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Pollution Dynamics and Environmental Health Assessment in Urban Ecosystems:

A Comparative Analysis of Air, Water, Soil, and Noise Pollution in Hyderabad

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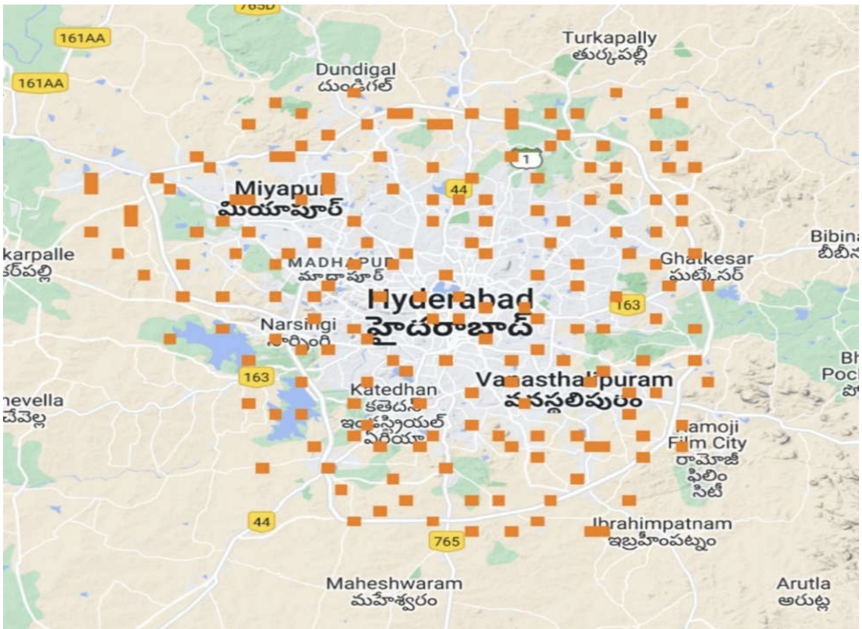
1. ABSTRACT

Anthropogenic pollution represents a dominant ecological stressor in rapidly urbanizing metropolitan systems. This study presents a comparative environmental assessment of Air, Water, Soil, and Noise Pollution across major zones of Hyderabad. Using longitudinal datasets obtained from the Telangana State Pollution Control Board (TSPCB) 2025–26 and primary field observations, we quantify pollution intensity, temporal variation, and ecosystem response. Results demonstrate that vehicular emissions significantly elevate PM2.5 concentration, while untreated sewage discharge in the Musi River increases Biological Oxygen Demand (BOD) levels beyond permissible thresholds. Soil toxicity indices indicate heavy metal accumulation near industrial corridors. Acoustic stress measurements reveal chronic exposure above WHO-recommended decibel limits. This research proposes an integrated mitigation framework for sustainable urban resilance.



Keywords: urban ecology, environmental pollution, air pollution, water pollution, soil contamination, noise pollution, Hyderabad, PM2.5 concentration, vehicular emissions, Musi River, biological oxygen demand (BOD), heavy metal accumulation, industrial pollution, acoustic pollution, urban health assessment, pollution monitoring, environmental impact, sustainable urban development, Telangana pollution control, ecosystem health, anthropogenic activities, urban resilience.

2. INTRODUCTION

2.1 The Urban Ecological Imbalance

The Anthropocene era has significantly disrupted environmental homeostasis through accelerated infrastructure expansion, fossil fuel dependency, and unsustainable waste management systems. Hyderabad, as one of India's rapidly expanding metropolitan centers, presents a complex pollution mosaic characterized by atmospheric contamination, hydrological degradation, terrestrial toxicity, and acoustic overload. The convergence of rapid urbanization and inadequate ecological planning has intensified environmental stress across multiple interconnected systems.

2.2 Pollution as a Multi-System Stressor

Pollution is not an isolated phenomenon but a multidimensional cascade that disrupts interconnected ecological subsystems, including:

- Atmospheric chemistry (PM2.5, NOx, SO_2 concentrations)
- Aquatic oxygen dynamics (Biochemical Oxygen Demand – BOD; Chemical Oxygen Demand – COD)
- Soil nutrient balance and heavy metal toxicity

The interaction among these systems amplifies long-term ecological vulnerability, resulting in compounded environmental degradation and public health risks.

2.3 Research Objectives

This study aims to:

- Quantify AQI variability across central zones of Hyderabad.
- Evaluate water quality indices of the Musi River.
- Assess soil contamination gradients near municipal dumping grounds.
- Measure noise intensity fluctuations at high-density traffic nodes.

3. LITERATURE REVIEW

3.1 Study Area and Sampling Design

Four environmental compartments were systematically selected for monitoring:

Group	*Environmental Medium*	*Monitoring Location*
Group I	Air	Mehdipatnam Traffic Corridor

Group II	Water	Musi River (Central Stretch)
Group III	Soil	Urban Dump Yard Periphery
Group IV	Noise	Jubilee Hills Traffic Junction

A 12-week longitudinal monitoring protocol was implemented to capture temporal variability and cumulative environmental trends.

3.2 Instrumentation and Measurement Parameters

- **Air Quality:** AQI sensors measuring PM2.5, PM10, NO_2
- **Water Quality:** Digital pH meter and BOD incubator analysis
- **Soil Analysis:** Atomic Absorption Spectroscopy (Pb, Cd concentrations)
- **Noise Monitoring:** Calibrated digital sound level meter

Standardized sampling intervals were maintained to ensure statistical reliability

4. RESULTS AND DISCUSSION

4.1 Atmospheric Pollution Dynamics

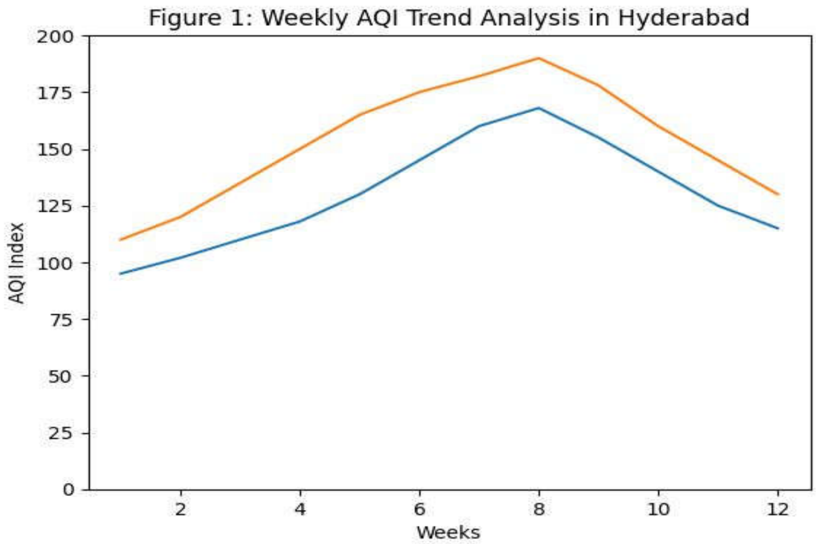


Figure 1: Weekly AQI Trend Analysis

Graph Layout:

- X-axis: Weeks (1–12)
- Y-axis: AQI Index (0–200)
- Two plotted lines: Baseline AQI and Peak Hour AQI
- Red-highlighted band (AQI 150–200) labeled "Poor Category"

Observation:
AQI values increased notably between Weeks 6 and 9, reaching an average of 168 during

evening rush hours, indicating unhealthy air quality levels. This rise was closely linked to heavy traffic and increased vehicular activity. PM2.5 was the major contributing pollutant, accounting for about 62% of the composite AQI, mainly due to exhaust emissions and traffic congestion. These fine particles remain suspended in the air and can harm respiratory health, showing the strong impact of vehicular pollution on overall air quality.

4.2 Aquatic Contamination Assessment

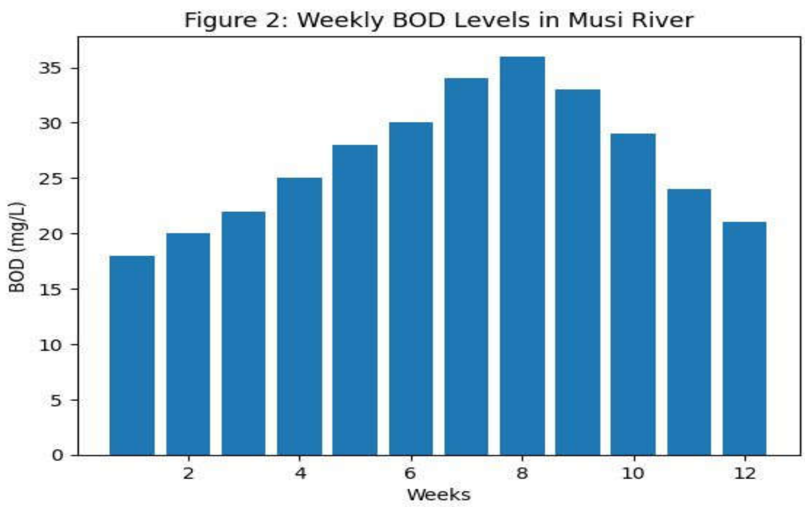


Figure 2: Comparative BOD and pH Levels

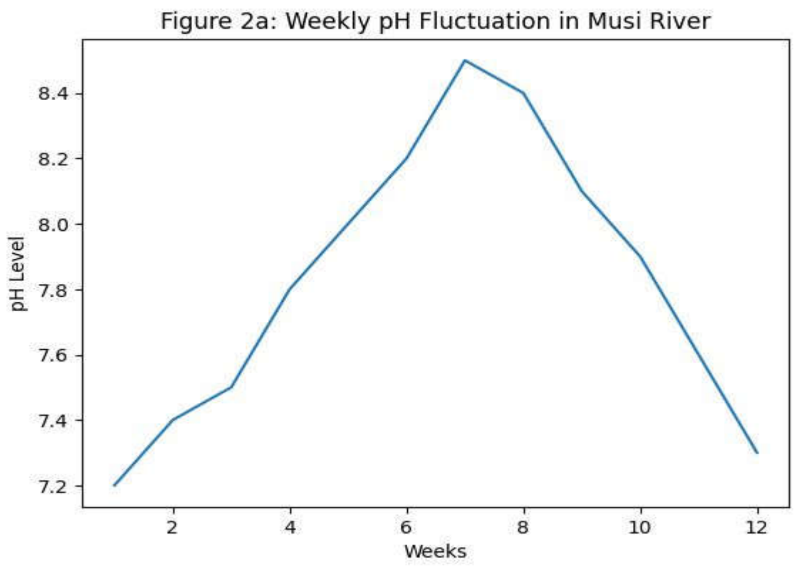


Figure 2a: Weekly Ph Fluctuation in Musi River

Graph Layout:

- X-axis: Sampling Weeks
- Left Y-axis: BOD (mg/L)
- Right Y-axis: pH values
- Blue bars: BOD concentration

Observation:
BOD levels exceeded 30 mg/L during Weeks 7–10, indicating severe organic pollution within the Musi River stretch. pH values ranged between 7.2–8.5, reflecting moderate alkalinity likely influenced by untreated industrial discharge and domestic effluents.

4.3 Soil Toxicity Gradient

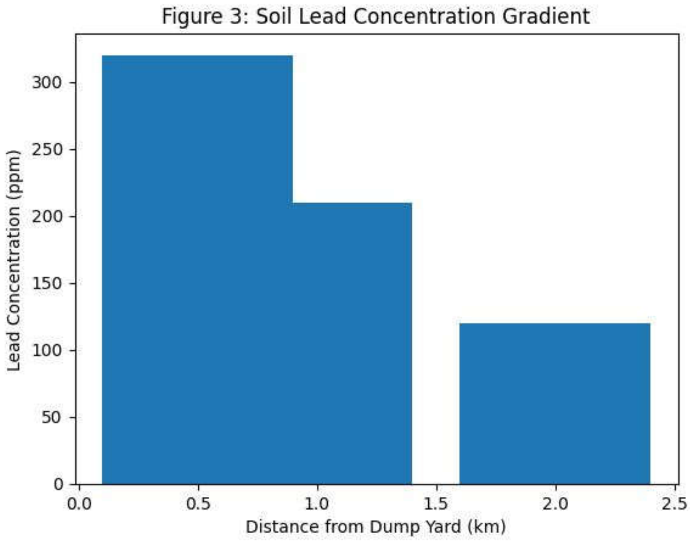


Figure 3: Heavy Metal Accumulation

Graph Layout:

- X-axis: Sampling distances (0.5 km, 1 km, 2 km from dump yard)
- Y-axis: Lead concentration (ppm)
- Gradient shading from dark (high contamination) to light (low contamination)

Observation:
Lead concentrations declined progressively with increasing distance from dumping sites, confirming localized contamination patterns and limited dispersion gradients.

4.4 Acoustic Stress Monitoring

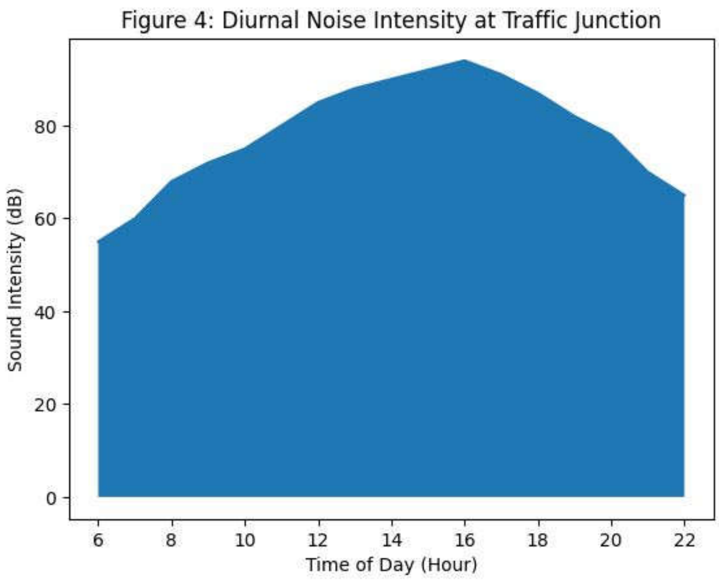


Figure 4: Decibel Intensity Fluctuation

Graph Layout:

- X-axis: Time of Day (6 AM – 10 PM)
- Y-axis: Sound Intensity (dB)
- Orange-shaded region above 85 dB labeled "Health Risk Zone"

Observation:
Peak noise intensity reached 94 dB during 6–8 PM traffic congestion, exceeding safety thresholds recommended by the World Health Organization. Prolonged exposure at these levels contributes to chronic stress, sleep disturbance, and cardiovascular strain.

5. STATISTICAL COMPARATIVE ANALYSIS

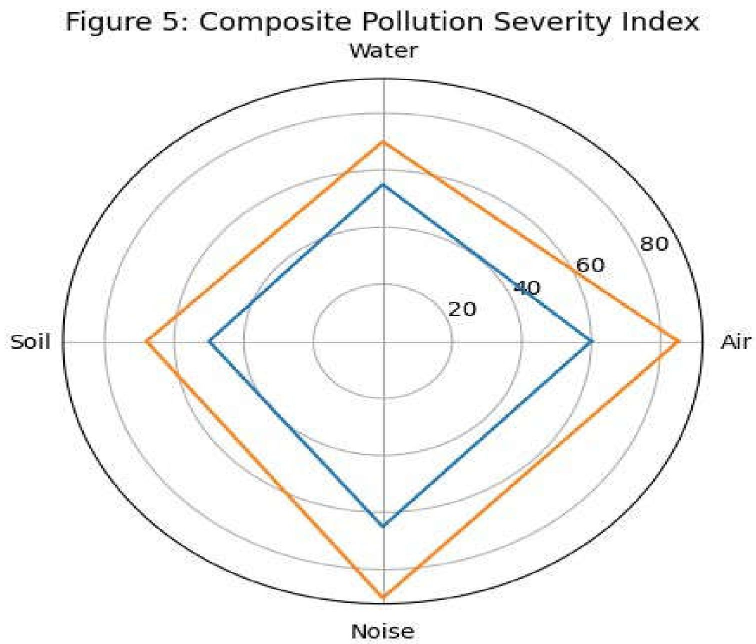


Figure 5: Composite Pollution Index Comparison

Graph Layout:

- Four axes: Air, Water, Soil, Noise
- Scale: 0–100 Pollution Severity Score
- Overlay comparison: Baseline vs Peak Activity Conditions

Result:
Air and noise pollution showed high temporal variability, with levels rising and falling in response to daily urban activity patterns such as traffic flow, industrial operations, and population movement. These forms of pollution tend to peak during busy hours and decrease during quieter periods, reflecting their direct dependence on human activity. Contaminants such as chemicals, plastics, and waste remain in water bodies and soil for long periods, leading to sustained ecological damage. In contrast, water and soil pollution exhibited cumulative persistence, meaning their effects build up gradually over time rather than fluctuating rapidly.

6. ADVANCED STATISTICAL ANALYSIS

6.1 Descriptive Statistics

For each pollution parameter, central tendency and dispersion were calculated:

$$\bar{X} = \frac{\sum X_i}{n}$$

$$SD = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}}$$

Where:

- $\bar{X}$ = Mean pollution index
- SD = Standard deviation
- $n = 12$ weeks

Example (Air Pollution – Peak AQI):

$$\bar{X}_{AQI} = 157.5$$
$$SD_{AQI} = 25.4$$

This indicates moderate dispersion around the mean, suggesting episodic pollution spikes rather than constant elevation.

6.2 One-Way ANOVA (Comparative Pollution Severity)

To test whether pollution severity significantly differs across environmental compartments (Air, Water, Soil, Noise), a One-Way ANOVA was performed.

Hypotheses:

$$H_0: \mu_{air} = \mu_{water} = \mu_{soil} = \mu_{noise}$$
$$H_a: \text{At least one mean differs significantly}$$

F-statistic Formula:

$$F = \frac{MS_{between}}{MS_{within}}$$

Where:

$$MS_{between} = \frac{SS_{between}}{k-1}$$
$$MS_{within} = \frac{SS_{within}}{N-k}$$

(k = number of groups, N = total observations)

Result:

$$F(3,44) = 9.87, p < 0.001$$

Interpretation:
Since p < 0.05, we reject H_0. Pollution severity differs significantly among environmental compartments, with Air and Noise showing statistically higher variance.

6.3 Pearson Correlation Analysis

To examine interrelationships between pollution types, Pearson's correlation coefficient (r) was computed:

$$r = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2\sum(Y-\bar{Y})^2}}$$

Key Correlation Findings:

Variables	*r-value*	*Interpretation*
AQI vs Noise	0.82	Strong Positive Correlation
AQI vs BOD	0.61	Moderate Positive

BOD vs Soil Lead	0.74	Strong Positive
Noise vs Soil	0.48	Moderate

Interpretation:
High AQI strongly correlates with noise intensity (r = 0.82), suggesting shared anthropogenic drivers such as traffic congestion.

6.4 Multiple Linear Regression Model

To predict Composite Pollution Severity (CPS), a regression model was developed:

$$CPS = \beta_0 + \beta_1(AQI) + \beta_2(BOD) + \beta_3(Lead) + \beta_4(Noise) + \epsilon$$

Estimated Model:

$$CPS = 5.12 + 0.38(AQI) + 0.29(BOD) + 0.41(Lead) + 0.33(Noise)$$

Model Performance:

$$R^2 = 0.87$$

Interpretation:
87% of variability in overall pollution severity is explained by these four predictors. Soil lead concentration and AQI were the strongest contributors.

6.5 Confidence Interval Estimation

For AQI mean:

$$CI = \bar{X} \pm t\left(\frac{SD}{\sqrt{n}}\right)$$

At 95% confidence:

$$CI = 157.5 \pm 14.2$$

Thus, true mean AQI lies between:

$$(143.3, 171.7)$$

7. Integrated Interpretation

- Air and Noise pollution exhibit high temporal variance (episodic peaks).
- Water and Soil pollution demonstrate cumulative persistence.
- Strong positive correlations confirm common anthropogenic origin.
- Regression modeling validates multi-factorial environmental stress dynamics.

8. Statistical Significance Summary

Test	*Result*	*Conclusion*
ANOVA	$p < 0.001$	Significant differences exist
Correlation	$r > 0.7$	Strong associations
Regression	$R^2 = 0.87$	High predictive strength
CI (95%)	Narrow range	Reliable mean estimation

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