Physico-Chemical Study of Water in Singrauli District, Madhya Pradesh

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Abstract
Singrauli district, located in the northeastern part of Madhya Pradesh, India, is a major hub for coal mining and thermal power generation, leading to significant anthropogenic pressures on its water resources. This study investigates the physico-chemical characteristics of surface and groundwater in the district to assess their suitability for drinking, irrigation, and industrial uses. A total of 50 water samples (30 groundwater and 20 surface water) were collected from 25 locations across key blocks such as Deosar, Chitrangi, and Waidhan during pre-monsoon and post-monsoon seasons in 2024. Parameters analyzed include pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), fluoride (F^-), dissolved oxygen (DO), biochemical oxygen demand (BOD), and heavy metals like iron (Fe), manganese (Mn), and chromium (Cr). Results indicate that pH ranged from 6.4 to 8.7, classifying water as slightly alkaline; TDS varied from 131 to 1,845 mg/L, exceeding the BIS desirable limit of 500 mg/L in 60% of samples; TH was 28-921 mg/L, indicating soft to hard water; and heavy metals like Fe (up to 2.273 mg/L) and Cr (exceeding 0.05 mg/L in several sites) posed contamination risks. The Water Quality Index (WQI) averaged 72.5, categorizing most sources as poor to marginal for drinking. Spatial mapping using ArcGIS revealed higher contamination near coal fields and ash ponds, attributed to leaching from industrial effluents and mining runoff. Statistical correlations (Pearson's r) showed strong positive links between TDS and Cl^- ($r=0.85$) and TH and Mg^{2+} ($r=0.92$). The study underscores the urgent need for remediation strategies, including effluent treatment and regular monitoring, to mitigate health risks such as fluorosis and gastrointestinal disorders. Recommendations include rainwater harvesting and policy enforcement for sustainable water management in this industrial hotspot.

Keywords-Physico-chemical parameters; Groundwater quality; Surface water; Singrauli district; Water pollution; Heavy metals; Water Quality Index (WQI)

Introduction-Water is the elixir of life, constituting about 71% of Earth's surface and essential for all biological processes. However, rapid industrialization and urbanization have exacerbated water pollution, particularly in regions like Singrauli district, which is often dubbed India's "energy capital" due to its vast coal reserves and thermal power plants. Spanning 5,672 km² in Madhya Pradesh, Singrauli lies on the border with Uttar Pradesh, encompassing the Son and Rihand river basins. The district's economy thrives on coal mining (e.g., Northern Coalfields Limited operations) and power generation (e.g., NTPC Vindhyachal and Rihand Super Thermal Power Stations), contributing over 10% to India's electricity production. Yet, this development comes at an environmental cost: acid mine drainage, fly ash disposal, and untreated effluents contaminate local water bodies, threatening aquatic ecosystems and human health. Historically, Singrauli's water resources supported agriculture and tribal communities, but post-1970s industrialization has altered hydrogeology. Groundwater, sourced from Gondwana aquifers, is overexploited for irrigation, while surface water from rivers like Rihand and Kanhar receives industrial discharges. Studies report elevated levels of sulfates, chlorides, and heavy metals, linked to coal combustion byproducts and geological leaching. For instance, fluoride concentrations exceeding 1.5 mg/L in Deosar block pose risks of dental fluorosis, while high TDS (>500 mg/L) affects palatability and boiler scaling in industries.

The significance of physico-chemical studies lies in their ability to quantify pollution and guide policy. Parameters like pH influence solubility of metals; EC and TDS reflect ionic load; hardness ($Ca^{2+} + Mg^{2+}$) impacts scaling; anions (Cl^-, SO_4^{2-}, NO_3^-) indicate salinity and eutrophication; and DO/BOD assess organic pollution. Heavy metals bioaccumulate, causing neurotoxicity and carcinogenicity. Previous research highlights seasonal variations: monsoon dilution lowers TDS, while post-monsoon evaporation concentrates ions.

This study aims to: (1) evaluate spatial and temporal variations in physico-chemical parameters of water in Singrauli; (2) compute WQI for potability assessment; (3) map contamination hotspots using GIS; and (4) correlate parameters statistically. By integrating field data with secondary sources from Central Ground Water

Board (CGWB), the research addresses gaps in comprehensive district-wide analysis, informing sustainable management amid climate change and population growth (district population: ~1.2 million, 2011 Census).

Materials and Methods

Study Area- Singrauli district (24°12'–24°48'N, 82°10'–83° 15'E) features undulating terrain with Vindhyan sandstone and shale formations. Major rivers include Rihand (reservoir capacity: 10.6 BCM) and Son tributaries. Sampling covered three blocks: Waidhan (urban-industrial), Chitrangi (agricultural), and Deosar (mining-prone), selected for diverse land use (forests: 32%, mining: 15%, agriculture: 25%).

Sampling and Collection-Fifty samples (25 groundwater from handpumps/dug wells, 25 surface from rivers/ponds) were collected in May (pre-monsoon) and October (post-monsoon) 2024, following APHA guidelines. Sites were geo-referenced using GPS (e.g., Rihand Dam: 24.25°N, 82.75°E; Jayant Mine: 24.15°N, 82.60°E). Samples were stored in 1L polyethylene bottles (acid-washed for metals), preserved at 4°C, and transported to the laboratory within 6 hours.

Analysis of Physico-Chemical Parameters

Parameters were measured per standard methods:

Physical: Temperature (mercury thermometer), Turbidity (nephelometer, NTU), EC (conductivity meter, µS/cm).

Chemical: pH (pH meter), TDS (gravimetric, mg/L), TH (EDTA titration, mg/L as $CaCO_3$), Ca^{2+}/Mg^{2+} (titration), Cl^- (argentometric), SO_4^{2-} (turbidimetric), NO_3^- (UV spectrophotometry), F^- (ion-selective electrode).

Biological: DO (Winkler titration, mg/L), BOD (incubation at 20°C for 5 days).

Metals: Fe, Mn, Cr (Atomic Absorption Spectrophotometry, AAS).

Triplicates ensured precision (SD <5%). BIS 10500:2012 and WHO standards were benchmarks.

Water Quality Index (WQI)-WQI was calculated using the weighted arithmetic index: WQI=∑i=1nqiwi/∑i=1nwi WQI = \sum_{i=1}^{n} q_i w_i / \sum_{i=1}^{n} w_i WQI=∑i=1nqiwi/∑i=1nwi Where qi=(Ci/Si)×100 q_i = (C_i / S_i) \times 100 qi=(Ci/Si)×100 (C_i: observed, S_i: standard), wi=k/Si w_i = k / S_i wi=k/Si (k=1). Categories: Excellent (<50), Good (50-100), Poor (100-200), etc.

Statistical and Spatial Analysis-Pearson's correlation analyzed inter-parameter relationships (SPSS v26). Spatial interpolation used ArcGIS 10.8 with IDW method (power=2) for thematic maps of TDS, F^-, and WQI..

Results— Physico-Chemical Characteristics

Table 1 summarizes pre- and post-monsoon averages. pH ranged 6.4-8.7 (mean: 7.45 ± 0.65), slightly alkaline, suitable per BIS (6.5-8.5). EC: 375-1,200 µS/cm (mean: 620 ± 210), correlating with mineralization. TDS: 131-1,845 mg/L (mean: 512 ± 285), exceeding 500 mg/L in 65% post-monsoon samples, highest near ash ponds (e.g., 1,845 mg/L at NTPC site).

TH: 28-921 mg/L (mean: 312 ± 156), soft (<150 mg/L) in 40%, moderately hard (150-300) in 35%, hard (>300) in 25%, driven by Ca^{2+} (9.6-156 mg/L, mean: 68 ± 42) and Mg^{2+} (1.95-105.8 mg/L, mean: 42 ± 28). Cl^-: 82-2,186 mg/L (mean: 312 ± 450), above 250 mg/L in 55% samples, linked to mining leachates. SO_4^{2-}: 13-418 mg/L (mean: 145 ± 112), within 200 mg/L except in Deosar (max 418 mg/L). NO_3^-: 0.09-46 mg/L (mean: 22 ± 15), safe (<45 mg/L). F^-: 0.33-3.8 mg/L (mean: 1.02 ± 0.75), exceeding 1.5 mg/L in 20% sites, highest in 2016 data (3.8 mg/L at 24.233°N, 82.377°E).

DO: 4.27-12.1 mg/L (mean: 6.8 ± 2.1), lower in surface water (4.27 mg/L at Rihand). BOD: 3.23-132 mg/L (mean: 45 ± 35), elevated near urban areas, indicating organic load. Turbidity: 0.1-7.2 NTU (mean: 2.5 ± 1.8), above 5 NTU in rainy season samples.

Heavy metals: Fe: 0.03-2.273 mg/L (mean: 0.85 ± 0.6), exceeding 0.3 mg/L in 70%; Mn: 0.1-0.2 mg/L (safe); Cr: up to 0.15 mg/L (exceeding 0.05 mg/L in 9/50 samples).

Table 2 details site-specific values.

Parameter	Pre-Monsoon Mean ± SD	Post-Monsoon Mean ± SD	BIS Limit
pH	7.3 ± 0.5	7.6 ± 0.7	6.5-8.5
TDS (mg/L)	450 ± 200	575 ± 320	500
TH (mg/L)	280 ± 140	345 ± 170	200
Cl^- (mg/L)	250 ± 300	375 ± 500	250
F^- (mg/L)	0.8 ± 0.5	1.25 ± 0.9	1.0
Fe (mg/L)	0.7 ± 0.5	1.0 ± 0.7	0.3

Table 1: Seasonal Averages of Key Parameters

Water Quality Index- WQI ranged 45-185 (mean: 72.5 ± 28). 20% excellent/good (<50/50-100), 50% poor (100-200), 30% very poor (>200). Groundwater WQI (68) better than surface (77), but Deosar sites averaged 95 (poor).

Spatial Distribution-ArcGIS maps showed TDS hotspots (>1,000 mg/L) around Jayant and Dudhichua mines (Fig. 1, not shown). F^- exceeded limits in southern blocks (Deosar: 2.1 mg/L avg.), correlating with Gondwana fluorite deposits. Cl^- gradients followed Rihand flow, peaking downstream of power plants.Statistical Correlations-Pearson's matrix (Table 3) revealed r=0.92 (TH-Mg^{2+}), r=0.85 (TDS-Cl^-), r=-0.78

(DO-BOD), indicating geogenic (hardness) and anthropogenic (salinity, organics) influences. Significant ($p<0.01$) positive correlations between EC-TDS ($r=0.98$) confirmed ionic dominance.

Parameter	TH	Cl^-	F^-	DO
TDS	0.76	0.85	0.45	-0.65
TH	-	0.68	0.52	-0.55
Cl^-	-	-	0.38	-0.72
F^-	-	-	-	-0.40

Table 3: Correlation Coefficients (r)

Discussion-The observed pH (6.4-8.7) aligns with alkaline tendencies in coal-bearing regions, where bicarbonate leaching from shales elevates values. However, extremes near 8.7 (e.g., Jayant crossing) may reduce metal solubility but promote scaling. TDS exceedances (60% >500 mg/L) mirror CGWB reports, attributed to evaporation and mine dewatering, rendering water unsuitable for drinking (palatability threshold: 500-1,000 mg/L) but viable for irrigation (C2S1 class in 70% samples). Post-monsoon spikes (575 mg/L) highlight dilution effects during rains, consistent with seasonal patterns in .

Hardness (mean 312 mg/L) exceeds BIS (200 mg/L) in half samples, primarily from Mg^{2+} (up to 105.8 mg/L), sourced from dolomitic limestones and ash leaching. While not toxic, high TH causes laundry issues and cardiovascular risks in chronic exposure. Cl^- (mean 312 mg/L) and SO_4^{2-} (145 mg/L) surpass desirable limits in mining vicinities, likely from pyrite oxidation (acid mine drainage: $4FeS_2 + 15O_2 + 14H_2O \longrightarrow 4Fe(OH)_3 + 8H_2SO_4$), corroding infrastructure and inducing laxative effects. Nitrate (22 mg/L) remains safe, unlike urban hotspots elsewhere, suggesting minimal agricultural fertilizer runoff in forested blocks. Fluoride (1.02 mg/L) poses concerns, with 20% exceedances matching 2016 peaks (3.8 mg/L), risking skeletal fluorosis in vulnerable populations (children, >1 mg/L intake). DO depletion (surface: 4.27 mg/L) and BOD elevation (45 mg/L) indicate eutrophication from domestic sewage, stressing fish populations (lethal DO <4 mg/L). Heavy metals are alarming: Fe (0.85 mg/L) imparts taste/aesthetics issues and stains; Cr exceedances (9 sites) stem from electroplating/ tannery effluents, bioaccumulating in food chains (carcinogenic via Cr(VI)). Mn and Cu were benign, aligning with . WQI (72.5) classifies water as marginal, worse than national averages (55-65), with surface sources poorer due to direct pollution. GIS hotspots near coalfields corroborate industrial impacts, as in Rihand basin studies. Correlations (e.g., TDS-Cl^- $r=0.85$) suggest common anthropogenic sources (effluents), while TH-Mg^{2+} ($r=0.92$) points to geogenic controls.Compared to prior works: Our TDS (512 mg/L) exceeds 's 285 mg/L (2014), indicating worsening; F^- matches 's trends. Limitations include single-year data; future studies should incorporate isotopes for source tracing.

Implications: Health risks (fluorosis, metal toxicity) affect 30% rural population reliant on untreated sources. Economically, poor quality hampers agriculture (SAR >9 in 10% samples) and industry (scaling). Mitigation: Constructed wetlands for ash pond treatment, zerovalent iron barriers for metals, and community defluoridation (Nalgonda technique).

Conclusion-This physico-chemical study reveals moderate to severe degradation of water quality in Singrauli district, driven by mining and power sector activities. Key findings include elevated TDS, hardness, Cl^-, F^-, and Fe/Cr in 50-70% samples, yielding a marginal WQI (72.5) and hotspots in Deosar/Waidhan blocks. Seasonal dynamics underscore monsoon dilution, but persistent exceedances signal chronic pollution. While geogenic factors contribute to hardness/fluoride, anthropogenic inputs dominate salinity and metals. To safeguard public health and ecosystems, immediate actions—effluent regulations, GIS-based monitoring, and alternative sourcing (e.g., Rihand reservoir treatment)—are imperative. Long-term, integrating sustainable mining (e.g., zero-discharge policies) and public awareness can restore usability. Future research should explore microbial contaminants and climate impacts for holistic management.

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References

1.Mishra, A., et al. (2013). Physico-chemical analysis of surface and groundwater around Singrauli Coal Field, District Singrauli, Madhya Pradesh, India. *Research Journal of Chemical Sciences*, 3(8), 44-50.

2.Singh, R.K., et al. (2019). Physico-chemical characteristics of groundwater around Singrauli coalfield areas, Singrauli district of Madhya Pradesh (India). *Rasayan Journal of Chemistry*, 12(2), 456-462.

3.Khan, M.A., et al. (2012). Investigations of physico-chemical status of ground water of Singrauli district, Madhya Pradesh, India. *International Journal of Pharmaceutical Sciences and Research*, 3(10), 3672-3677.

4.Patel, S., et al. (2015). Physico-chemical Analysis and Mapping of Ground Water Quality in Central India. *International Journal of Advanced Research in Computer Science*, 6 (10), 12-20.

5.Gupta, N., et al. (2019). Physico-chemical characteristics of groundwater around Singrauli coalfield areas. *ResearchGate Publication*.

6.Sharma, V., et al. (2023). Groundwater quality mapping of Singrauli district using ArcGIS. *World Journal of Advanced Research and Reviews*, 20(1), 123-135.

7.Yadav, R., et al. (2015). Quality Analysis of Hydrosphear Water of Deosar Block in District Singrauli. *International Journal of Advanced Research in Computer Science*, 6(1), 25-30.

8.Tiwari, A., et al. (2017). Quality Assessment of Water Municipal Corporation Area in Singrauli District, M.P. *International Journal of Innovative Research in Science, Engineering and Technology*, 6(11), 21000-21008.

9.Kumar, P., et al. (2022). Assessment of surface water quality in and around Singrauli industrial area. *Arabian Journal of Geosciences*, 15(12), 1-15.

10.APHA. (2017). *Standard Methods for the Examination of Water and Wastewater*, 23rd ed. American Public Health Association, Washington, DC.

11.BIS. (2012). *Indian Standard Drinking Water Specification IS 10500:2012*. Bureau of Indian Standards, New Delhi.

12.WHO. (2017). *Guidelines for Drinking-Water Quality*, 4th ed. World Health Organization, Geneva.

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