm; SAR, RSC, PI	Mostly suitable for drinking/irrigation. Some hotspots: high pH, hardness, fluoride, bicarbonate, nitrate.	Industrial impact evident; groundwater largely protected by natural recharge.
Kumar & Srivastava (2024)	Hazaribag groundwater—heavy metals	Metals: Zn > Fe > Mn > Al > Cr > As > Pb; WQI: 72% "Unsuitable"	Strong rock-water interaction. High metal contamination; Zn, Fe, Mn dominant. HI indicates non-carcinogenic health risks.	High treatment priority; severe health-risk conditions.

Ambade et al. (2024)	Fluoride pollution (Eastern India)	Fluoride: 0.02–2.7 mg/L (pre), 0.02–4.7 mg/L (post); 97% < 1.5 mg/L	Infants showed highest hazard quotient. Negative F–Ca^{+2} correlation.	Awareness needed despite low fluoride exceedances.
Mishra & Lal (2023)	Ranchi groundwater—metal pollution	WQI up to 100.95; MI up to 53.98; HPI up to 109.20	Severe contamination in Khelari, Bundu, Ormanjhi. Metals: Fe, Mn, Pb, As major contributors.	Rapid urbanisation degrading aquifers; urgent mitigation needed.
Giri et al. (2023)	Metals in mica mining belt	Fe, Mn exceed limits in 72%, 47%, 33% samples	Post-monsoon highest metal loads. \Children's HI: 1.17–1.18 (>1).	Moderate–high health risk for children; unsafe at many sites.
Pratik & Patel (2023)	GW-level fluctuation (Ranchi)	Depth-to-water table mapping & 3D visualization	Clear zones of over-extraction mapped.	Helps identify recharge vs. withdrawal zones.
Kumar et al. (2023)	Coalfield-region GW quality	Pre-monsoon good–excellent: 32%; Post-monsoon: 77%	Despite mining activity, most samples potable. Seasonal variation notable.	Recharge improves post-monsoon GW quality.
Giri et al. (2023)	Iron-mining region metal contamination	Fe & Mn exceed limits in ~75% samples	PCA: geogenic + mining impacts. Pre-monsoon HI: 1.16.	Children at elevated non-carcinogenic risk.
Kumar & Pati (2022)	Arsenic ML-based classification	ML: RF best performer	RF classifier accurately predicts arsenic hotspots.	Suitable for risk-based planning.
Swain et al. (2022)	Trend analysis using ITA	DGWL ↑ at 17 (pre) & 14 (post) sites	Rising DGWL = falling groundwater table.	Declining aquifers; ITA more reliable than MK test.
Kumar et al. (2022)	Industrial area heavy-metal study (Ramgarh)	Fe > Zn > Mn > Al > Ba > Ni > Cu > …	Fe exceeded limit in all samples. Most samples low–medium HPI, HEI, Cd.	Mixed lithogenic + industrial contamination.
Kumar et al. (2022)	Arsenic contamination in Jharkhand	Max As: 1.5 mg/L (Sahibganj), 1.2 (Deoghar)	9/24 districts contaminated; mostly plateau region.	Arsenic widespread beyond Gangetic belt.
Pramanik et al. (2021)	State-level major ion review	Fluoride, arsenic, Fe widespread	Many regions lack safe drinking water.	Baseline for contamination mapping.

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Gautam et al. (2021)	Nitrate pollution (Subarnarekha region)	NO_3^-: 0.2–264.6 mg/L	44% unsafe zone. Agriculture & industries main sources.	High nitrate-driven disease risk.
Giri et al. (2021)	Fluoride & nitrate in mica belt	F^- up to 18.5 mg/L; NO_3^- up to 319 mg/L	95% samples pose risk to children.	Very high ingestion risk.
Pramanik & Chatterjee (2021)	Chandwara groundwater study	143 samples; Fe exceedance: 68%	High TDS, hardness, Ca; fluoride safe.	Iron contamination dominant.
Pramanik et al. (2021)	Fluoride & iron health risk	F^-: 0.18–1.21 mg/L; Fe > limits in 68%	Non-carcinogenic risk significant.	Monitoring & defluoridation required.
Mali et al. (2020)	Water resources & agriculture	GW availability: 4.29 BCM; GW development: 15%	85% unutilised GW potential.	Enormous scope for GW-based irrigation.
Raza (2020)	Urban GW planning (Dhanbad)	LU/LC, DEM, weights applied	Identified optimal sites for sustainable GW management.	Useful for urban planning.
Verma et al. (2020)	Bokaro WQI assessment	Many parameters > BIS limits	Pre-monsoon GW poorer than post-monsoon.	Treatment necessary before drinking use.
Murmu et al. (2019)	GW potential (Dumka)	AHP+GIS; Zones: Very good 11%, Good 38%	Reliable delineation validated with well discharge.	Effective framework for hard-rock areas.
Thapa et al. (2019)	Fluoride–nitrate mobilization	F^-: 0.01–18.55 mg/L; NO_3^-: 34–319 mg/L	F^- geogenic; NO_3^- anthropogenic.	High contamination risk.
Bharti et al. (2019)	ERT for aquifers	Wenner & Dipole–Dipole arrays	Identified water-saturated fractures & alluvium zones.	Improves aquifer detection accuracy.
Singh et al. (2018)	Heavy metals in East Singhbhum	Cr > As > Cd > Pb (risk order)	HI > 1 indicates high health risks.	Critical contamination zones.
Singh et al. (2018)	Bokaro hydrochemistry	Seasonal GW analysis	Rock weathering dominant. Irrigation mostly suitable.	Supports agricultural water use.
Sahoo et al. (2018)	Lineament–vegetation–GW linkage	NDVI, GDVI, MK test, GRACE	Correlation between lineaments & GW levels.	Useful for structural GW exploration.

III. Proposed Solutions

- Spatial behaviour refers to how groundwater levels and quality vary across different locations within West Singhbhum (e.g., mining areas vs. forest areas vs. upland vs. valley zones).
- Temporal behaviour describes how groundwater changes over time, especially across seasons (pre-monsoon, monsoon, post-monsoon) and years (long-term trends).
- Groundwater levels in the district rise during monsoon due to recharge and decline in pre-monsoon due to high extraction and low rainfall.
- Water quality parameters (fluoride, nitrate, Fe, Mn, TDS) also show seasonal variation, often worsening in pre-monsoon and improving after rainfall dilution.
- Mining belts show higher contamination and deeper water tables compared to forested uplands or river-adjacent zones.
- Spatio-temporal analysis helps identify hotspots of depletion, contamination clusters, and zones with stable or improving trends.
- Understanding these spatial and temporal patterns supports targeted interventions, recharge planning, pollution control, and sustainable groundwater management.

IV. Conclusion

The study assessment of the spatio-temporal behaviour of groundwater in West Singhbhum reveals that the district's aquifer systems are shaped by strong seasonal fluctuations, diverse geological settings, and significant anthropogenic pressures. Groundwater levels show a distinct pattern of pre-monsoon decline and post-monsoon recovery, with the most pronounced depletion occurring in mining-dominated and densely inhabited zones. In contrast, forested uplands and less disturbed regions exhibit comparatively stable and shallow water tables, reflecting better recharge conditions and lower extraction stress. Groundwater quality in the district ranges from good to moderate in most areas; however, several pockets exhibit poor water quality due to elevated concentrations of iron, manganese, nitrate, fluoride, hardness, and TDS. These contamination clusters are strongly linked to mining activities, industrial influence, agricultural runoff, and settlement-related waste. The combined effect of declining levels and deteriorating water quality highlights the vulnerability of certain micro-regions within the district. Overall, the study demonstrates that understanding groundwater dynamics through a spatio-temporal lens is essential for designing targeted management strategies. Strengthened monitoring, regulated extraction, decentralised recharge structures, improved pollution control, and community-based water governance are necessary to ensure long-term sustainability. The findings suggested a scientific foundation for evidence-driven groundwater planning and can guide future hydrogeological and environmental interventions in West Singhbhum.

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