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Spatial Distribution of Organic Pollution from Rubber Industry Effluent in the Ciseel River, Banjar City, Indonesia

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Abstract
Rubber-processing wastewater may contain organic matter, suspended solids, and nitrogen compounds that affect receiving rivers when treatment performance is unstable. This study evaluated treated rubber-industry effluent and the spatial distribution of pollutants in the Ciseel River, Batulawang, Banjar City, during dry and rainy conditions. River samples were collected at five points: 200 m upstream, the discharge mixing zone, and 300 m, 600 m, and 900 m downstream. The monitored parameters were TDS, EC, COD, TSS, total ammonia, total nitrogen, and pH. Effluent quality was compared with the Indonesian wastewater standard for rubber industries, while river water was assessed using Class IV criteria and the Pollution Index. COD and TSS exceeded the effluent limits in both seasons; COD reached 555.02 mg/L in the dry season and 455.31 mg/L in the rainy season. In the river, COD was the dominant parameter controlling water-quality status. Downstream COD remained above the Class IV criterion up to 900 m, showing that dilution and natural attenuation were insufficient within the monitored reach. The upstream stations met the standard, whereas the mixing zone and downstream stations were lightly polluted.
Keywords: *ciseel river; effluent control; pollution index; river water quality; rubber wastewater*

Abstrak
Air limbah pengolahan karet dapat mengandung bahan organik, padatan tersuspensi, dan senyawa nitrogen yang memengaruhi badan air penerima apabila kinerja pengolahan tidak stabil. Penelitian ini mengevaluasi efluen industri karet dan distribusi pencemar pada Sungai Ciseel, Batulawang, Kota Banjar, pada kondisi musim kemarau dan musim hujan. Sampel sungai diambil pada lima titik, yaitu 200 m sebelum titik buang, zona pencampuran efluen, serta 300 m, 600 m, dan 900 m setelah titik buang. Parameter yang dianalisis meliputi TDS, daya hantar listrik, COD, TSS, amonia total, nitrogen total, dan pH. Kualitas efluen dibandingkan dengan baku mutu air limbah industri karet, sedangkan air sungai dievaluasi menggunakan kriteria Kelas IV dan metode Indeks Pencemaran. COD dan TSS efluen melampaui baku mutu pada kedua musim; COD mencapai 555,02 mg/L pada musim kemarau dan 455,31 mg/L pada musim hujan. Pada badan air penerima, COD menjadi parameter utama yang menentukan status mutu. COD hilir masih melampaui kriteria Kelas IV hingga 900 m, menunjukkan bahwa pengenceran dan pemulihan alami belum cukup memulihkan kualitas air. Titik hulu memenuhi baku mutu, sedangkan zona pencampuran dan titik hilir termasuk cemar ringan.
Kata kunci: *air limbah karet; indeks pencemaran; kualitas air sungai; pengendalian efluen; sungai ciseel*

1. Introduction

Natural rubber processing remains an important agro-industrial activity in many tropical regions, including Indonesia. The process requires substantial water for washing, coagulation, milling, and equipment cleaning, and these operations generate wastewater that may contain high concentrations of organic matter, suspended solids, ammonia, and other dissolved substances. Globally, wastewater management is now closely linked to Sustainable Development Goal 6, particularly the need to reduce pollution, improve ambient water quality, and increase the proportion of safely treated wastewater [1]-[5]. In industrial river catchments, this issue is especially important because treated effluent may still alter the quality of receiving waters when outlet performance is unstable or when dilution capacity is limited.

Industrial wastewater discharge should therefore be understood not only as a compliance issue at the treatment outlet, but also as a pressure on the receiving river. Organic matter represented by COD can consume dissolved oxygen during degradation, while suspended solids can increase turbidity, deposit on the river bed, and transport associated pollutants. Nitrogen compounds may further influence nutrient dynamics and local microbial activity. Recent global assessments emphasise that ambient water-quality monitoring should combine source-oriented control with river-based observation so that treatment compliance and downstream effects can be interpreted together [2], [3].

Previous river-water studies have shown that water quality often varies spatially and seasonally because of differences in pollutant inputs, hydrological condition, dilution, sediment interaction, and local land use [6]-[14]. These studies are useful for interpreting river data because a single sampling point cannot fully describe the behaviour of a pollutant after discharge. A spatial approach, supported by upstream, mixing-zone, and downstream observations, can distinguish background river quality from the incremental effect of an effluent input. This approach is consistent with current international guidance that treats ambient water-quality monitoring as an essential basis for river management, pollution tracking, and evidence-based intervention [3], [4], [15].

For the present study, regulatory interpretation is a key methodological concern. Rubber-industry effluent should be compared with the applicable wastewater-quality standard for the industrial activity, while the receiving river should be evaluated using river-water criteria that reflect its intended use. Mixing these two benchmarks may lead to an overly optimistic interpretation because a concentration that satisfies an effluent standard may still exceed the criterion for the receiving water. The Pollution Index method is therefore useful because it integrates several parameter-to-standard ratios into a single status value while retaining the regulatory context of the intended water class [6], [7], [16], [17].

The Ciseel River in Batulawang, Pataruman District, Banjar City, receives treated effluent from a rubber-processing facility and also supports local environmental functions, including irrigation-related use. Field observations and preliminary monitoring indicated a visible change in water condition around the effluent entry point. However, the extent to which this discharge affects downstream water quality requires a more careful spatial interpretation, particularly for COD and TSS. Recent river-water assessments have demonstrated that upstream-downstream monitoring is effective for identifying localised pollution pressure and for separating point-source effects from background water-quality variation [10], [11].

This study evaluates rubber-industry effluent quality and the spatial distribution of pollutants in the Ciseel River under dry and rainy conditions. The analysis focuses on parameters that represent dissolved material, organic load, nitrogen species, suspended solids, and acidity/alkalinity. The novelty of the study lies in the combined interpretation of outlet compliance, river-class criteria, seasonal comparison, and spatial downstream response in a small receiving river affected by rubber-processing effluent. This framing is expected to provide a practical basis for improving treatment performance and strengthening river-water monitoring in Banjar City.

2. Materials and Methods

2.1 Study area and sampling design

The study was conducted along the Ciseel River in Batulawang Village, Pataruman District, Banjar City. The study area is a lowland river reach at approximately 85 m above sea level. Sampling was carried out in two hydrological conditions, namely the dry season and the rainy season, in order to capture the contrast between lower dilution capacity and higher rainfall-driven flow conditions.

River samples were collected at five locations along the receiving water. The first point was located 200 m upstream of the effluent discharge and was used to represent the upstream condition. The second point was located at the discharge mixing zone. The remaining points were located 300 m, 600 m, and 900 m downstream from the mixing point. One additional sample was taken at the outlet of the wastewater treatment plant before discharge to the river. The sampling layout is presented in Figure 1, and the role of each sampling point is summarized in **Table 1**. **Table 1** serves as the basis for distinguishing the upstream reference condition, the effluent mixing zone, and the downstream response points used in the spatial analysis.

As shown in **Figure 1**, the sampling design follows the flow direction of the Ciseel River from the upstream reference station (S1) to the effluent mixing zone (S2), and then to three downstream stations (S3-S5). This arrangement was used to distinguish the background condition of the river from the immediate effect of the rubber industry effluent and the subsequent changes along the downstream reach. The downstream sequence also provides a basis for evaluating whether pollutant concentrations decreased after mixing and dilution or remained elevated farther from the discharge point.

Table 1. Sampling locations and purpose of observation

Code	Location	Purpose
S1	-200 m from discharge point	Upstream river condition before effluent influence
S2	0 m	Initial mixing zone between effluent and river water
S3	300 m downstream	Early downstream response after discharge
S4	600 m downstream	Intermediate downstream response
S5	900 m downstream	Farthest monitored downstream location

Source: primary data analysis

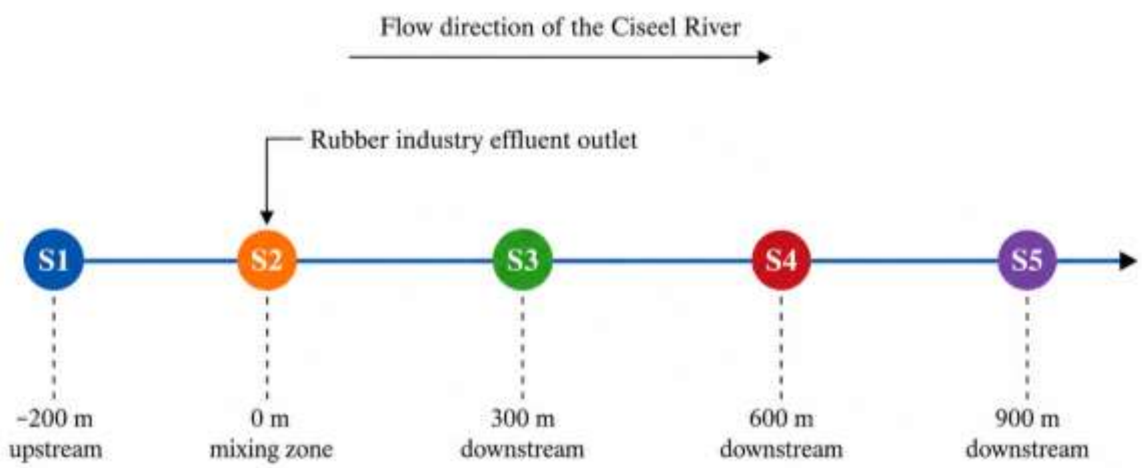

Figure 1. Sampling scheme along the Ciseel River

2.2 Water-quality parameters and regulatory benchmarks

The measured parameters were total dissolved solids (TDS), electrical conductivity (EC), COD, total ammonia, total nitrogen, TSS, and pH. Parameters that may change rapidly after sampling were measured in the field whenever possible, whereas chemical parameters were analysed in the laboratory. The sampling procedure followed the principles of surface-water sampling in SNI 6989.57:2008 [18] and recognised water and wastewater examination procedures [19].

Two regulatory comparisons were used. The effluent was compared with the wastewater standard for rubber industries under the concentrated-latex category, namely COD 250 mg/L, TSS 100 mg/L, total ammonia 15 mg/L, total nitrogen 25 mg/L, and pH 6.0-9.0 [20]. Because regulatory classification depends on the process and environmental permit of the facility, this category should be verified during compliance reporting. If the facility is formally classified as dry-rubber processing, the COD and nitrogen limits would be more stringent.

River-water quality was assessed against the Indonesian national water-quality criteria for Class IV rivers, which are relevant to water intended for irrigation and similar uses [16]. The Class IV criteria used in the Pollution Index calculation were TDS 2,000 mg/L, COD 80 mg/L, TSS 400 mg/L, and pH 6.0-9.0. EC was interpreted as a supporting indicator of dissolved ionic content because it is useful for detecting changes in river chemistry, although it was not used as a regulatory parameter in the Pollution Index calculation.

2.3 Data analysis

Data were analysed descriptively by comparing measured concentrations with the appropriate regulatory criteria. For the effluent, the ratio between measured concentration and effluent limit was calculated to identify parameters exceeding the standard. For river water, spatial patterns were evaluated by comparing the upstream, mixing-zone, and downstream concentrations in both seasons.

River-water status was determined using the Pollution Index method [17]. For each parameter, the ratio between the measured concentration and the relevant water-quality criterion was calculated. When the ratio exceeded 1.0, the adjusted ratio was obtained using $1 + 5 \log(C_i/L_{ij})$, where C_i is the measured concentration and L_{ij} is the water-quality criterion for parameter i and water class j. The final index was calculated from the maximum and average ratios. Pollution Index values of 0-1 indicate that water quality meets the standard, values greater than 1 to 5 indicate light pollution, values greater than 5 to 10 indicate moderate pollution, and values greater than 10 indicate heavy pollution.

3. Results and Discussion

3.1 Effluent quality at the treatment outlet

Table 2 indicates that the treated effluent still failed to consistently comply with the rubber-industry wastewater standard. COD was the main concern, with concentrations of 555.02 mg/L in the dry season and 455.31 mg/L in the rainy season. These levels were about 2.22 and 1.82 times higher than the permitted limit, showing that the organic load had not been sufficiently reduced before discharge. TSS showed a similar compliance problem, reaching 220.60 mg/L during the dry season and increasing to 279.70 mg/L during the rainy season. By comparison, total ammonia, total nitrogen, and pH remained within the allowable ranges, suggesting that the treatment limitation was more closely related to organic matter removal and suspended-solid control than to nitrogen or acidity conditions.

Table 2. Effluent quality at the rubber industry treatment outlet

Parameter	Unit	Dry season	Rainy season	Effluent limit	Ratio to limit (dry; rainy)
COD	mg/L	555.02	455.31	250	2.22; 1.82
Total ammonia (NH_3)	mg/L	0.20	0.29	15	0.01; 0.02
Total nitrogen (as N)	mg/L	0.26	0.41	25	0.01; 0.02
TSS	mg/L	220.60	279.70	100	2.21; 2.80
pH	-	6.15	6.38	6.0-9.0	Within range

Source: primary data analysis

Figure 2 summarizes the relative position of each effluent parameter against its corresponding standard. Instead of presenting the concentrations alone, the ratio format helps show which parameters were actually driving non-compliance. Values above 1.0 indicate exceedance of the applied limit. In both seasons, only COD and TSS crossed this threshold, while total ammonia, total nitrogen, and pH remained below their respective limits. This pattern reinforces that the main treatment weaknesses were associated with residual organic matter and suspended solids rather than nitrogen compounds or pH control.

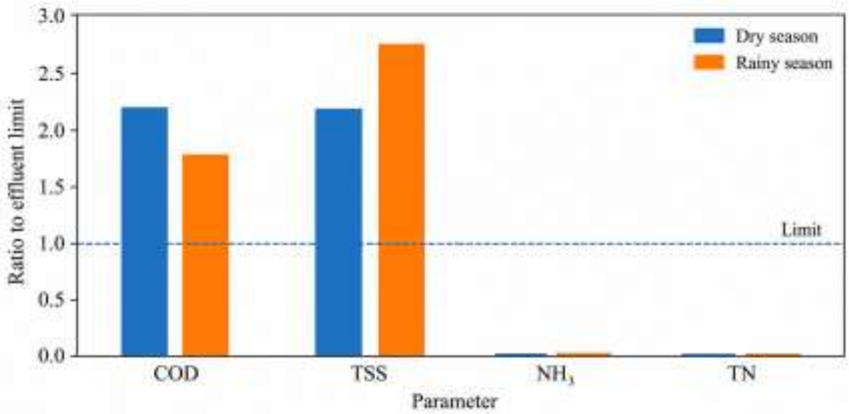

Figure 2. Effluent concentration ratios to the applied wastewater standard

The seasonal difference in COD and TSS provides an important clue about treatment behaviour. COD was higher in the dry season, which is consistent with lower dilution and a higher apparent concentration of soluble and colloidal organic matter. TSS, however, was higher in the rainy season. This pattern may indicate hydraulic disturbance, stormwater intrusion, resuspension of settled solids, or insufficient solids retention in the treatment unit during wet conditions. In rubber-processing wastewater, suspended rubber particles and organic colloids are often difficult to separate when preliminary treatment, settling, or sludge withdrawal is not well controlled.

The high outlet COD suggests that the biological and/or physicochemical treatment steps were not sufficient to remove the remaining organic load before discharge. Recent studies on natural-rubber processing wastewater have reported that anaerobic treatment followed by polishing units can substantially reduce biodegradable organic matter, while adsorption and electrocoagulation may assist in removing residual colour, colloids, ammoniacal nitrogen, COD, and suspended solids [21], [22]. Nevertheless, the success of these technologies depends on stable hydraulic loading, adequate sludge management, good contact between wastewater and biomass or adsorbent, and consistent operation. Incomplete solid-liquid separation may also explain why TSS remained above the effluent limit in both seasons.

3.2 River-water quality during the dry season

As shown in **Table 3**, the dry-season data indicate a noticeable shift in river water quality after the effluent entered the Ciseel River. Electrical conductivity increased sharply from 243 µS/cm at the upstream station to 1,257 µS/cm at the mixing zone, reflecting the additional input of dissolved ions from the wastewater. COD also rose from 86.55 mg/L upstream to 150.56 mg/L at the discharge point. The upstream COD value was already slightly higher than the Class IV criterion of 80 mg/L, suggesting that the river had received organic inputs before the industrial outlet. However, the further increase at the mixing zone confirms that the rubber industry effluent contributed an additional organic load, which remained evident at the downstream stations.

Table 3. Water quality of the Ciseel River during the dry season

Parameter	Unit	-200 m	0 m	300 m	600 m	900 m
TDS	mg/L	4.20	4.10	3.00	3.80	4.90
EC	µS/cm	243	1257	1249	1054	1031
COD	mg/L	86.55	150.56	130.77	169.16	169.16
Total ammonia (NH_3)	mg/L	0.04	0.17	0.15	0.12	0.12
Total nitrogen (as N)	mg/L	0.03	0.16	0.14	0.12	0.10
TSS	mg/L	12.40	21.45	5.61	4.89	5.86
pH	-	7.21	8.04	7.20	7.11	7.10

Source: primary data analysis.

The persistence of COD at 600 m and 900 m, both 169.16 mg/L, indicates that the river had not returned to its upstream condition within the monitored reach. The increase at the farther downstream points may be related to incomplete mixing near the outlet, additional local inputs, sediment-water interaction, or lower flow conditions that reduce the river capacity to disperse organic matter. This pattern is important because organic load can reduce dissolved oxygen during microbial decomposition, especially when flow is slow and reaeration is limited.

TSS remained low in the river relative to the Class IV criterion, even though the effluent TSS exceeded the wastewater standard. The highest dry-season river TSS was 21.45 mg/L at the mixing zone and then decreased to 5.61 mg/L, 4.89 mg/L, and 5.86 mg/L at 300 m, 600 m, and 900 m, respectively. This suggests that some suspended particles settled rapidly, were diluted, or were retained within the river channel. However, the low TSS in the river should not be interpreted as evidence that the treatment unit was working well; it only indicates that suspended solids were not the main driver of river-class exceedance in this monitoring event.

3.3 River-water quality during the rainy season

A different pattern is observed during the rainy season, as presented in Table 4. The COD concentration increased markedly from 48.97 mg/L at the upstream station to 234.44 mg/L at the mixing zone. After this point, the concentration decreased along the downstream reach, reaching 147.27 mg/L at 300 m, 153.82 mg/L at 600 m, and 129.57 mg/L at 900 m. Although part of the organic load appeared to be diluted under higher-flow conditions, the COD level at all downstream stations still exceeded the Class IV criterion. This indicates that rainfall-driven dilution was not sufficient to recover the river water quality within the 900 m observation reach.

Table 4. Water quality of the Ciseel River during the rainy season

Parameter	Unit	-200 m	0 m	300 m	600 m	900 m
TDS	mg/L	4.80	1.90	2.40	2.00	2.40
EC	µS/cm	261	1076	1071	896	841
COD	mg/L	48.97	234.44	147.27	153.82	129.57
Total ammonia (NH_3)	mg/L	0.12	0.55	0.53	0.46	0.42
Total nitrogen (as N)	mg/L	0.07	0.44	0.43	0.39	0.25
TSS	mg/L	8.89	75.19	4.19	7.45	8.45
pH	-	7.39	7.87	7.55	7.50	7.56

Source: primary data analysis.

Figure 3 provides a direct comparison of COD behaviour along the sampling transect under dry- and rainy-season conditions. The plot is useful because it shows not only the increase at the mixing zone, but also the extent to which COD remained elevated farther downstream. In this study, the downstream trend was interpreted in relation to the Class IV criterion to assess the river's short-distance recovery capacity. A return to values below the criterion within 900 m would indicate effective dilution and natural attenuation, whereas persistently high COD would suggest that the organic load continued to influence the monitored river reach.

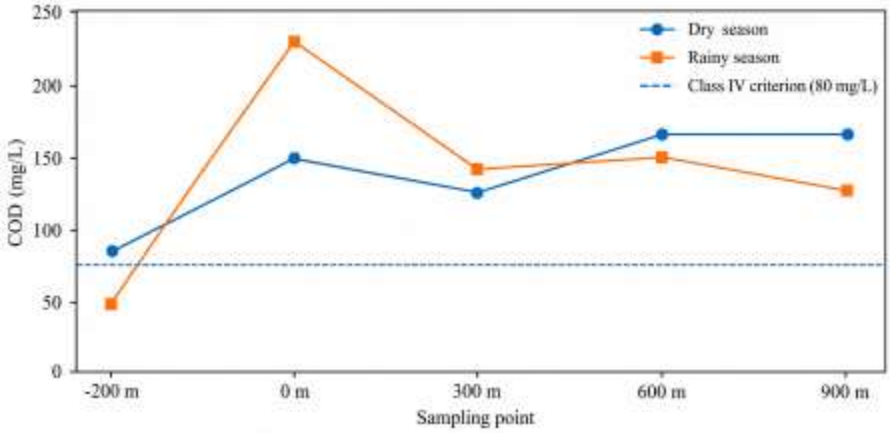

Figure 3. COD distribution in the Ciseel River compared with the Class IV criterion

Rainfall seemed to influence the river in two different ways. Before the effluent entered the river, COD was lower during the rainy season than during the dry season, indicating that higher flow may have diluted the background organic load. However, this dilution effect was not enough to offset the pollutant input at the discharge point. COD and TSS both increased sharply at the mixing zone, showing that the effluent still introduced a considerable load under wet-season conditions. TSS reached 75.19 mg/L at the mixing point but dropped to below 10 mg/L at the downstream stations, suggesting rapid dilution and possible settling of suspended particles. COD, in contrast, declined more slowly, which indicates that part of the organic matter was likely present in dissolved or colloidal forms that were not removed as quickly along the monitored reach.

Ammonia and total nitrogen also increased after the effluent entered the river. During the rainy season, total ammonia rose from 0.12 mg/L upstream to 0.55 mg/L at the mixing zone and remained at 0.53 mg/L at 300 m. Although ammonia did not dominate the Pollution Index calculation, it remains environmentally relevant. Depending on pH and temperature, total ammonia can partly occur as unionized ammonia, which is more toxic to aquatic organisms. The pH values observed in this study remained within the range 6.0-9.0, but future monitoring should include temperature and dissolved oxygen to better interpret the ecological risk of nitrogen compounds.

One data-quality issue should be noted. TDS values were very low compared with EC, particularly at downstream points where EC remained high while TDS was below 5 mg/L. This mismatch may be caused by instrument calibration, unit recording, or conversion differences. The mismatch does not alter the main conclusion, because COD was the dominant parameter controlling river status, but TDS should be checked carefully in future monitoring.

3.4 Pollution Index and water-quality status

Table 5 further distinguishes the upstream condition from the water-quality changes observed after the effluent discharge. The upstream station remained within the acceptable category in both seasons, with Pollution Index values of 0.86 during the dry season and 0.45 during the rainy season. In contrast, the sampling points located at and downstream of the discharge point were consistently classified as lightly polluted. The most pronounced deterioration was recorded at the rainy-season mixing zone, where the Pollution Index reached 2.45. This value supports the COD pattern discussed earlier, showing that the strongest water-quality response occurred immediately after the effluent entered the river.

Figure 4 was used to translate the concentration data into an overall water-quality status along the monitored reach. The upstream stations in both seasons remained within the category that met the standard, while the stations beginning from the mixing zone shifted into the lightly polluted category. This contrast shows that the effluent input changed the river condition most clearly after the discharge point. The highest

Pollution Index was recorded at the rainy-season mixing zone, which is consistent with the COD peak observed at the same location.

Table 5. Pollution Index of the Ciseel River based on Class IV criteria

Sampling point	Dry season PI	Dry season status	Rainy season PI	Rainy season status
-200 m	0.86	Meets standard	0.45	Meets standard
0 m	1.75	Lightly polluted	2.45	Lightly polluted
300 m	1.52	Lightly polluted	1.70	Lightly polluted
600 m	1.93	Lightly polluted	1.76	Lightly polluted
900 m	1.93	Lightly polluted	1.49	Lightly polluted

Source: primary data analysis.

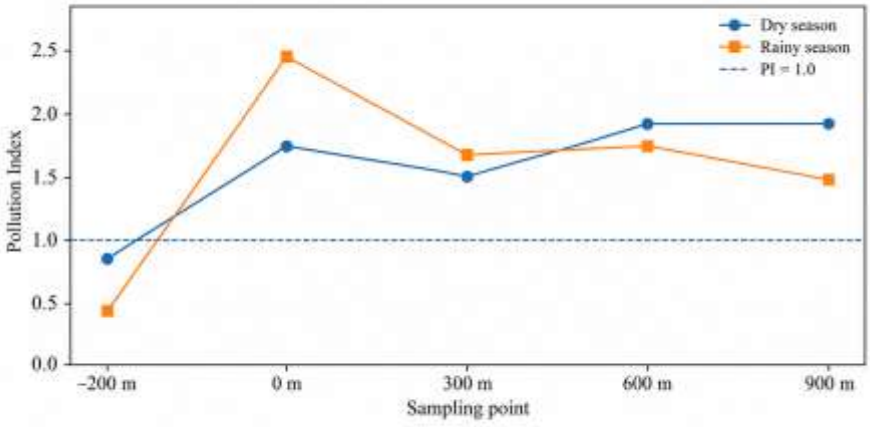

Figure 4. Pollution Index of the Ciseel River during dry and rainy conditions

COD was the main factor shaping the index. TDS, TSS, and pH were well within or near the Class IV criteria, while COD exceeded the 80 mg/L criterion at most river points. The dry-season upstream COD was already slightly above the criterion, indicating that background inputs or low-flow concentration may also influence the river. Nevertheless, the much higher COD at the mixing zone and downstream locations confirms that the rubber industry effluent added a measurable organic load to the receiving water. Recent WQI and Pollution Index literature cautions that index values are sensitive to parameter selection and regulatory thresholds; therefore, the dominant parameter should always be discussed together with the final index class [6]-[9], [11].

The classification as lightly polluted should not be read as a minor issue. It means that the river still failed to meet the selected water-quality class after receiving the effluent. For a river used for irrigation and local environmental functions, persistent COD elevation can contribute to odour, oxygen depletion, changes in microbial activity, and reduced aesthetic quality. The finding also indicates that compliance at the outlet and river recovery downstream must be evaluated together. A treatment plant that releases effluent with high COD may shift the burden of purification to the river, which is not acceptable as a long-term management strategy.

3.5 Recommendations for Pollution Control and Monitoring

The first management priority is source control. The treatment unit should be evaluated from the inlet to the outlet, including screening, rubber-particle trapping, equalisation, primary settling, sludge withdrawal, and biological treatment stability. High COD points to the need for stronger organic-matter removal, while high TSS indicates that solids separation and sludge handling are not yet reliable. Equalisation is particularly important because rubber-processing wastewater can fluctuate in flow and concentration, especially during washing and rainfall events.

Several process improvements may be considered. For high-strength rubber wastewater, anaerobic treatment such as an upflow anaerobic sludge blanket reactor or an anaerobic baffled reactor can reduce a substantial part of the biodegradable organic load. Aerobic post-treatment or attached-growth polishing can then improve residual COD and nitrogen removal [21], [22]. Where suspended rubber particles and colloids are dominant, improved settling, fine screening, coagulation-electrocoagulation, or adsorption may be used as supporting units [21], [22]. The selection of technology should be based on wastewater strength, flow fluctuation, sludge production, land availability, operator capacity, and the effluent limit stated in the environmental permit.

Monitoring also needs improvement. Concentration data are useful, but they are not enough to describe the actual pollutant load. Effluent flow and river flow should be measured so that COD and TSS loads can be estimated, particularly during rainy periods when runoff and hydraulic fluctuation may change both concentration and loading. Routine monitoring should also include quality assurance for units and analytical consistency, especially for TDS and EC, where the present dataset suggests a possible inconsistency. Recent global water-monitoring reports highlight the importance of reliable, comparable, and repeated water-quality data for assessing ambient-water status and for translating monitoring results into management action [2]-[5].

4. Conclusions

The rubber industry effluent entering the Ciseel River did not fully comply with the applied wastewater standard. COD and TSS exceeded the effluent limits in both dry and rainy seasons, while total ammonia, total nitrogen, and pH remained within the applied limits. The receiving river showed a clear response to the discharge, particularly through increased EC and COD at the mixing zone and downstream locations.

COD was the dominant parameter controlling river-water status. When river samples were evaluated against Class IV criteria, the upstream point met the standard, but the mixing zone and downstream points were classified as lightly polluted in both seasons. COD remained above the Class IV criterion up to 900 m downstream, indicating that dilution and natural attenuation were not sufficient to restore water quality within the monitored reach. The result highlights the importance of evaluating effluent quality and receiving-water status separately, using the correct regulatory benchmark for each.

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