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Impact of Monsoon Dynamics on Water Quality of the Dhamodar River: Physicochemical and Sub-Index Analysis

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Abstract

Monsoon-induced rainfall and runoff significantly alter river water quality by introducing sediments, nutrients, and pollutants, impacting aquatic ecosystems and human use. This study evaluates the Dhamodar River's water quality during the monsoon season across seven stations (DC-1 to DC-7), focusing on physicochemical parameters and sub-indices. Parameters analyzed included pH, EC, TDS, turbidity, DO, BOD, COD, TSS, nitrate, nitrite, ammonia, phosphate, sulfate, chloride, TOC, alkalinity, and hardness. Sub-indices ((qi)) were calculated using ($q_i=(C_i \div S_i)\times 100$), where (C_i) is the measured concentration and (S_i) is the regulatory standard, to assess compliance. Data, visualized in bar plots (Figures 1 and 3), radar plots (Figures 2 and 5), and a line plot (Figure 4), revealed significant spatial and temporal variations. Turbidity peaked at DC-5 (11.5 NTU), with TSS reaching 81 mg/L, indicating heavy sediment load from runoff. EC (1200 µS/cm) and TDS (780 mg/L) were highest at DC-7, reflecting ionic inputs from urban or industrial sources. BOD (4.0 mg/L) and COD (25 mg/L) at DC-7 suggested elevated organic pollution, while nutrient levels, particularly nitrate (32.5 mg/L) and phosphate (0.84 mg/L) at DC-5, pointed to agricultural runoff. Sub-indices highlighted severe pollution, with turbidity (230.00 at DC-5) and COD (250.00 at DC-7) indicating significant deviations from standards. Figures 1 and 2 showed how dilution and silt altered parameters, while Figures 3–5 underscored site-specific impacts, with DC-5 and DC-7 most affected. These findings emphasize the monsoon's role in exacerbating water quality degradation through sediment and pollutant transport, highlighting the need for targeted management strategies to mitigate runoff impacts in the Dhamodar River basin.

Key words : Monsoon, Dhamodar River, water quality, runoff, physicochemical parameters, sub-indices

Introduction

Rivers are critical to global ecosystems, supporting biodiversity, agriculture, and human livelihoods[1,2]. However, their water quality is increasingly threatened by anthropogenic activities and climatic factors, particularly during monsoon seasons when heavy rainfall and runoff alter physicochemical and biological parameters[3,4]. Worldwide, monsoon-driven changes in water quality are well-documented, with studies from Southeast Asia, Africa, and South America reporting increased turbidity, nutrient loads, and organic matter due to runoff from agricultural lands, urban areas, and industrial zones[5,6]. For instance, rivers in Southeast Asia, such as the Mekong, experience elevated sediment loads during monsoons, impacting aquatic ecosystems and water usability. These global patterns underscore the need to understand region-specific responses to monsoon dynamics, particularly in countries like India, where rivers are vital for economic and cultural sustenance.

In India, rivers face significant pollution challenges due to rapid urbanization, industrialization, and agricultural intensification. The monsoon season, typically spanning June to September, brings heavy rainfall that exacerbates water quality issues by mobilizing pollutants from land surfaces into rivers. Studies on Indian rivers, such as the Ganges and Yamuna, have shown increased turbidity, nutrient enrichment, and organic pollution during monsoons, driven by runoff from agricultural fields and urban sewage[7-9]. These changes affect water potability, aquatic life, and downstream irrigation, necessitating detailed assessments of monsoon impacts on river systems. The Dhamodar River, located in eastern India, is a prime example of a river system under stress from both natural and anthropogenic influences. Originating in Jharkhand and flowing through West Bengal, the Dhamodar River basin supports agriculture, industry, and urban populations but is heavily impacted by coal mining, industrial effluents, and agricultural runoff[10-12]. During the monsoon, the river experiences significant hydrological changes, with increased flow rates and sediment transport altering its water quality.

This study focuses on the Dhamodar River to investigate how monsoon-driven runoff affects water quality across seven sampling stations (DC-1 to DC-7). By analyzing physico-chemical parameters such as pH, EC, TDS, turbidity, DO, BOD, COD, TSS, nutrients (nitrate, nitrite, ammonia, phosphate), sulfate, chloride, TOC, alkalinity, and hardness, the study aims to quantify the impact of rainfall and runoff. Additionally, water quality sub-indices were calculated to assess compliance with regulatory standards, providing a comprehensive evaluation of pollution levels. Visualizations, including bar plots (Figures 1 and 3), radar plots (Figures 2 and 5), and a line plot (Figure 4), were used to illustrate spatial and temporal variations. This research contributes to understanding monsoon-related water quality dynamics in the Dhamodar River, offering insights for sustainable river management in India and other monsoon-dominated regions.

Experimental Section :

Sample Collection and Site Description :

Water samples were collected from seven distinct locations (DC-1 to DC-7) along a river system during the monsoon season to evaluate the impact of rainfall and runoff on water quality. The study sites were categorized based on their respective codes and location types. Site DC-1 was identified as an urban residential area, while DC-2 represented a commercial zone. DC-3 corresponded to an industrial zone, and DC-4 was classified as a mixed residential area combining different housing patterns. Site DC-5 was located within a market area, whereas DC-6 covered the educational precinct. Finally, DC-7 was designated as the municipal core, representing the administrative and civic center of activity. Sampling followed standard protocols to ensure representative data, with sites chosen based on their proximity to urban, agricultural, and industrial areas. Samples were collected in pre-cleaned polyethylene bottles, stored at 4°C, and transported to the laboratory within 6 hours for analysis.

Physicochemical Parameter Analysis :

Water quality parameters measured included pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrate, nitrite, ammonia, phosphate, sulfate, chloride, total organic carbon (TOC), alkalinity, and hardness. pH was determined using a calibrated pH meter. EC was measured with a conductivity meter, expressed in µS/cm. TDS was calculated using the formula:

$$TDS(mg/L) = k \times EC(\mu S/cm)$$

where k is a constant (0.64 for natural waters). Turbidity was quantified in nephelometric turbidity units (NTU) using a turbidimeter. DO was measured via the Winkler titration method, while BOD and COD were determined using standard incubation and titration protocols, respectively. TSS was assessed by filtration and gravimetric analysis. Nutrient parameters (nitrate, nitrite, ammonia, phosphate) and anions (sulfate, chloride) were analyzed using ion chromatography. TOC was measured with a TOC analyzer, alkalinity by titration with 0.02 M HCl, and hardness by EDTA titration.

Water Quality Sub-Indices Calculation

Water quality sub-indices (qi) for each parameter were calculated to assess their relative contribution to overall water quality. The sub-index for each parameter was derived using the formula:

$$qi = (Ci \div Si) \times 100$$

where Ci is the measured concentration of parameter i, and Si is the standard permissible limit for that parameter, based on regulatory guidelines for surface water quality. Parameters included pH, EC, TDS, turbidity, DO, BOD, COD, TSS, nitrate, nitrite, ammonia, phosphate, sulfate, chloride, TOC, alkalinity, and hardness. The sub-indices were computed for each sampling location (DC-1 to DC-7) to quantify the impact of monsoon-related changes.

Quality Control and Assurance :

All analytical instruments were calibrated prior to use, and measurements were performed in triplicate to ensure reproducibility. Blank samples and certified reference materials were analyzed to validate accuracy. The relative standard deviation for replicate measurements was maintained below 5%. All chemicals used were of analytical grade, and deionized water was employed for dilution and reagent preparation.

Results

Physicochemical Water Quality Parameters:

The water quality data collected from seven locations (DC-1 to DC-7) along the Dhamodar River during the monsoon season, as depicted in Figure 1 (a bar plot illustrating changes in water quality metrics) and Figure 2 (a radar plot showing variations in these metrics), revealed significant impacts of dilution and silt on water quality. The pH ranged from 7.0 (DC-3) to 8.6 (DC-6), indicating slightly acidic to alkaline conditions, likely due to runoff carrying organic and inorganic materials. Electrical conductivity (EC) varied from 378 µS/cm (DC-6) to 1200 µS/

cm (DC-7), suggesting higher ionic content at DC-7 due to urban or industrial runoff. Total dissolved solids (TDS), calculated using the formula TDS(mg/L)=0.64×EC(μS/cm), ranged from 245 mg/L (DC-6) to 780 mg/L (DC-7), aligning with EC trends. Turbidity was highest at DC-5 (11.5 NTU) and lowest at DC-6 (6.2 NTU), reflecting sediment influx from runoff, as visualized in Figures 1 and 2. Dissolved oxygen (DO) levels, critical for aquatic ecosystems, ranged from 6.1 mg/L (DC-5) to 7.9 mg/L (DC-2), indicating moderate oxygenation. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) peaked at DC-7 (4.0 mg/L and 25 mg/L, respectively), suggesting elevated organic pollution, while DC-6 showed the lowest COD (13 mg/L). Total suspended solids (TSS) were highest at DC-5 (81 mg/L), consistent with high turbidity due to silt. Nutrient levels, including nitrate (6.2–32.5 mg/L), nitrite (0.013–0.020 mg/L), ammonia (0.06–0.14 mg/L), and phosphate (0.12–0.84 mg/L), were elevated at DC-5, indicating nutrient enrichment from runoff. Sulfate (63–330 mg/L) and chloride (39–290 mg/L) concentrations were highest at DC-1, suggesting industrial or agricultural inputs. Total organic carbon (TOC) ranged from 1.0 mg/L (DC-6) to 2.5 mg/L (DC-7), reflecting organic matter contributions. Alkalinity (42–186 mg/L) and hardness (120–254 mg/L) peaked at DC-5 and DC-7, respectively, indicating geological influences amplified by runoff. Figures 1 and 2 highlight how dilution from rainfall and silt from runoff altered these parameters across the monsoon season.

Water Quality Sub-Indices Analysis :

The water quality sub-indices (qi), calculated using the formula qi = Ci/Si ×100, were analyzed to assess deviations from regulatory standards, as shown in Figure 3 (a bar plot of monsoon season sub-indices), Figure 4 (a line plot showing temporal and spatial changes), and Figure 5 (a radar map illustrating sub-indices across locations). The pH sub-index ranged from 0.00 (DC-3, highly acidic relative to standards) to 106.67 (DC-6, highly alkaline), indicating significant variability in pH compliance. EC and TDS sub-indices were highest at DC-7 (53.33 and

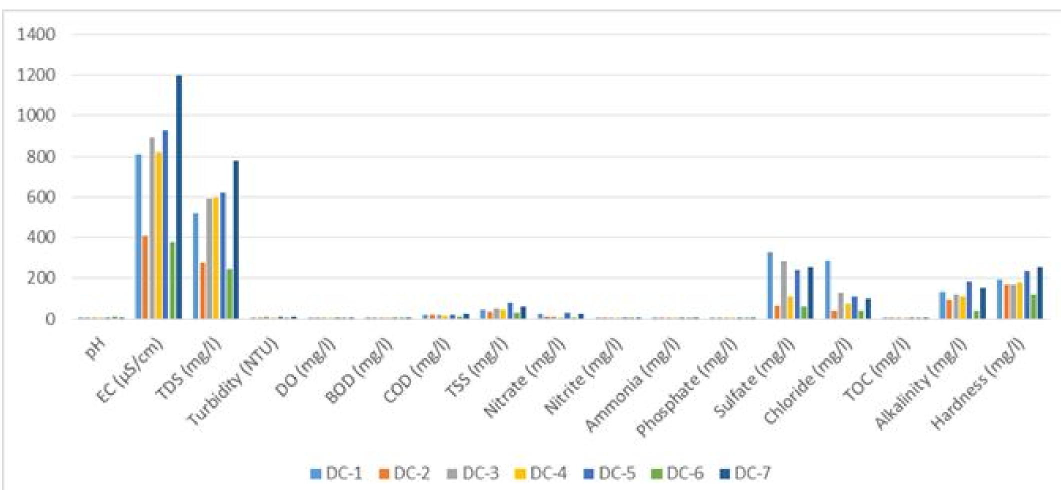

Figure 1: A bar plot that shows how the same water quality metrics changed throughout the monsoon season at the Dhamodar River sample stations, revealing how dilution and silt affected them.

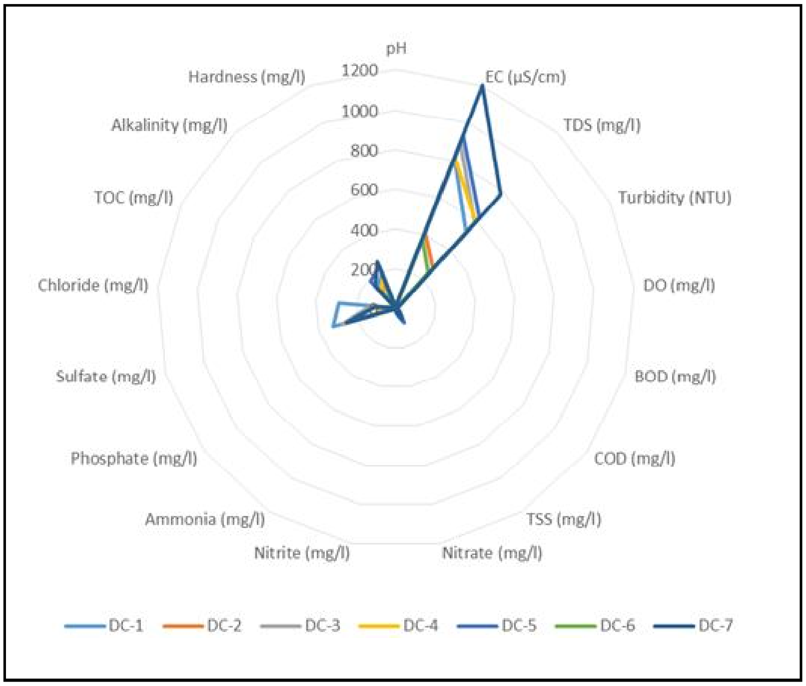

Figure 2: A radar plot that shows how the same water quality metrics changed throughout the monsoon season at the Dhamodar River sample stations, revealing how dilution and silt affected them.

52.00, respectively), reflecting elevated ionic and dissolved solid loads due to runoff, as depicted in Figures 3 and 5. Turbidity sub-indices were notably high, with DC-5 recording the highest (230.00), indicating severe sediment pollution during the monsoon, as shown in Figures 3, 4, and 5. DO sub-indices ranged from 63.21 (DC-2) to 80.19 (DC-5), suggesting adequate oxygenation despite runoff impacts. BOD and COD sub-indices were highest at DC-7 (133.33 and 250.00, respectively), signaling significant organic pollution, while DC-6 showed the lowest COD sub-index (130.00). TSS sub-indices peaked at DC-5 (81.00), consistent with high turbidity. Nutrient sub-indices for nitrate, nitrite, ammonia, and phosphate were highest at DC-5 (65.00, 100.00, 26.00, and 168.00, respectively), indicating nutrient pollution from agricultural or urban runoff, as visualized in Figure 5. Sulfate and chloride sub-indices were elevated at DC-1 (82.50 and 48.33), reflecting specific ionic inputs. TOC sub-indices ranged from 50.00 (DC-6) to 125.00 (DC-7), highlighting organic matter variations. Alkalinity and hardness sub-indices peaked at DC-5 (93.00) and DC-7 (84.67), respectively, as shown in Figures 3 and 5. Figure 4 illustrates how sub-indices fluctuated over time, with peaks corresponding to heavy rainfall events that caused dilution and particle movement.

Spatial and Monsoon Influences :

The spatial and temporal variability in water quality parameters and sub-indices, as illustrated in Figures 1–5, underscores the influence of monsoon dynamics and local land use along the Dhamodar River. Sites like DC-5 and DC-7, with elevated turbidity, TSS, and nutrient levels (*e.g.*, turbidity: 11.5 NTU at DC-5, TSS sub-index: 81.00 at DC-5), are likely near areas with intense agricultural or urban activity, where runoff carries sediments, fertilizers, and organic waste, as shown in Figures 1, 3, and 5. In contrast, DC-6 exhibited lower values for most parameters *(e.g.*, EC: 378 µS/cm, TDS: 245 mg/L, TSS sub-index: 30.00), suggesting less anthropogenic impact or greater dilution from rainfall, as depicted in Figures 2 and 5. The high turbidity and COD sub-indices across all sites (*e.g.*, COD sub-index: 250.00 at DC-7), visualized in Figures 3 and 4, highlight the monsoon's role in increasing sediment and organic loads due to soil erosion and runoff. Nutrient sub-indices, particularly for phosphate and ammonia at DC-5, indicate localized pollution sources exacerbated by monsoonal runoff, as shown in Figure 5. Figure 4 further reveals that sub-index peaks coincided with periods of intense rainfall, emphasizing the role of dilution and particle movement. These findings, supported by the visual representations in Figures 1–5, demonstrate that monsoon-driven hydrological changes significantly alter water quality, with site-specific impacts reflecting the interplay of rainfall, runoff, and land use patterns along the Dhamodar River.

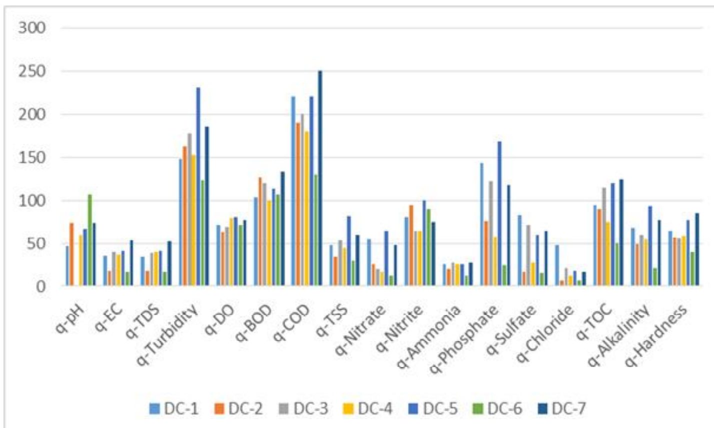

Figure 3: A bar plot that shows the monsoon season water quality sub-indices at seven different locations. It shows how seasonal dilution and sediment movement affect water quality metrics.

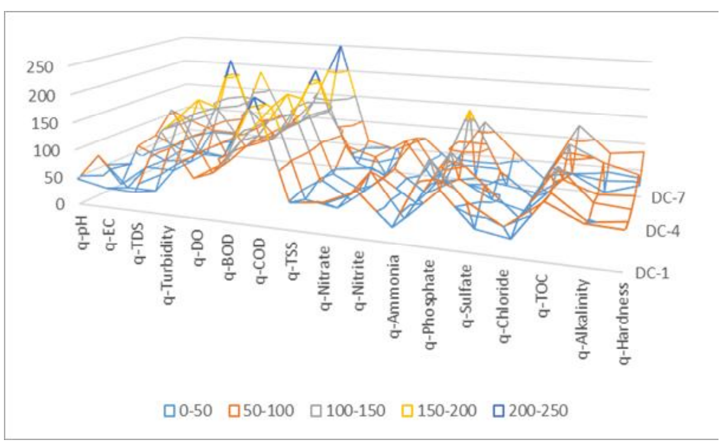

Figure 4: A line plot that shows how water quality sub-indices changed over time and at different sites during the monsoon, indicating how rainfall caused dilution and movement of particles.

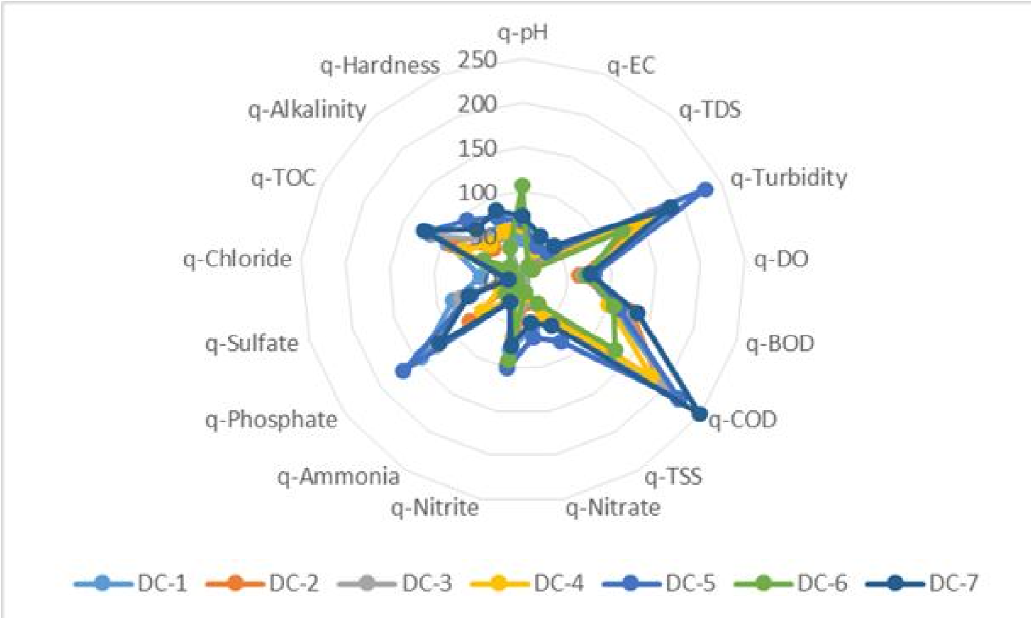

Figure 5: A radar map that shows the monsoon season water quality sub-indices at all locations. It shows how monsoonal runoff affects physicochemical and biological parameters in different ways.

Discussion

The analysis of water quality parameters and sub-indices in the Dhamodar River during the monsoon season, as depicted in Figures 1–5, reveals significant spatial and temporal variability driven by rainfall and runoff. The physicochemical parameters, visualized in Figure 1 (bar plot) and Figure 2 (radar plot), highlight the influence of dilution and silt. For instance, pH ranged from 7.0 (DC-3) to 8.6 (DC-6), with DC-3's acidic nature potentially linked to industrial effluents, while DC-6's alkalinity suggests carbonate inputs from geological sources. EC and TDS, peaking at DC-7 (1200 µS/cm, 780 mg/L), indicate high ionic content from urban or industrial runoff, as shown in Figures 1 and 2. Turbidity and TSS were notably high at DC-5 (11.5 NTU, 81 mg/L), reflecting sediment influx from agricultural or urban areas, consistent with monsoon-driven erosion. DO levels, ranging from 6.1 mg/L (DC-5) to 7.9 mg/L (DC-2), suggest moderate oxygenation, though lower values at DC-5 indicate organic pollution stress, corroborated by high BOD (4.0 mg/L at DC-7) and COD (25 mg/L at DC-7). Nutrient parameters, particularly nitrate (32.5 mg/L at DC-5) and phosphate (0.84 mg/L at DC-5), point to agricultural runoff, while elevated sulfate (330 mg/L at DC-1) and chloride (290 mg/L at DC-1) suggest industrial contributions. TOC (2.5 mg/L at DC-7) and alkalinity (186 mg/L at DC-5) further indicate organic and carbonate inputs, as visualized in Figures 1 and 2.

The sub-indices, shown in Figure 3 (bar plot), Figure 4 (line plot), and Figure 5 (radar map), provide a standardized measure of water quality deviation. The turbidity sub-index at DC-5 (230.00) and COD sub-index at DC-7 (250.00) highlight severe sediment and organic pollution, driven by monsoon runoff, as seen in Figures 3 and 5. The pH sub-index varied widely (0.00 at

DC-3 to 106.67 at DC-6), indicating non-compliance at DC-3, likely due to acidic inputs. Nutrient sub-indices, especially for phosphate (168.00 at DC-5), underscore agricultural pollution, while high sulfate and chloride sub-indices at DC-1 (82.50, 48.33) reflect industrial impacts. Figure 4 illustrates temporal fluctuations, with sub-index peaks corresponding to heavy rainfall events, confirming the role of dilution and particle movement. Compared to global studies, such as those on the Mekong River, the Dhamodar River's high turbidity and nutrient loads align with monsoon-driven patterns in tropical rivers. However, the elevated COD and nutrient levels at DC-5 and DC-7 suggest localized pollution sources, distinguishing the Dhamodar from less anthropogenically impacted rivers. These findings emphasize the need for site-specific interventions, such as runoff management and industrial effluent treatment, to mitigate monsoon-related water quality degradation.

Conclusion

This study on the Dhamodar River demonstrates that monsoon-driven runoff significantly impacts water quality, with elevated turbidity, TSS, and nutrient levels at sites like DC-5 and DC-7, as shown in Figures 1–5. High sub-indices for turbidity (230.00 at DC-5) and COD (250.00 at DC-7) highlight sediment and organic pollution, driven by agricultural and urban runoff. These findings underscore the need for targeted pollution control measures, including improved land-use practices and wastewater treatment, to ensure the sustainability of the Dhamodar River during the monsoon season.

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