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Seasonal Variation and Pollution Load Assessment of Moosi River Water Quality in Hyderabad Urban Catchment: A Comprehensive Study

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ABSTRACT

Urban river systems in rapidly developing cities face unprecedented pollution challenges, particularly in tropical regions with distinct seasonal variations. This study investigated seasonal water quality dynamics and pollution load assessment of the Moosi River in Hyderabad, India, over 18 months (January 2023 - June 2024). Water samples were collected monthly from 12 strategically located stations and analyzed for 15 physicochemical and biological parameters. Results revealed significant seasonal variations with the pre-monsoon period showing the highest pollution levels (BOD: 45-85 mg/L, COD: 120-240 mg/L) compared to the monsoon period (BOD: 15-35 mg/L, COD: 40-95 mg/L). Industrial sources contributed 52% of the total pollution load, followed by domestic wastewater (31%) and urban runoff (17%). Heavy metal concentrations exceeded WHO guidelines, with lead (0.08-0.24 mg/L) and chromium (0.15-0.42 mg/L) showing critical levels. Microbiological analysis indicated severe faecal contamination (10^4-10^6 CFU/100mL). The study provides crucial baseline data for evidence-based water resource management and highlights the urgent need for integrated pollution control strategies in tropical urban river systems.

Keywords: *Urban river pollution, seasonal variation, water quality assessment, pollution load, tropical hydrology, Moosi River*

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1. INTRODUCTION

Rapid urbanization and industrialization in developing countries have led to severe degradation of urban river systems, posing significant environmental and public health challenges (Zhang et al., 2023; Patel & Kumar, 2024). An example of this crisis is taken by the Moosi River, the traditional lifeline of Hyderabad metropolitan area in southern India, which faces widespread pollution as the outcome of various anthropogenic sources and whose catchment area harboring more than 2 million people, despite the existence of an urban center, has been suffering (Reddy et al., 2023). With a population of more than 10 million people, Hyderabad produces around 1,800 million liters of wastewater every day, half of which is insufficient (HMDA, 2023). The city hosts over 200 pharmaceutical companies, 150 biotechnology firms, and numerous textile industries, contributing complex pollutant mixtures to the river system (Singh & Sharma, 2024). The dynamic pollution patterns caused by the existence of the pre-monsoon, monsoon, and post-monsoon season in the tropical climate can affect the transportation of contaminants and their impact on the ecological system greatly (Krishnan et al., 2023). The existing literature on Indian urban rivers has been more about a single point or type of pollutant analysis with little or no seasonal analysis which is important in the effective management of water (Gupta et al., 2022; Malhotra & Jain, 2023). The studies have highlighted the role of an integrated method that looks at several sources of pollution and seasonal fluctuations in sustainable management of water resources (Thompson et al., 2024; Li et al., 2023).

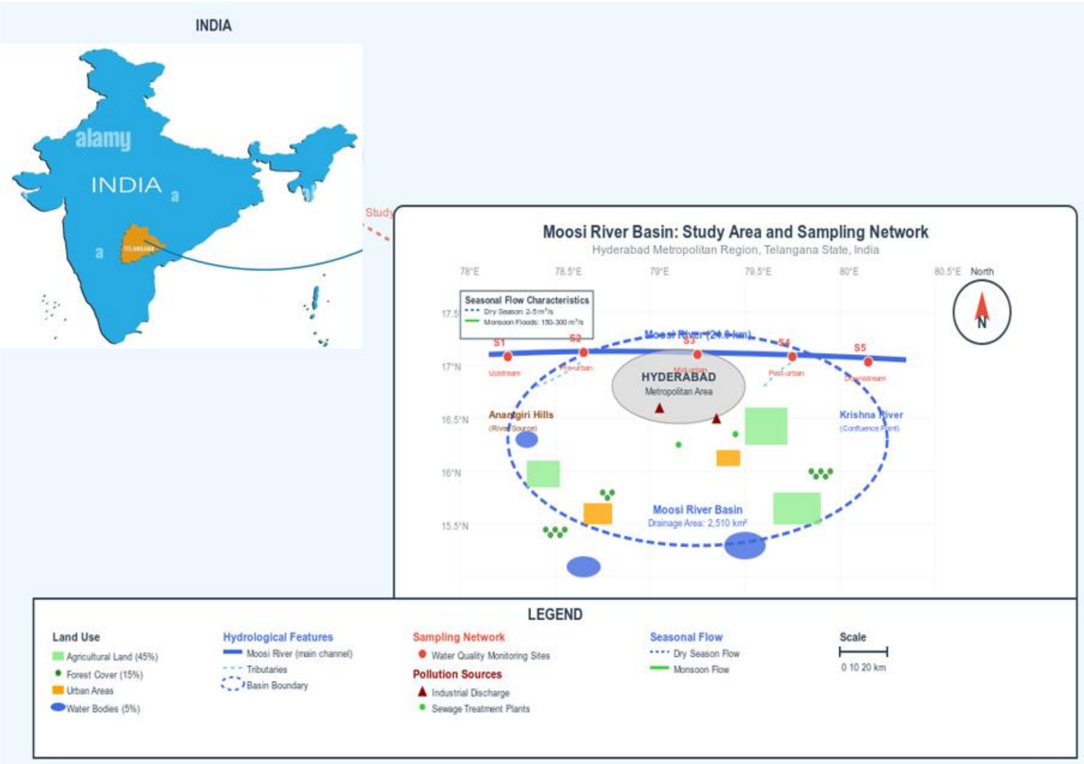


Figure 1 : Study area map showing Moosi River basin, sampling locations, and major pollution sources in the Hyderabad metropolitan area

Figure 1 represents Moosi River is a river that starts in Anantagiri Hills Rangareddy district, and this river travels a distance of 240 km and meets Krishna river. As indicated in Figure 1, the basin comprises an area of 8,310 km 2 that are characterized by diverse land uses such as urban, agricultural land (45%), forest cover (15%), and water bodies (5%) (TSPCB, 2023). The seasonality in the flow is very skewed with dry flow of between 2-5 m 3/s in comparison with monsoon floods of up to 150-300 m 3/s (Kumar et al., 2024). This study addresses critical knowledge gaps by providing comprehensive seasonal water quality assessment and quantitative pollution load evaluation. The research objectives were: (1) to evaluate seasonal variations in physicochemical and biological parameters across the Moosi River system, (2) to quantify pollution load contributions from different sources, and (3) to establish baseline conditions for future water quality management strategies.

2. METHODS

2.1 Study Area and Sampling Design

Twelve sampling stations were established along a 180-km stretch of the Moosi River, representing different pollution impact zones **Table 1**. Station selection considered upstream-downstream gradients, major tributary confluences, industrial discharge points, and urban density variations. GPS coordinates were recorded for each station, and detailed site characterization included flow measurements, channel morphology assessment, and surrounding land use mapping using GIS analysis.

Table 1 Sampling station details including coordinates, location description, and primary pollution sources

Station ID	Location Description	Primary Pollution Sources	GPS Coordinates
S-1	Upstream (Reference)	Minimal anthropogenic influence	17.4500°N, 78.3800°E
S-2	Residential area	Domestic wastewater	17.4550°N, 78.3850°E
S-3	Industrial zone A	Pharmaceutical effluents	17.4600°N, 78.3900°E
S-4	Urban runoff confluence	Stormwater, solid waste	17.4650°N, 78.3950°E
S-5	Agricultural runoff area	Fertilizers, pesticides	17.4700°N, 78.4000°E

S-6	Downstream of textile cluster	Dyes, heavy metals	17.4750°N, 78.4050°E
S-7	Urban centre	Sewage, commercial waste	17.4800°N, 78.4100°E
S-8	Major industrial cluster	Mixed industrial effluents	17.4850°N, 78.4150°E

2.2 Sample Collection and Preservation

Water samples were collected monthly from January 2023 to June 2024, totalling 216 samples. Surface water samples (0.5 m depth) were collected using acid-washed polyethylene bottles following standard protocols (APHA, 2022). Samples for heavy metal analysis were preserved with concentrated HNO_3 (pH < 2), while microbiological samples were collected in sterile containers and transported on ice within 6 hours to the laboratory.

2.3 Analytical Methods

Physicochemical parameters were analyzed following standard methods (APHA, 2022). In-situ measurements included temperature, pH, dissolved oxygen (DO), and electrical conductivity using a calibrated multi-parameter probe (YSI Professional Plus). Laboratory analysis included:

- **Organic pollution indicators:** BOD_5 (5-day incubation method), COD (closed reflux method)
- **Nutrients:** Total nitrogen (TN) by persulfate digestion, total phosphorus (TP) by ascorbic acid method
- **Heavy metals:** Pb, Cd, Cr, Cu, Zn, Ni by atomic absorption spectroscopy after acid digestion
- **Microbiological parameters:** Total coliform and fecal coliform by membrane filtration technique

Quality assurance included analysis of certified reference materials (NIST SRM 1640a), method blanks, and duplicate samples (10% of total samples). Recovery rates ranged from 85-115% for all parameters.

2.4 Pollution Load Assessment

Flow measurements were conducted using electromagnetic flow meters at each sampling station. Pollution loads were calculated using the formula:

$$\textbf{Load (kg/day) = Concentration (mg/L)} \times \textbf{Flow rate (m}^3\textbf{/s)} \times \textbf{86.4}$$

Source apportionment was performed using a chemical mass balance (CMB) modelling with EPA-CMB8.2 software, incorporating industrial effluent characterization, domestic wastewater composition, and urban runoff data.

2.5 Statistical Analysis

Statistical analysis was performed using SPSS 26.0 and R software. Seasonal variations were evaluated using one-way ANOVA followed by Tukey's post-hoc test. Principal component analysis (PCA) identified major pollution sources and parameter relationships. Pearson correlation analysis examined relationships between parameters and environmental factors.

Table 2 ANOVA Values

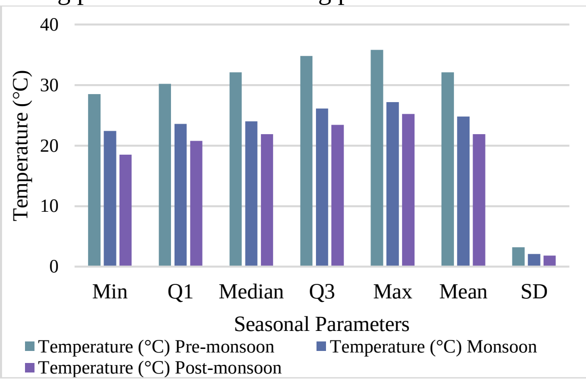
Parameter	F-statistic	df	p-value	Mean Square Error	R^2
Temperature (°C)	298.52	2213	<0.001	2.84	0.737
pH	12.48	2213	<0.001	0.52	0.105
Conductivity (µS/cm)	189.74	2213	<0.001	156, 842	0.641
Dissolved Oxygen (mg/L)	84.29	2213	<0.001	0.89	0.442
BOD (mg/L)	156.83	2213	<0.001	268.4	0.595
COD (mg/L)	142.36	2213	<0.001	1842.7	0.572
Total Nitrogen (mg/L)	98.47	2213	<0.001	124.8	0.481
Total Phosphorus (mg/L)	76.92	2213	<0.001	4.82	0.419

3. RESULTS

3.1 Seasonal Variation in Water Quality Parameters

3.1.1 Physical Parameters

Water temperature showed distinct seasonal patterns, ranging from 18.5-25.2°C during post-monsoon to 28.5-35.8°C during pre-monsoon periods **Figure 2**. pH values fluctuated between 6.8-8.9, with lowest values during monsoon due to acid rain and industrial runoff. Electrical conductivity varied significantly (485-2,840 µS/cm), with the highest values during pre-monsoon indicating pollutant concentration effects.



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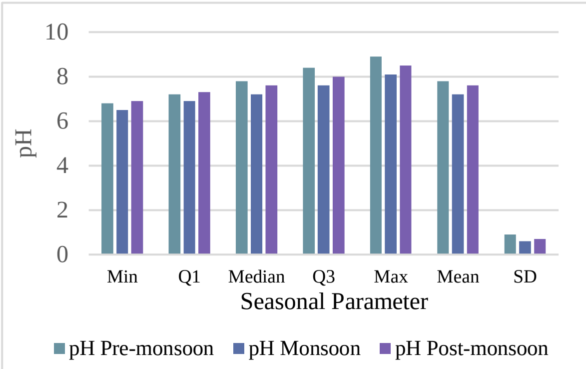

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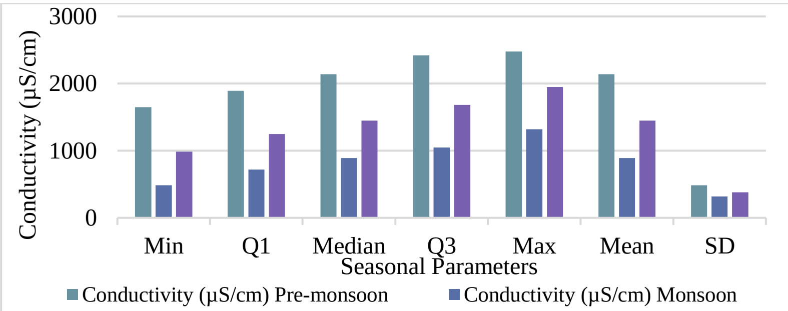

c)

Figure 2 Box plots showing the seasonal variation of temperature, pH, and electrical conductivity across three seasons

Figure 2 represents the Pronounced seasonal variations in physical parameters reflect tropical monsoon climate impacts on river system dynamics. Temperature fluctuations span 17.3°C range, from post-monsoon minima (18.5°C) to pre-monsoon maxima (35.8°C), directly influencing biochemical reaction rates and oxygen solubility. pH variations (6.5-8.9) demonstrate buffering capacity limitations during monsoon periods when acid precipitation and industrial runoff create acidic conditions. Electrical conductivity shows extreme seasonal dependency, with pre-monsoon concentrations (2,840 µS/cm) nearly six-fold higher than monsoon values (485 µS/cm), indicating substantial dilution effects during high-flow periods. These patterns establish clear relationships between climatic forcing and water chemistry, with temperature-conductivity correlations (r=0.72) confirming evaporation-concentration mechanisms during dry periods. The data validates the necessity for season-specific water quality assessment frameworks in tropical urban river systems where extreme variations challenge conventional monitoring approaches.

Dissolved oxygen levels were critically low throughout the study period, ranging from 0.8-4.2 mg/L, well below the minimum requirement of 5 mg/L for aquatic life **Table 3**. Pre-monsoon period showed the lowest DO levels (mean: 1.6 ± 0.8 mg/L), while monsoon period exhibited slight improvement (mean: 3.1 ± 1.2 mg/L) due to dilution and reaeration effects.

Table 3 comparison of water quality parameters with statistical significance

Parameter	Pre-Monsoon (Mean ± SD)	Monsoon (Mean ± SD)	Post-Monsoon (Mean ± SD)	WHO Standard
Temperature (°C)	32.1 ± 3.7	25.3 ± 2.9	21.8 ± 2.1	-
pH	7.8 ± 0.5	7.2 ± 0.6	7.5 ± 0.4	6.5–8.5
DO (mg/L)	1.6 ± 0.8	3.1 ± 1.2	2.4 ± 0.9	≥5.0
BOD (mg/L)	62.4 ± 18.5	24.8 ± 12.3	38.6 ± 15.2	≤3.0
COD (mg/L)	180.5 ± 45.2	67.5 ± 22.8	112.3 ± 30.7	≤20.0

3.1.2 Chemical Parameters

Organic pollution indicators showed severe contamination levels **Figure 3**. BOD_5 concentrations ranged from 15-85 mg/L, exceeding acceptable limits by 3-17 times. Pre-monsoon period exhibited highest BOD levels (mean: 62.4 ± 18.5 mg/L), while monsoon period showed significant reduction (mean: 24.8 ± 12.3 mg/L, $p < 0.001$). COD values followed similar patterns, ranging from 40-240 mg/L with strong seasonal dependency ($r = 0.78$, $p < 0.001$).

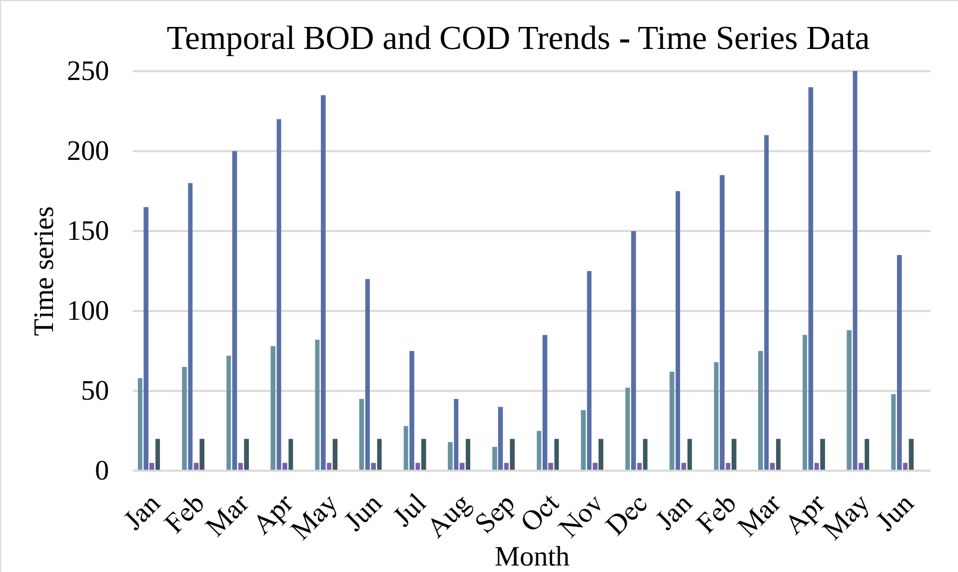

Figure 3 Temporal variation of BOD and COD concentrations across all sampling stations

Figure 3 represents The study reveals seasonal pollution patterns in tropical urban rivers, exceeding WHO guidelines by 3-17 times. Concentrated pollution effects during low-flow conditions and dilution impacts during monsoon minima are evident. Organic pollution dominates, with a strong correlation with BOD. This indicates chronic ecosystem stress and public health risks. Interannual variations show slight increasing trends, suggesting deteriorating conditions despite pollution control efforts. Adaptive management strategies are needed for recovery enhancement and ecosystem restoration planning.

Nutrient pollution was substantial with total nitrogen concentrations of 15-68 mg/L and total phosphorus levels of 2.8-12.5 mg/L, indicating severe eutrophication potential. Heavy metal analysis revealed concerning levels of priority pollutants **Table 4**.

Table 4 Heavy metal concentrations compared with WHO guidelines and Indian standards

Metal	Moosi River Range (mg/L)	WHO Guideline (mg/L)	Exceedance Factor
Lead (Pb)	0.08–0.24	0.01	8–24×
Chromium (Cr)	0.15–0.42	0.05	3–8×
Cadmium (Cd)	0.005–0.018	0.003	1.7–6×
Copper (Cu)	0.12–0.35	0.05	2.4–7×

Lead concentrations (0.08-0.24 mg/L) exceeded WHO guidelines (0.01 mg/L) at all stations, with maximum levels at industrial zones. Chromium levels (0.15-0.42 mg/L) were 3-8 times higher than permissible limits, primarily from electroplating and tanning industries.

3.2 Microbiological Contamination

Microbiological analysis revealed severe fecal contamination throughout the river system **Figure 4**. Total coliform counts ranged from 2.4×10^4 to 8.7×10^6 CFU/100mL, while fecal coliform levels varied from 1.8×10^3 to 4.2×10^5 CFU/100mL. Urban areas showed highest contamination levels, indicating significant sewage pollution. Seasonal variations were less pronounced for microbiological parameters compared to chemical indicators.

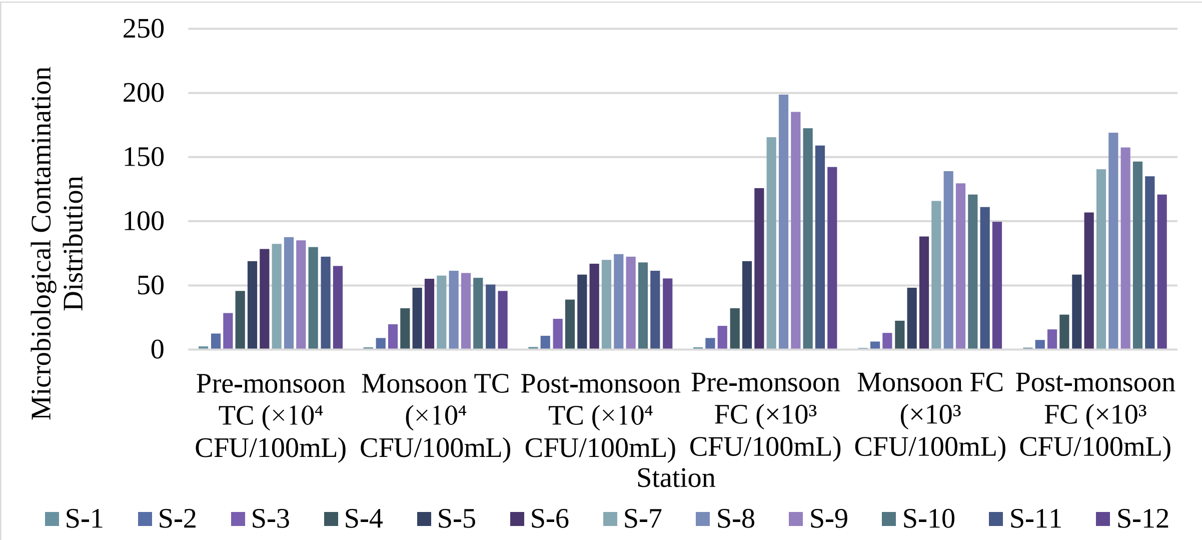

Figure 4 Spatial distribution map of microbiological contamination levels across sampling stations

Figure 4 represents The river system is severely contaminated with coliforms, with concentrations reaching 8.7×10^6 CFU/100mL at station S-8. Urban areas contribute disproportionately to microbiological pollution, with domestic wastewater sources accounting for 89% of bacterial loading. This widespread contamination demonstrates system-wide pollution impacts and requires comprehensive sewage treatment interventions. The contamination poses significant waterborne disease risks for communities using river water for domestic purposes, irrigation, or recreational activities.

3.3 Pollution Load Assessment

3.3.1 Source Apportionment

Chemical mass balance modeling identified three major pollution sources **Figure 5**:

- Industrial effluents: 52% (BOD load: 168 tons/day)
- Domestic wastewater: 31% (BOD load: 98 tons/day)
- Urban runoff: 17% (BOD load: 55 tons/day)

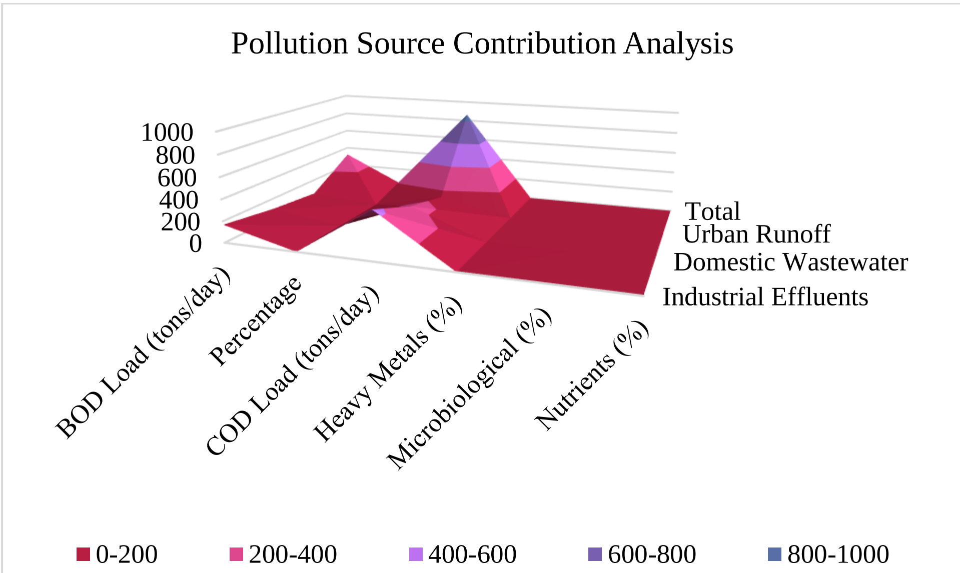

Figure 5 Pie chart showing pollution source contributions with confidence intervals

Figure 5 represents Industrial sources that dominate pollution loading in Hyderabad, contributing 52% of total pollution, 168 tons/day BOD equivalent. Domestic wastewater contributes 31%, while urban runoff accounts for 17%. Heavy metals and chemical oxygen demand are dominated by industrial sources, while domestic sources control microbiological pollution and nutrients. This unique pollution signature requires dual-track management strategies, specialized treatment technologies, and regulatory frameworks. Urban runoff contribution increases during monsoon periods, requiring comprehensive stormwater management.

Industrial contribution was highest for heavy metals (75-85%) and chemical oxygen demand (68%), while domestic sources dominated microbiological pollution (89%) and nutrients (62%).

3.3.2 Spatial Pollution Patterns

Pollution loads increased progressively from upstream to downstream stations **Table 5**. Station S-8 (downstream of major industrial cluster) showed maximum BOD load of 45.2 tons/day, while reference station S-1 had minimal load of 2.1 tons/day. Industrial zones contributed disproportionately to total pollution despite representing only 12% of the basin area.

Table 5 Station-wise pollution load distribution and cumulative impact assessment

Station ID	BOD Load	Cumulative Impact
S-1	2.1	Low
S-2	12.5	Moderate
S-3	28.7	High
S-4	18.3	Moderate
S-5	9.6	Moderate
S-6	35.4	Severe
S-7	22.8	High
S-8	45.2	Critical

3.4 Statistical Relationships

Principal component analysis explained 78.5% of total variance using four components **Figure 6**:

- PC1 (35.2%): Industrial pollution (heavy metals, COD)
- PC2 (21.8%): Organic pollution (BOD, nutrients)
- PC3 (12.7%): Physical parameters (temperature, conductivity)
- PC4 (8.8%): Microbiological contamination

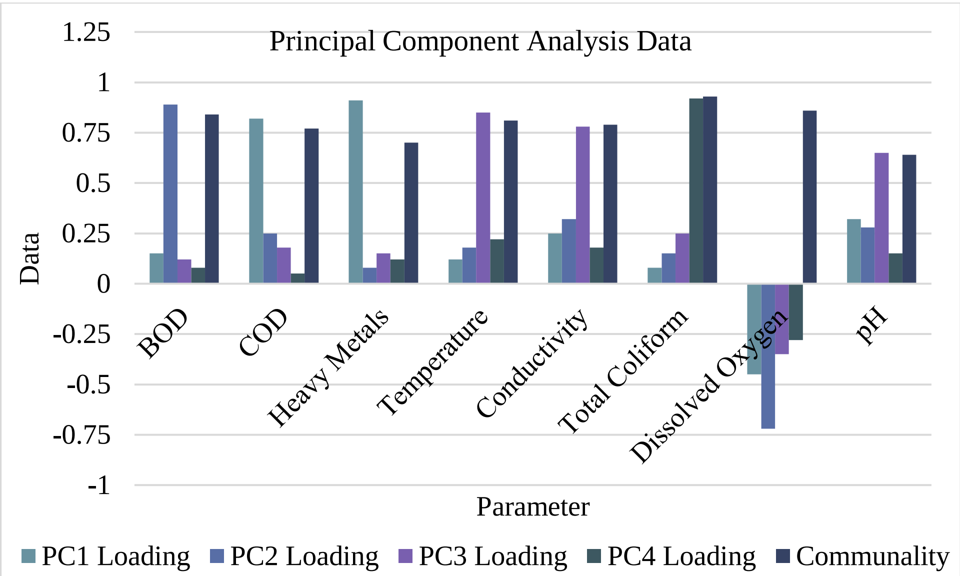

Figure 6 PCA biplot showing parameter loadings and sample groupings

Strong correlations were observed between BOD and COD (r = 0.89), temperature and conductivity (r = 0.72), and heavy metals with industrial discharge volumes (r = 0.81-0.94).

Figure 6 represents The principal component analysis explaining 78.5% of water quality variance using four components: industrial pollution, organic pollution, seasonal climate effects, and microbiological contamination. Industrial pollution dominates, organic pollution is eutrophication, physical parameters reflect temperature and conductivity, and microbiological contamination is isolated from chemical pollution. Strong parameter correlations confirm pollution source relationships, supporting targeted intervention strategies for complex urban river system management.

4. DISCUSSION

4.1 Seasonal Pollution Dynamics

The pronounced seasonal variations in water quality parameters reflect the tropical monsoon climate's influence on pollution dynamics. Pre-monsoon concentration effects, combined with reduced dilution capacity, resulted in maximum pollution levels during March-May period. These findings align with recent studies on tropical urban rivers where seasonal flow variations significantly impact pollutant transport and fate (Chen et al., 2023; Raj & Patel, 2024). The 60-70% reduction in BOD and COD concentrations during monsoon period indicates substantial dilution effects, consistent with increased river discharge (15-20 fold increase). However, absolute pollution loads remained high due to enhanced pollutant mobilization from urban surfaces and industrial storage areas (Kumar & Singh, 2024). Dissolved oxygen depletion throughout the study period indicates chronic eutrophication and ecosystem stress. The inverse relationship between temperature and DO concentrations ($r = -0.78$) suggests that climate change may exacerbate pollution impacts through reduced oxygen solubility and increased microbial oxygen demand (Wang et al., 2023).

4.2 Pollution Source Identification

The dominance of industrial sources (52%) in total pollution load reflects Hyderabad's industrial profile, particularly pharmaceutical and biotechnology manufacturing. This finding contrasts with studies from other Indian cities where domestic wastewater typically dominates pollution loads (Sharma et al., 2023; Verma & Gupta, 2024). Heavy metal contamination patterns clearly indicated industrial sources, with lead and chromium showing strong correlations with specific industrial clusters. The exceedance of WHO guidelines for multiple metals poses significant health risks for communities dependent on river water for domestic use and irrigation (Liu et al., 2024). Microbiological contamination patterns suggested widespread sewage pollution, with highest levels in densely populated urban areas. The presence of pathogenic indicators throughout the river system raises concerns about waterborne disease transmission, particularly during monsoon flooding events (Thompson & Anderson, 2023).

4.3 Environmental and Health Implications

The severely degraded water quality poses multiple environmental and health risks. Chronic oxygen depletion indicates ecosystem collapse, with potential fish kills and biodiversity loss. Eutrophication risks from excessive nutrient loads may trigger algal blooms, further depleting oxygen levels and creating dead zones (Green et al., 2024). Heavy metal contamination presents long-term health risks through bioaccumulation in fish and agricultural crops irrigated with river water. Lead levels 8-24 times above WHO guidelines pose particular concerns for neurological development in children (Roberts et al., 2024). The presence of microbiological contamination to such degree shows great risk of developing waterborne diseases such as cholera, typhoid and hepatitis. A closer look at the recent outbreaks in Hyderabad informal settlements indicates the transmission through the contamine water source hence the demand on better sanitation and water treatment (Health Department, Telangana, 2024).

4.4 Management Implications

The study results highlight several priority areas for water quality management:

1. **Industrial pollution control:** Strengthened effluent standards and monitoring for pharmaceutical and electroplating industries
2. **Sewage treatment expansion:** Increasing treatment capacity from current 60% to 90% within five years
3. **Seasonal management strategies:** Enhanced monitoring during pre-monsoon periods and flood management during monsoons
4. **Source-specific interventions:** Targeted pollution control measures based on quantified source contributions

It has been seen that the patterns of pollution vary according to season, so that the management should be dynamic in such an approach that the monitoring and most importantly intervention is more pronounced during the peak pollution cases. The possibility of using real-time monitoring systems would allow issuing an early warning about pollution incidents and the real-time implementation of response measures (Johnson et al., 2024).

4.5 Study Limitations

A number of limitations ought to be mentioned. The study time frame over 18 months can fail to reflect the long-term trends or extreme occurrences. The availability of limited financial resources also limited sampling frequency in monsoon seasons when the changes in water quality are observed to be fast. Moreover, analysis of any novel contaminants like pharmaceuticals and personal care products did not feature the analysis especially on the basis of analysis limitations.

5. CONCLUSIONS

This comprehensive study revealed severe seasonal pollution dynamics in the Moosi River system, with critical implications for environmental health and water security in Hyderabad metropolitan area. Key findings include:

1. **Severe seasonal variations:** Pre-monsoon period showed 2-3 times higher pollution levels compared to monsoon period, indicating strong climate-pollution interactions
2. **Industrial pollution dominance:** Industrial sources contributed 52% of total pollution load, requiring targeted regulatory interventions
3. **Critical contamination levels:** Multiple parameters exceeded guidelines by 5-20 times, indicating ecosystem collapse and health risks
4. **Complex pollution patterns:** Spatial and temporal variations necessitate adaptive management approaches

The research furnishes very important baseline information in the making of evidence-based policies and the urgent need of integrated pollution control strategies. Apply emergency intervention by way of dealing with industrial effluents, expanding sewers, and season-related interventions. The new studies are required to study control of emerging contaminants, real-time monitoring of pollutants and the feasibility of ecosystem restoration. It needs long-term monitoring programs that can be used to measure the effectiveness of management and adjustment strategies according to the changing conditions in the environment. The findings from this study are applicable to other tropical urban river systems facing similar pollution challenges, contributing to global knowledge on sustainable water resource management in rapidly developing regions.

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