

Analysis of Air Quality Index (AQI) Trends in Kathmandu Valley

1. Executive Summary

This report presents a comprehensive time-series analysis of the daily Air Quality Index (AQI) in the Kathmandu Valley over the past five years. By decomposing the time series into **Trend**, **Seasonal**, and **Residual** components, we have identified a clear **annual cycle** of pollution and quantified the underlying **long-term trend**. The analysis confirms that Kathmandu experiences a severe, predictable seasonal pollution peak, particularly in the winter/pre-monsoon months, and suggests that while annual variability is high, the underlying pollution burden remains a significant public health concern.

2. Methodology: Time Series Decomposition

The Air Quality Index (AQI) time series data was analyzed using the **Seasonal-Trend Decomposition using LOESS (STL)** method. This method breaks down the observed data (Y_t) into three main additive components:

$$Y_t = \text{Trend}_t + \text{Seasonality}_t + \text{Residual}_t$$

where:

- **Trend** (Trend_t): Represents the long-term progression of the series (e.g., changes over the five-year period), smoothed to remove short-term fluctuations.
- **Seasonality** (Seasonality_t): Captures the repeating cycle of high and low AQI values that occurs regularly every year.
- **Residual** (Residual_t): Represents the remaining irregular or random variation in the data not explained by the trend or seasonal components (e.g., specific events like major wildfires or temporary weather anomalies).

3. Results and Interpretation of Plots

The provided plots vividly illustrate the distinct components of Kathmandu's AQI:

3.1. Observed Data (Top Plot)

- **Visual Observation:** The original AQI plot shows a highly erratic series dominated by large, recurring peaks and troughs.
- **Key Finding:** The data is strongly **non-stationary**, confirming a clear, **annual cyclical pattern**. The high peaks consistently occur during the dry/winter months (typically December to April), while the lowest values occur during the monsoon season (typically June to September).

3.2. Seasonal Component (Third Plot)

- **Explanation:** This plot isolates the *average* annual pattern of air quality.
- **Key Findings:**
 - **Peak Season:** A large positive seasonal component is consistently observed during the winter and early pre-monsoon period. This indicates that **air quality is predictably at its worst during these months**, likely due to factors such as temperature inversion trapping pollutants, lower precipitation, and increased emissions from sources like biomass burning and brick kilns.
 - **Clean Season:** A large negative seasonal component is consistently observed during the monsoon season. This indicates that **air quality is predictably at its best** during these months, likely due to high rainfall washing out particulate matter (PM) and increased wind dispersion.
 - **Magnitude:** The magnitude of the seasonal variation is substantial, confirming seasonality as the **dominant factor** determining the daily AQI value.

3.3. Trend Component (Second Plot)

- **Explanation:** This plot reveals the underlying, smoothed change in the AQI over the five-year period.
- **Key Findings:**
 - **Overall Stagnation/Slight Decline:** Over the five-year period, the trend line appears relatively **flat**, with potentially a minor, very slight downward slope. This suggests that despite the high annual fluctuations, the fundamental long-term air pollution problem in Kathmandu has **not significantly improved or worsened** over the study period.
 - **Implication:** Efforts to control the core, non-seasonal sources of pollution (like vehicular emissions, construction dust, and industrial output) may be counterbalanced by factors like rapid urbanization or transboundary pollution, leading to a persistent baseline pollution level.

3.4. Residual Component (Bottom Plot)

- **Explanation:** This plot represents the unpredictable, high-frequency "noise" remaining after the seasonal and trend patterns are removed.
- **Key Findings:**
 - **High Variability:** The residuals are not uniformly distributed and show several large, isolated spikes (both positive and negative).
 - **Positive Spikes:** The significant positive spikes correspond to specific, high-pollution events not captured by the average seasonality (e.g., extreme regional wildfires, localized burning events, or severe, prolonged temperature inversion episodes in a given year).
 - **Implication:** The non-random appearance of the residuals suggests that **external, episodic factors** still contribute significantly to daily air quality. These events, likely corresponding to exceptional weather or widespread pollution sources (e.g., forest fires), can cause the AQI to spike far above its predictable seasonal high.

4. Discussion for Publication

4.1. The Dominance of Seasonality

The analysis underscores the critical role of meteorological and topographical factors (the Kathmandu Valley's basin-like structure and winter inversion) in concentrating pollutants. The strong and consistent seasonal component is the most significant driver of AQI variability, making pollution a predictable, **annual public health crisis**. This necessitates a seasonal-specific policy response, focusing on high-emission sources during the dry winter and pre-monsoon months.

4.2. Persistent Baseline Pollution (Trend)

The near-flat trend line is a critical, and worrying, finding. It implies that while the severity of specific pollution events may vary year-to-year, the **underlying, chronic exposure risk has not been mitigated**. This points to a failure to control persistent, year-round pollution sources such as vehicular emissions, construction dust, and local waste burning, which continue to set the baseline for air quality violation. The concentration of PM2.5 and PM10 remains the primary concern.

4.3. Implications of Residual Events

The presence of large positive residuals (outliers) confirms that air quality in Kathmandu is highly vulnerable to **episodic, non-seasonal sources** like regional biomass burning/wildfires and extreme weather conditions. These events result in short-duration, high-intensity pollution episodes that push the AQI into the "Very Unhealthy" or "Hazardous" categories, requiring an independent and rapid emergency response strategy.

5. Conclusion

The time-series decomposition of Kathmandu's AQI confirms a pattern of **strong, predictable seasonal pollution** superimposed on an **unmitigated long-term baseline**. Future research should focus on correlating the residual spikes with specific meteorological phenomena and emission inventories (e.g., forest fire data) to better understand and predict extreme events. Policy must target both the chronic, year-round sources (to lower the trend) and the seasonally amplified sources (to flatten the seasonal component).