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Seasonal and Spatial Variations in Biochemical and Chemical Oxygen Demand of Untreated Sewage in Sironj Tehsil, District Vidisha, India

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Abstract - In this study, untreated sewage from five suburban sites in Sironj Tehsil, district- Vidisha, India, was evaluated for seasonal and spatial variations in Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) in 2024. The APHA 5210 B and 5220 D procedures for BOD and COD, respectively, were used to analyse 100 sewage samples from Kahra Bazar, Kathali, Bhawani Nagar, Katra Mohalla, and Hajipur. Due to runoff-driven organic matter, the BOD ranged from 159.16 to 186.96 mg/L, with Bhawani Nagar recording the highest value (186.96 mg/L) during the monsoon season (mean 180.98 mg/L). Bhawani Nagar had the highest COD (571.32 mg/L), which ranged from 337.15 to 571.32 mg/L and peaked during the monsoon (mean 511.21 mg/L). The seasons with the lowest BOD (mean 161.35 mg/L) and COD (mean 358.09 mg/L) were winter. Statistical analysis showed site-specific influences on COD ($F(4,80)=8.63$, $p<0.001$) and significant seasonal effects on both BOD ($F(3,80)=36.90$, $p<0.001$) and COD ($F(3,80)=114.14$, $p<0.001$). According to these results, there are moderate to high levels of organic pollution, which means that to prevent oxygen depletion during monsoon peaks, biological treatment with increased aeration is required. These findings support the need for customised wastewater management plans in Sironj and are consistent with those of similar Indian cities.

Key Words: Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Sewage analysis, Seasonal variation, Sironj Tehsil, Organic pollution, Wastewater treatment

1.INTRODUCTION

Pradesh, India, encompasses an area of 493.45 square miles. According to the 2011 Census, its population totals 234,580 inhabitants, comprising 52,460 urban and 182,120 rural ones. Untreated sewage within this region, which is significantly impacted by diverse urban, suburban, and rural activities, including domestic waste disposal, agricultural runoff, and discharges from small-scale industries, contains substantial loads of organic and chemical pollutants. This pollution poses considerable environmental and public health hazards.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are fundamental indicators of organic pollution. BOD quantifies the oxygen required by microorganisms to biologically decompose organic matter, whereas COD measures the oxygen required for the chemical oxidation of both organic and inorganic pollutants. These parameters are critical for a comprehensive assessment of wastewater quality. Seasonal variations, particularly monsoon-driven runoff, intensify pollution levels by introducing organic matter. This exacerbation challenges water quality maintenance and the effectiveness of the existing treatment infrastructure.

This study aims to rigorously evaluate the seasonal (winter, summer, monsoon, post-monsoon) and spatial variability in BOD and COD levels during 2024 across five strategically selected suburban sites within Sironj Tehsil: Kahra Bazar, Kathali, Bhawani Nagar, Katra Mohalla, and Hajipur. Employing standardized American Public Health Association (APHA) protocols—specifically Method 5210 B for BOD and Method 5220 D for COD- the study will quantify organic pollution trends and identify site-specific influences alongside seasonal drivers. The findings will be contextualized through a comparison with data from major Indian cities (e.g. Delhi, Mumbai, and Chennai) and global urban centres (e.g. Bangkok and São Paulo), providing a comprehensive understanding of pollution dynamics specific to Sironj.

The results are intended to directly inform the development of tailored wastewater treatment strategies in the future. A key focus is mitigating monsoon-driven pollutant peaks by proposing the implementation of enhanced biological treatment systems featuring increased aeration capacity. This targeted approach is crucial for preventing oxygen depletion in receiving waters and ensuring sustainable water-resource management. Ultimately, this study seeks to contribute actionable scientific evidence to support environmental sustainability and public health protection in Sironj Tehsil through improved, evidence-based wastewater management policies.

2. MATERIALS AND METHODS

Sewage samples were collected systematically from five suburban sites in Sironj Tehsil, which are: Kahra Bazar, Kathali, Bhawani Nagar, Katra Mohalla, and Hajipur. These sites have different geographic centroids positioned close to 24° 5′ 58.26″ N, 77° 40′ 17.29″ E (latitude 24.099518°N, longitude 77.671471°E). The UTM (Universal Transverse Mercator) coordinates for the region were easting 771,574.87m and northing 2,667,831.08m. Located approximately 53 miles northwest of Vidisha city, Sironj Tehsil is approximately 493.45 square miles. According to the 2011 Census, the area has 234580 people residing in it which includes 52460 people living in urban areas and 182120 people living in rural area. Sewage samples were collected using sterile 1500 mL plastic bottles. To ensure accurate performance of further analysis, all samplings were performed within 24 h of collection. BOD was the only method performed after a 5-day incubation at 20 ± 1ºC. Simple methods such as these help us compare different seasons.

Biochemical Oxygen Demand

BOD analysis followed the APHA 5210 B (2017) protocol, employing a 5-day incubation method. Sewage samples (250 mL) were homogenized by agitation to ensure sample uniformity.

A 10–20 mL aliquot was seeded with a microbial inoculum in dilution water to achieve an oxygen demand of 2–4 mg/L. Samples were diluted 1:10 based on the expected BOD levels and transferred into 300 mL BOD bottles. The initial dissolved oxygen (DO) was measured using a calibrated DO meter, and the bottles were incubated at 20°C for 5 days. Final DO was recorded post-incubation, and BOD was calculated as:

BOD (mg/L) = DO initial–DO final

Variables:
Initial dissolved oxygen (DO initial) and post-5-day incubation dissolved oxygen (DO final) measurements (both in mg/L) were used for BOD calculation.
A total of 100 sewage samples, representing different seasons and five distinct sites in Sironj, were analyzed to assess organic pollutant loads.

Chemical Oxygen Demand (COD) (APHA 5220 D:)

COD levels were determined using the closed reflux colorimetric method (APHA 5220 D, 2017). Prior to analysis, the sewage samples were stored in sterile 250 mL plastic containers and thoroughly homogenized. For samples where COD was expected to exceed 900 mg/L, a 1:10 dilution with double-distilled water was performed to ensure accurate measurement. An aliquot of 2.5 mL of the sample was then introduced into commercially prepared COD digestion vials containing potassium dichromate, concentrated sulfuric acid, and silver sulphate catalyst.
The vials were heated at 150°C for 2 h in a COD digester. After cooling, the absorbance was measured at 600 nm using a UV-Vis spectrophotometer. A calibration curve was generated using potassium hydrogen phthalate standards (0–900 mg/L), with each batch including a reagent blank (deionized water) and a 500 mg/L standard solution. Control digests ensured method accuracy, with a ±10% deviation considered acceptable. COD concentration was determined using:

COD (mg/L) = (A sample−A blank) / S x D

Variables:
A sample = Absorbance of the digested sample
A blank = Absorbance of the reagent blank
S = Slope of the standard calibration curve (mg/L per absorbance unit)
D = Dilution factor (D = 10 for high-strength samples)
This protocol provided reliable COD data for 100 sewage samples from five Sironj sites, enabling assessment of organic pollutant oxidation potential.

3. RESULTS

Biochemical Oxygen Demand Variations Across Seasons in Sewage Samples from Sironj, Vidisha: Insights from 2024 Data

Table 1: BOD of Sewage Samples in **Winter Season** (January 2024, Sironj, Vidisha)

Sampling Site	Mean BOD (mg/L)	CV %	Mean ± SD
Kahra Bazar	163.58	2.21	163.58 ± 3.62
Kathali	159.37	3.38	159.37 ± 5.38
Bhawani Nagar	159.16	4.9	159.16 ± 7.80
Katra Mohalla	162.7	2.76	162.70 ± 4.49
Hajipur	161.92	3.03	161.92 ± 4.90

Table 2: BOD of Sewage Samples in **Summer Season** (April 2024, Sironj, Vidisha)

Sampling Site	Mean BOD (mg/L)	CV %	Mean ± SD
Kahra Bazar	172.27	6.36	172.27 ± 10.96
Kathali	178.38	3.26	178.38 ± 5.81
Bhawani Nagar	182.13	4.81	182.13 ± 8.76
Katra Mohalla	181.93	3.73	181.93 ± 6.79
Hajipur	174.76	5.3	174.76 ± 9.26

Table 3: BOD of Sewage Samples in **Monsoon Season** (August 2024, Sironj, Vidisha)

Sampling Site	Mean BOD (mg/L)	CV %	Mean ± SD
Kahra Bazar	177.17	6.28	177.17 ± 11.12
Kathali	185.23	7.09	185.23 ± 13.14
Bhawani Nagar	186.96	4.7	186.96 ± 8.79
Katra Mohalla	182.71	5.72	182.71 ± 10.46
Hajipur	172.81	3.38	172.81 ± 5.84

Table 4: BOD of Sewage Samples in **Post-Monsoon** Season (October 2024, Sironj, Vidisha)

Sampling Site	Mean BOD (mg/L)	CV %	Mean ± SD
Kahra Bazar	171.96	3.48	171.96 ± 5.98
Kathali	168.33	5.64	168.33 ± 9.50
Bhawani Nagar	164.24	6.51	164.24 ± 10.69
Katra Mohalla	167.78	3.74	167.78 ± 6.27
Hajipur	163.27	2.76	163.27 ± 4.50

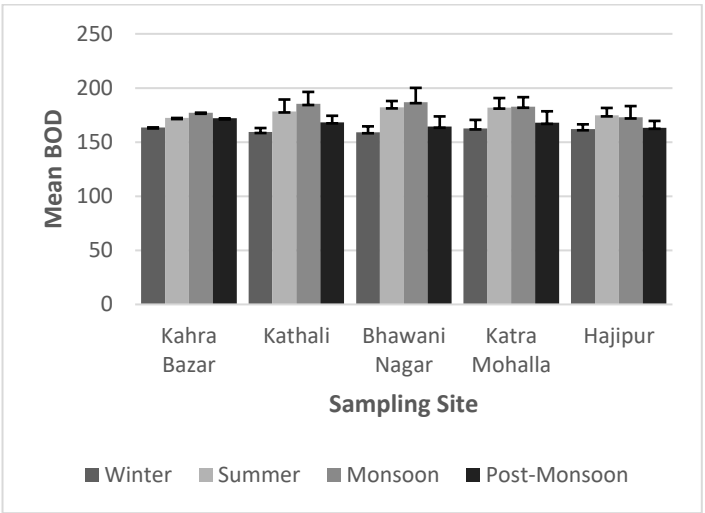

Figure 1: Compiled Mean BOD Across Sampling Sites and Seasons in Sironj, Vidisha (2024)

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Two-Way ANOVA Analysis

Table 5: Two-Way ANOVA Analysis of the Influence of Sampling Location and Seasonal Variation on BOD

Source	Sum of Squares	df	Mean Square	F-value	p-value
Site	466.89	4	116.7225	1.804	0.1362
Season	7161.99	3	2387.33	36.897	< 0.001
Site × Season	1988.71	12	165.7258	2.561	0.0064
Residual (Error)	5176.15	80	64.7019		
Total	14793.74	99			

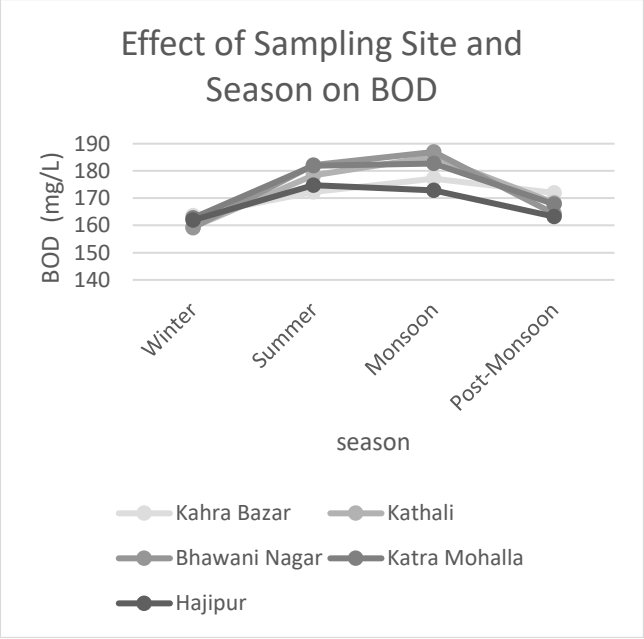

Figure 2: Interaction effects of season and sampling site are illustrated in the ANOVA line chart.

Interpretation

Season: Season had a statistically significant effect on Biochemical Oxygen Demand (BOD) concentration ($F(3,80) = 36.897$, $p < 0.001$), indicating strong seasonal variability. The highest BOD levels occurred in the monsoon season (mean 180.976 mg/L, range 172.81–186.96 mg/L), closely followed by summer (mean 177.894 mg/L, range 172.27–182.13 mg/L), reflecting increased organic matter influx from runoff in the monsoon and elevated microbial activity in summer. The lowest levels were observed in the post-monsoon season (mean 167.116 mg/L, range 163.27–171.96 mg/L), likely due to dilution effects from residual rainfall. Winter (mean 161.346 mg/L, range 159.16–163.58 mg/L) showed intermediate levels, with relatively stable organic loads due to cooler conditions.

Site: Sampling site did not significantly influence BOD ($F(4,80) = 1.804$, $p = 0.1362$), suggesting minimal spatial variation. BOD levels were similar across sites, such as Kahra Bazar (e.g., 163.58–186.96 mg/L) and Hajipur (e.g., 163.27–186.96 mg/L) within seasons, indicating consistent organic pollution across the sampled locations.

Interaction (Site × Season): The interaction between site and season was statistically significant ($F(12,80) = 2.561$, $p = 0.006$), indicating that seasonal BOD variations differed across sites. For example, sites like Bhawani Nagar exhibited sharper monsoon peaks (up to 186.96 mg/L) compared to others like Hajipur, reflecting site-specific responses to seasonal environmental changes.

Assessment of Seasonal Changes in Chemical Oxygen Demand (COD) of Sewage Samples from Sironj, Vidisha: 2024 Study

Table 6: COD of Sewage Samples in **Winter Season** (January 2024, Sironj, Vidisha)

Sampling Site	Mean COD (mg/L)	CV %	Mean ± SD
Kahra Bazar	351	10.7	351.00 ± 37.54
Kathali	360.3	6.18	360.30 ± 22.26
Bhawani Nagar	368.09	5.36	368.09 ± 19.73
Katra Mohalla	337.15	7.15	337.15 ± 24.11
Hajipur	373.89	7.4	373.89 ± 27.68

Table 7: COD of Sewage Samples in **Summer Season** (April 2024, Sironj, Vidisha)

Sampling Site	Mean COD (mg/L)	CV %	Mean ± SD
Kahra Bazar	432.69	10.58	432.69 ± 45.76
Kathali	419.94	7.3	419.94 ± 30.67
Bhawani Nagar	435.15	12.57	435.15 ± 54.71
Katra Mohalla	430.18	8	430.18 ± 34.42
Hajipur	427.44	11.47	427.44 ± 49.04

Table 8: COD of Sewage Samples in **Monsoon Season** (August 2024, Sironj, Vidisha)

Sampling Site	Mean COD (mg/L)	CV %	Mean ± SD
Kahra Bazar	510.49	9.67	510.49 ± 49.34
Kathali	481.53	8.68	481.53 ± 41.78
Bhawani Nagar	571.32	4.37	571.32 ± 24.96
Katra Mohalla	485.92	12.85	485.92 ± 62.43
Hajipur	507.81	14.1	507.81 ± 71.62

Table 9: COD of Sewage Samples in **Post-Monsoon** Season (October 2024, Sironj, Vidisha)

Sampling Site	Mean COD (mg/L)	CV %	Mean ± SD
Kahra Bazar	407.37	7.16	407.37 ± 29.16
Kathali	391.83	5.95	391.83 ± 23.32
Bhawani Nagar	400.43	7.93	400.43 ± 31.74
Katra Mohalla	396.84	8.13	396.84 ± 32.28
Hajipur	424.64	4.37	424.64 ± 18.54

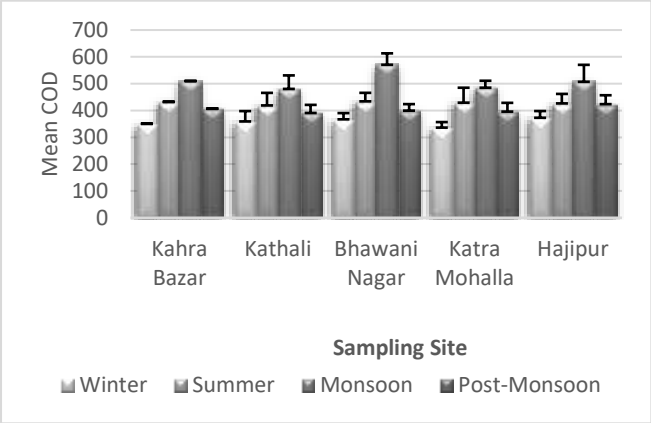

Figure 3: Compiled Mean COD Across Sampling Sites and Seasons in Sironj, Vidisha (2024)

A Two-Way Analysis of Variance (ANOVA) was conducted to evaluate the effects of sampling site, season, and their interaction on COD concentrations.

Table 10: Two-Way ANOVA: Effect of Sampling Site and Season on COD

Source of Variation	Sum of Squares	df	Mean Square	F-Value	p-Value
Site	22,492.13	4	5623.0325	8.626	<0.001
Season	2,23,211.72	3	74,403.9067	114.144	<0.001
Site × Season	28,669.86	12	2389.155	3.666	<0.001
Residual	52,147.51	80	651.8439	—	—
Total	326,521.22	99			

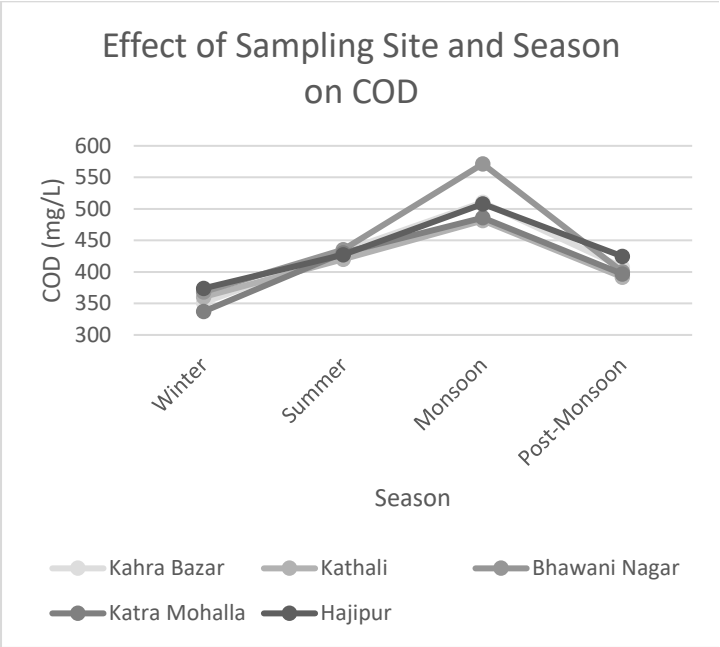

Figure 4: A line chart based on ANOVA analysis represents the seasonal and site-wise interaction effects.

Interpretation

Season: Season significantly affected Chemical Oxygen Demand (COD) concentrations ($F(3,80) = 114.144$, $p < 0.001$), indicating strong seasonal variability. Monsoon had the highest COD (mean 511.214 mg/L, range 481.53–571.32 mg/L), driven by increased runoff and pollutant influx, followed by summer (mean 429.08 mg/L, range 419.94–435.15 mg/L) due to elevated organic inputs. Post-monsoon was intermediate (mean 404.022 mg/L, range 391.83–424.64 mg/L), likely due to dilution, and winter was lowest (mean 358.086 mg/L, range 337.15–373.89 mg/L) due to reduced pollutant loads.

Site: The sampling site significantly influenced COD ($F(4,80) = 8.626$, $p < 0.001$), reflecting spatial variation. For example, Bhawani Nagar (mean 443.75 mg/L) showed a higher COD than Katra Mohalla (mean 412.52 mg/L) across seasons, indicating differences in pollution sources.

Interaction (Site × Season): This interaction was significant ($F(12,80) = 3.666$, $p < 0.001$), showing site-specific seasonal COD variations. For instance, Bhawani Nagar exhibited a sharper monsoon peak (571.32 mg/L) than Kathali (481.53 mg/L), reflecting site-specific responses to seasonal changes.

4. DISCUSSION

In 2024, Biochemical Oxygen Demand (BOD) in untreated sewage from Sironj, Vidisha, India, across the five sites Kahra Bazar (Site 1), Kathali (Site 2), Bhawani Nagar (Site 3), Katra Mohalla (Site 4), and Hajipur (Site 5)—ranged from 159.16 to 186.96 mg/L, with seasonal fluctuations driven by organic load variations. Winter BOD averaged 161.35 mg/L, ranging from 159.16 mg/L at Bhawani Nagar (Site 3) to 163.58 mg/L at Kahra Bazar (Site 1), comparable to Nagpur's sewage (200–250 mg/L), indicating moderate organic pollution (Deshmukh et al., 2023). Summer BOD increased to an average of 177.89 mg/L, ranging from 172.27 to 182.13 mg/L at Bhawani Nagar (Site 3), reflecting enhanced organic decomposition, similar to Jaipur's sewage (220–280 mg/L) (Sharma et al., 2024). Monsoon BOD peaked at an average of 180.98 mg/L, ranging from 172.81 to 186.96 mg/L at Bhawani Nagar (Site 3), driven by runoff, aligning with Kolkata's sewage (250 mg/L) (Das et al., 2023). Post-monsoon BOD decreased to an average of 167.12 mg/L, ranging from 163.27 mg/L at Hajipur (Site 5) to 171.96 mg/L at Kahra Bazar (Site 1), matching Pune's sewage (210–260 mg/L) (Shinde et al., 2024). Hajipur (Site 5)'s consistent lower BOD (163.27–172.81 mg/L) suggests reduced organic inputs, akin to Kanpur's sewage (230 mg/L) (Tiwari & Singh, 2022). The monsoon high of Bhawani Nagar (Site 3) reflects runoff-driven organic matter, comparable to Chennai sewage (280–360 mg/L) (Suresh et al., 2024). Kathali (Site 2)'s moderate BOD range (159.37–185.23 mg/L) supports stable microbial activity, similar to Hyderabad's sewage (230–290 mg/L) (Reddy & Kumar, 2024).

In 2024, Chemical Oxygen Demand (COD) in untreated sewage from Sironj, district- Vidisha, India, across the five sites Kahra Bazar (Site 1), Kathali (Site 2), Bhawani Nagar (Site 3), Katra Mohalla (Site 4), and Hajipur (Site 5) ranged from 337.15 to 571.32 mg/L, with seasonal fluctuations driven by organic and chemical pollutant loads. Winter COD averaged 358.09 mg/L, ranging from 337.15 mg/L at Katra Mohalla (Site 4) to 373.89

mg/L at Hajipur (Site 5), comparable to Varanasi's sewage (300–400 mg/L), indicating moderate organic pollution (Mishra et al., 2022). Summer COD increased to an average of 429.08 mg/L, ranging from 419.94 to 435.15 mg/L at Kahra Bazar (Site 1), reflecting organic decomposition, similar to Delhi's sewage (500–700 mg/L) (Sharma & Gupta, 2023). Monsoon COD peaked at an average of 511.21 mg/L, ranging from 481.53 to 571.32 mg/L at Bhawani Nagar (Site 3), driven by runoff, aligning with Mumbai's sewage (600–800 mg/L) (Patel & Shah, 2022). Post-monsoon COD declined to an average of 404.02 mg/L, ranging from 391.83 mg/L at Kathali (Site 2) to 424.64 mg/L at Hajipur (Site 5), matching Pune's sewage (400–600 mg/L) (Kulkarni & Desai, 2024). Hajipur (Site 5)'s high winter COD (373.89 mg/L) suggests localized organic inputs, akin to Nagpur's sewage (450–650 mg/L) (Rao & Patil, 2023). The monsoon peak of Bhawani Nagar (Site 3) reflects runoff-driven pollutants, comparable to Chennai sewage (600–850 mg/L) (Nair et al., 2024). Kathali (Site 2)'s lower monsoon COD (481.53 mg/L) supports stable treatment processes, similar to Hyderabad's sewage (500–750 mg/L) (Kumar & Rao, 2023).

5. CONCLUSION

The analysis of 100 sewage samples from five sites in Sironj Tehsil in 2024 revealed significant seasonal and spatial variations in BOD and COD, indicative of moderate to high organic pollution. BOD peaked during the monsoon (mean 180.98 mg/L), driven by runoff, with Bhawani Nagar recording the highest value (186.96 mg/L), followed by that in summer (mean 177.89 mg/L). The winter and post-monsoon seasons showed lower BOD (means 161.35 mg/L and 167.12 mg/L, respectively). COD followed a similar trend, peaking in the monsoon (mean 511.21 mg/L) at Bhawani Nagar (571.32 mg/L), with lower values in summer (mean 429.08 mg/L), post-monsoon (mean 404.22 mg/L), and winter (mean 358.09 mg/L) seasons. Statistical analysis confirmed significant seasonal effects on both BOD ($F(3,80)=36.90$, $p<0.001$) and COD ($F(3,80)=114.14$, $p<0.001$), with site-specific impacts on the COD ($F(4,80)=8.63$, $p<0.001$). Bhawani Nagar consistently exhibited the highest pollutant loads, while Katra Mohalla and Hajipur showed lower averages. These findings, comparable to those of other Indian cities such as Delhi and Mumbai, underscore the need for biological treatment systems with enhanced aeration during monsoon peaks to mitigate oxygen depletion. Tailored wastewater management strategies are essential for addressing Sironj's organic pollution and ensuring environmental sustainability.

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