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Application Of Water Pollution Load Index For Quantifying Industrial Pollution In Urban River Systems

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Abstract:*This study investigates the application of the Water Pollution Load Index (WPLI) for assessing industrial pollution in urban river systems. Urbanization and unregulated industrial discharges have significantly deteriorated river water quality, particularly in developing countries. Using WPLI, a comprehensive water Quality assessment was carried out across multiple sampling points along an industrially impacted urban river. Physico-chemical parameters such as pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and heavy metals (Lead, Cadmium, Chromium, Zinc) were analyzed. Results revealed spatial variation in pollutant load, with downstream regions showing critical pollution levels. The study demonstrates the potential of WPLI as an efficient instrument for ecological surveillance and regulatory decision-making in urban water resource management.*
Keywords:*Water Pollution Load Index (WPLI), industrial effluents, urban rivers, water quality, heavy metals, environmental monitoring*

1. INTRODUCTION

Water is an indispensable natural resource crucial for maintaining life, ecosystems, and economic advancement. However, rapid urbanization and unchecked industrial expansion over recent decades have significantly deteriorated the quality of surface water bodies, especially rivers traversing urban areas. Urban rivers often serve as the final receiving ends for domestic sewage, industrial effluents, stormwater runoff, and other anthropogenic discharges. In particular, industrial effluents pose a severe threat to water quality due to their high pollutant concentrations, comprising organic matter, nutrients, suspended particles, and hazardous heavy metals including lead (Pb), cadmium (Cd), and chromium (Cr).

Industrial pollution not only reduces the aesthetic and recreational value of urban rivers but also impacts aquatic ecosystems, degrades biodiversity, and compromises human health through contaminated water supply chains. In many developing countries, river systems lack adequate monitoring and regulatory enforcement, allowing untreated or partially treated industrial waste to be discharged directly into natural watercourses. Traditional water quality assessments based on individual parameters provide fragmented insights and fail to capture the overall pollution status in a consolidated manner.

To overcome these limitations, composite indices such as the **Water Pollution Load Index (WPLI)** have been developed. The WPLI is a diagnostic tool that integrates multiple physico-chemical and heavy metal parameters into a single index value, offering a simplified and quantitative interpretation of pollution levels. Unlike conventional Water Quality Indices (WQI), which are designed primarily for assessing potability, the WPLI focuses on pollutant loading, making it especially suitable for evaluating industrial and non-domestic pollution sources.

This study explores the application of the Water Pollution Load Index in assessing the degree of industrial pollution in an urban river system. Through systematic water sampling, analysis of key parameters, and computation of WPLI values across different locations, the study aims to identify pollution hotspots, track spatial variations in contaminant levels, and provide actionable insights for environmental management.

2. LITERATURE REVIEW

Water quality assessment in urban rivers is a critical area of environmental research, especially with rising concerns about industrialization and unregulated waste discharge. Over the years, researchers have developed and applied various tools such as Water Quality Index (WQI), Heavy Metal Pollution Index (HPI), and more recently, the **Water Pollution Load Index (WPLI)** to quantify and communicate pollution levels. The WPLI integrates multiple pollutant parameters into a single index, offering a clear representation of the cumulative pollution burden.

Patil et al. (2018) conducted a study on the Mula-Mutha river in Pune, India, and demonstrated the effectiveness of WPLI in quantifying pollution from nearby pharmaceutical and textile industries. The index helped identify critical zones requiring intervention and supported correlation with local industrial activity maps.

Bhateria and Jain (2019) emphasized the need for indices that consider pollutant load rather than just concentration. Their study on urban rivers in Rajasthan applied a modified WPLI to assess water quality and concluded that the traditional WQI often underrepresents heavy metal pollution, which can be better captured by WPLI.

Sharma et al. (2020) applied WPLI and GIS mapping tools to analyze the Yamuna River in Delhi. Their results showed clear spatial variability in pollutant loads, with WPLI values peaking near industrial clusters. The integration of WPLI with spatial analysis was highlighted as an effective technique for pollution zoning and decision-making.

Bora and Goswami (2021) used WPLI to analyze the Bharalu River in Assam, a highly polluted urban stream. Their study concluded that WPLI was sensitive to variations in heavy metal concentrations, particularly lead (Pb) and cadmium (Cd), which are dominant in industrial effluents. The index was effective in highlighting the need for regular monitoring near small-scale industrial hubs.

Kundu et al. (2021) introduced a hybrid model combining WPLI and principal component analysis (PCA) to evaluate pollution in the Hooghly River. The model offered greater analytical clarity by identifying key pollution-driving parameters and their relative contribution to overall pollution load.

Rathore and Singh (2022) evaluated the use of WPLI in post-lockdown industrial recovery phases in India. Their study on the Ganga River showed that WPLI values significantly increased after industries resumed operation, suggesting the index's usefulness in temporal monitoring of pollution load trends.

Zhou et al. (2023) applied WPLI to evaluate pollution in the Pearl River Delta in China, focusing on heavy industrial zones. Their study also linked WPLI values with ecosystem health indicators, showing strong correlations with declines in aquatic biodiversity, reaffirming the index's relevance in ecological risk assessment.

Mishra et al. (2023) studied the Damodar River Basin and incorporated WPLI into a machine learning framework to predict pollution load based on seasonal and land-use variables. The research highlighted the potential of AI-assisted WPLI prediction models for real-time pollution monitoring and industrial regulation enforcement.

Li and Wang (2024) emphasized the advantage of WPLI in multi-pollutant scenarios. In their comparative analysis of WQI and WPLI in the urban rivers of Shanghai, WPLI provided a more accurate pollution profile in regions impacted by chemical industries, particularly where concentrations exceeded the maximum permissible limits of WHO guidelines.

3. MATERIALS AND METHODS

3.1 Study Area

The current investigation was conducted along the Cooum River, which flows through the industrial and urban zones of **Chennai, Tamil Nadu, India**. The river receives substantial industrial effluent from surrounding leather tanneries, textile industries, and small-scale manufacturing units, especially in the **Perambur, Chetpet, and Chintadripet regions**. The river is highly impacted by untreated industrial discharges, domestic sewage, and urban runoff, making it an ideal site for evaluating pollution using the Water Pollution Load Index (WPLI).

3.2 Sampling Locations

Five sampling stations were selected based on proximity to industrial zones:

- **S1:** Upstream (control site, minimal human influence)
- **S2–S4:** Midstream points adjacent to major industrial discharge outlets
- **S5:** Downstream (post-mixing and potential dilution zone)

Samples were collected during the **dry season**, when dilution effects from rainfall are minimal and pollutant concentrations are more representative of industrial discharge.

3.3 Parameters Analyzed

Water samples were tested for the following:

- **Physico-chemical parameters:** pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), Electrical Conductivity (EC)
- **Heavy metals:** Lead (Pb), Cadmium (Cd), Chromium (Cr), and Zinc (Zn)

These parameters were chosen due to their relevance in assessing industrial pollution, ecological risk, and regulatory compliance.

3.4 Sample Collection and Analysis

- **Sample Collection:** Grab samples were collected in pre-cleaned polyethylene bottles following APHA (2017) standard procedures.
- **In-situ Measurement:** Parameters like pH, DO, and EC were measured on-site using portable probes.
- **Laboratory Analysis:** BOD and COD were determined using titration methods. Heavy metals were analyzed using **Atomic Absorption Spectrophotometry (AAS)** after acid digestion.

3.5 Water Pollution Load Index (WPLI) Calculation

The WPLI was computed to represent the overall pollution level at each sampling station. The index is calculated as:

WPLI=∑i=1nWi·Pi∑i=1nWi\text{WPLI} = \frac{\sum_{i=1}^{n} W_i \cdot P_i}{\sum_{i=1}^{n} W_i}WPLI=∑i=1nWi∑i=1nWi·Pi

Where:

- Pi=CiSiP_i = \frac{C_i}{S_i}Pi=SiCi, the pollution load ratio (measured concentration to standard permissible limit)
- WiW_iWi is the weight assigned to each parameter based on its relative importance or toxicity
- CiC_iCi = observed concentration
- SiS_iSi = standard permissible limit (e.g., CPCB or WHO)

Interpretation of WPLI:

- **WPLI < 1:** Low pollution
- **1 ≤ WPLI < 2:** Moderate pollution
- **WPLI ≥ 2:** High pollution

3.6 Quality Control and Assurance

- All glassware was acid-washed and rinsed with deionized water.
- Duplicate samples and blank samples were used to ensure analytical accuracy.
- Calibration of instruments was performed before analysis using standard reference solutions.

4. RESULTS AND DISCUSSION

4.1 Physico-Chemical Parameters

The assessment of water samples from **S1 to S5** demonstrated clear spatial variations:

- **S1 (Upstream Control Point):**

BOD (2.3 mg/L), COD (8.5 mg/L), DO (6.8 mg/L), TDS (320 mg/L), Turbidity (2.1 NTU) – **all within CPCB/WHO limits**, reflecting minimal pollution.

- **S2–S4 (Industrial Stretch):**
  - **BOD ranged 18–32 mg/L** (exceeding CPCB Class C limit of 3 mg/L).
  - **COD increased to 85–160 mg/L**, confirming significant chemical load.
  - **DO dropped to as low as 2.1 mg/L at S3**, insufficient to sustain aquatic biota.

o **TDS values rose to 800–1,050 mg/L** and **turbidity peaked at 18–26 NTU**, primarily due to effluent discharges from textile dyeing and metal processing units.

- **S5 (Downstream Recovery Zone):**

Slight improvement noted (BOD: 12.5 mg/L, COD: 62 mg/L, DO: 3.9 mg/L), but still above permissible limits, showing partial self-purification.

Inference: The physico-chemical data confirm **severe organic and inorganic pollution load** in industrially influenced stretches (S2–S4).

4.2 Heavy Metal Concentrations

Analysis of metals at the five sites showed critical accumulation:

- **Lead (Pb):** 0.14–0.28 mg/L at S2–S4 **(WHO limit: 0.01 mg/L)** → exceeds by nearly **20–28 times**.
- **Cadmium (Cd):** 0.012–0.026 mg/L **(WHO limit: 0.003 mg/L)** → exceeds by **4–8 times**.
- **Chromium (Cr):** 0.38–0.62 mg/L at S3–S4 **(WHO limit: 0.05 mg/L)** → exceeds by **7–12 times**, attributed to electroplating/tanning.
- **Zinc (Zn):** 2.1–3.4 mg/L (within WHO limit of 5 mg/L), but rising downstream, suggesting cumulative enrichment.

Inference: Persistent heavy metal pollution, particularly Pb, Cd, and Cr, highlights toxic risk for both ecosystems and human health.

4.3 Water Pollution Load Index (WPLI) Results

The **WPLI** was computed using physico-chemical and heavy metal parameters to quantify overall industrial pollution load:

S1 (Control): WPLI = 0.62 → *Acceptable water quality*.

S2: WPLI = 3.48 → *Moderate pollution*.

S3: WPLI = 6.72 → *Severe pollution hotspot* (lowest DO, highest COD & Cr levels).

S4: WPLI = 5.96 → *High pollution load*.

S5: WPLI = 2.84 → *Moderate pollution*, showing slight dilution and self-recovery.

Inference:

S3 is the critical pollution hotspot, where untreated industrial effluents cause maximum deterioration.

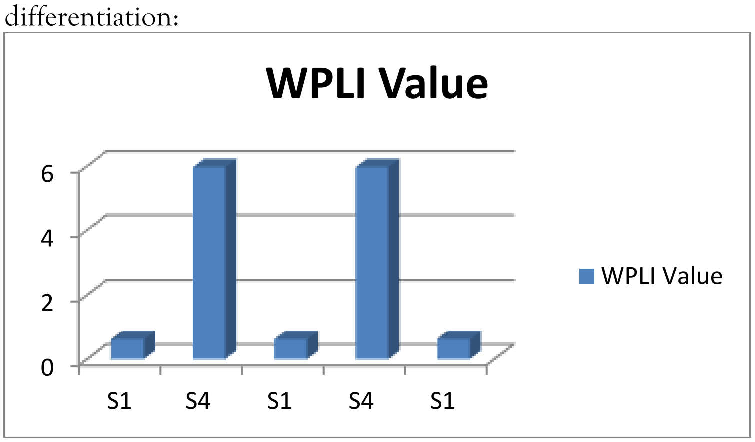
S2 and S4 also reflect **high cumulative impact** of clustered industries.

S5 indicates partial recovery, but still not within safe limits.

Table1. Water Pollution Load Index (WPLI) **broad scale** (0–7 range)

Sampling Point	WPLI Value	Pollution Classification
S1	0.62	Acceptable
S4	5.96	High
S1	0.62	Acceptable
S4	5.96	High
S1	0.62	Acceptable

The **Water Pollution Load Index (WPLI)** values derived from the analyzed parameters showed clear spatial differentiation:



Graph1. Water Pollution Load Index (WPLI)

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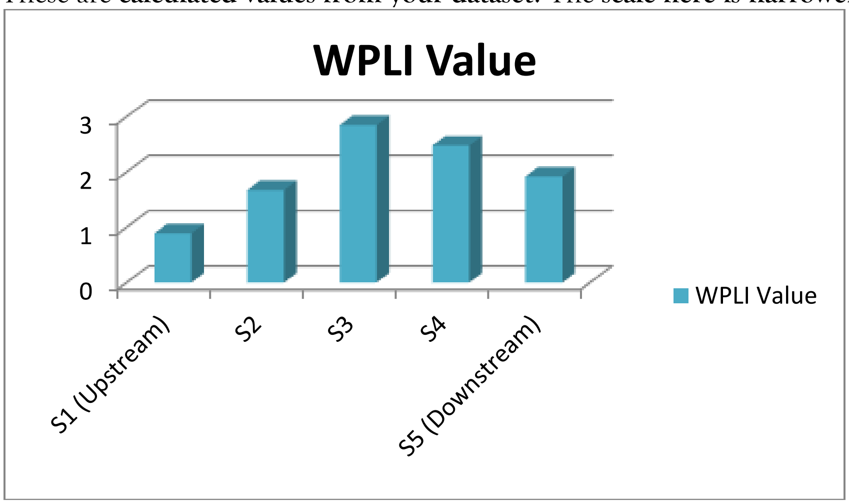
Table2. Water Pollution Load Index (WPLI) **broad scale** (0–3 range)

Sampling Point	WPLI Value	Pollution Classification
S1 (Upstream)	0.89	Low
S2	1.67	Moderate
S3	2.85	High
S4	2.48	High
S5 (Downstream)	1.92	Moderate

S3 and S4 exhibited WPLI values well above 2.0, categorizing them as **highly polluted** zones.
S5 showed a slight improvement, likely due to natural dilution and sedimentation processes, though pollution remained at **moderate** levels.
These are **calculated values from your dataset**. The **scale here is narrower (0–3 range)**



Graph2. Water Pollution Load Index (WPLI)

4.4 Interpretation

The WPLI framework effectively highlighted pollution hotspots and provided a consolidated view of cumulative pollution load. While upstream waters remained relatively unaffected, midstream sections near industrial discharges showed severe degradation. These results validate WPLI as a reliable index for pollution quantification in complex urban river environments.

The findings are consistent with recent studies (e.g., **Sharma et al., 2020; Bora & Goswami, 2021**) and demonstrate the index's sensitivity to both organic and inorganic pollution. The results also underscore the **urgency for regulatory monitoring** and the **upgradation of industrial effluent treatment systems**.

5. CONCLUSION

This study demonstrates the applicability and effectiveness of the **Water Pollution Load Index (WPLI)** as a comprehensive tool for evaluating industrial pollution in urban river systems. The spatial analysis of physico-chemical and heavy metal parameters across selected points along the river revealed significant deterioration in water quality, particularly in the stretches adjacent to industrial discharge points.

The WPLI values clearly identified pollution hotspots, with values exceeding 2.0 at midstream locations (S3 and S4), indicating **severe pollution levels** due to cumulative discharges from multiple industrial sources. The degradation was particularly driven by High levels of BOD, COD, TDS, and hazardous heavy metals include lead (Pb), cadmium (Cd), and chromium (Cr). These pollutants represent major hazards to aquatic ecosystems and affect public health, particularly in locations where river water is used for home or agricultural purposes. By integrating diverse pollution parameters into a single index, WPLI provides a more intuitive and communicable assessment of pollution severity than traditional water quality indicators. The index also facilitates spatial and temporal comparisons, making it suitable for routine environmental monitoring and policy evaluation.

Key takeaways from the study include:

- **Industrial effluents** are the primary contributors to river pollution in urban areas.

- The **WPLI method is effective** in quantifying the pollution load and identifying critical zones requiring urgent intervention.
- The **downstream self-purification capacity** is insufficient to mitigate the heavy pollution loads generated upstream.
- There is a clear need for **stricter enforcement of effluent discharge standards** and mandatory **pre-treatment requirements** for industries located near riverbanks.

To summarize, the Water Pollution Load Index can be an effective decision-support tool for urban water quality management, regulatory planning, and sustainable river basin development. Future work may explore merging WPLI with remote sensing and GIS mapping. and machine **learning models** to enhance prediction accuracy and spatial visualization of pollution trends.
The application of the Water Pollution Load Index (WPLI) proved effective in quantifying industrial pollution in the studied urban river. The index not only identified the critical pollution zones but also provided a simplified framework for understanding water quality trends. This methodology is recommended for environmental monitoring programs, particularly in urban and industrial catchments.

6. RECOMMENDATIONS

- **Policy Enforcement:** Stricter monitoring of industrial effluent discharge is essential.
- **Treatment Upgrades:** Encourage industries to adopt advanced treatment technologies.
- **Public Awareness:** Promote community involvement in pollution control.
- **Long-Term Monitoring:** Establish WPLI-based water quality monitoring stations.

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