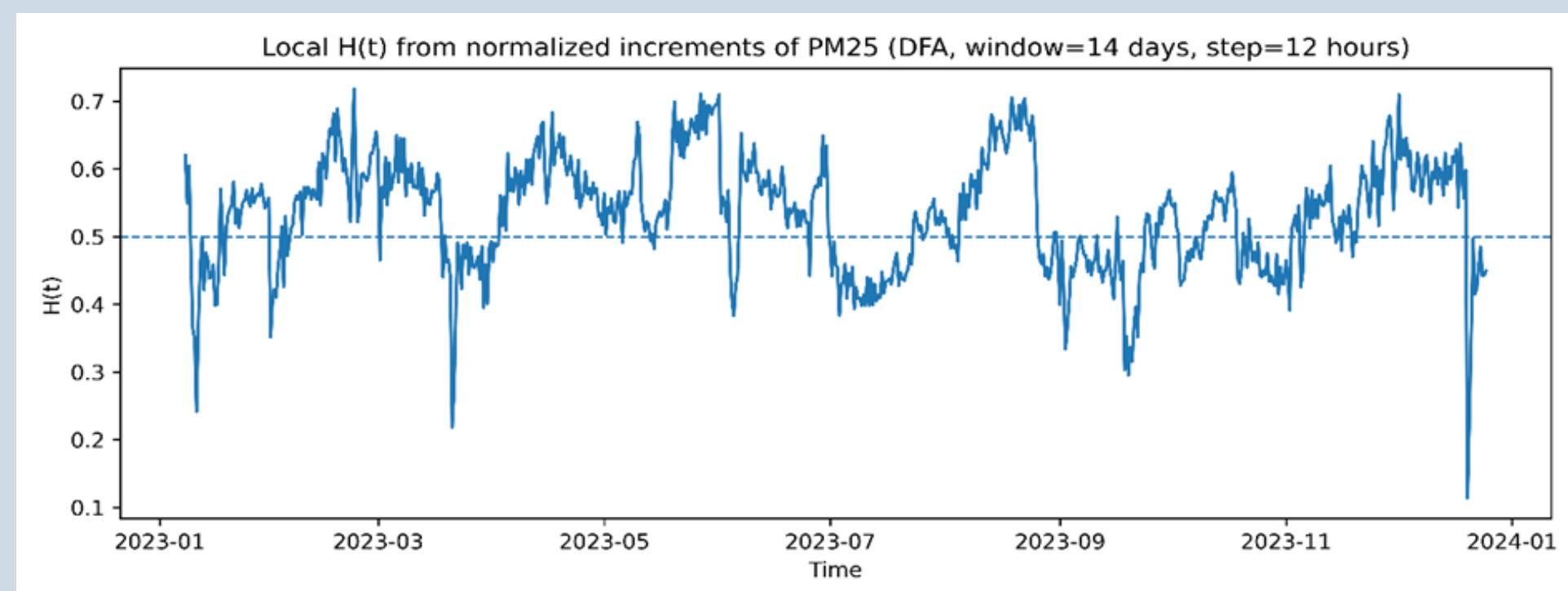
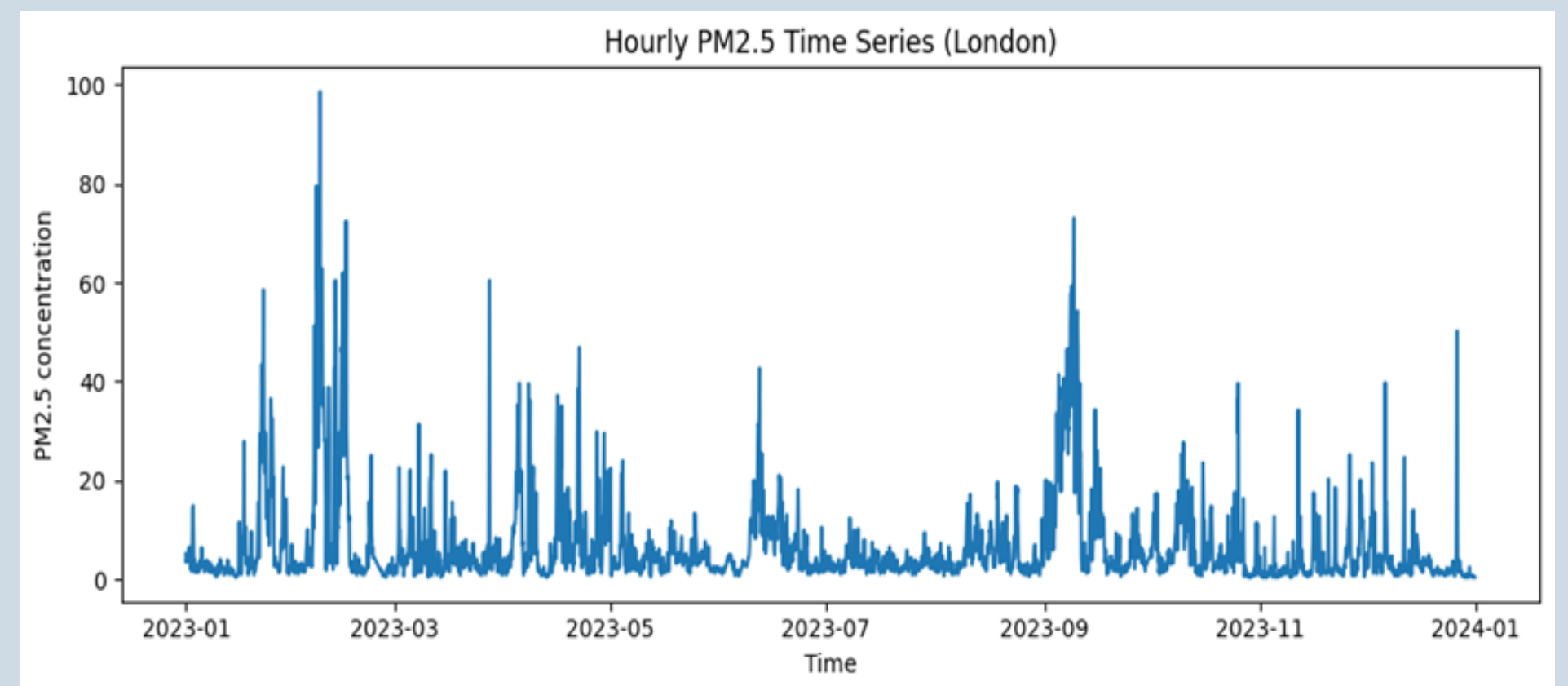


The study investigates the fractal properties of air pollution time series based on hourly measurements of PM<sub>2.5</sub>, PM<sub>10</sub>, and NO<sub>2</sub> concentrations in London for the period 2022-2023. The analysis was performed using **detrended fluctuation analysis combined with a sliding window** approach to evaluate the temporal variability of the local Hurst exponent.

The results demonstrate that time series exhibit pronounced **non-stationary behavior and complex fractal dynamics characterized by transitions between persistent and anti-persistent regimes.**



## Introduction

**Air pollution is a major environmental problem** that affects public health and urban environments. Air quality monitoring systems measure key pollutants, including fine particulate matter (diameter less than 2.5 micrometers) PM<sub>2.5</sub>, coarser particulate matter (diameter less than 10 micrometers) PM<sub>10</sub>, nitrogen dioxide NO<sub>2</sub>, sulfur dioxide, and ground-level ozone.

**The aim of this study** is to analyze the fractal properties of time series of atmospheric pollutant concentrations and to investigate the temporal variability of these properties. To achieve this goal, the detrended fluctuation analysis method is applied to identify long-term correlations, scaling behavior, and possible transitions between different pollution regimes.

## Sliding Window Hurst Estimation

A **self-similar (fractal) time series** is a time series whose statistical properties remain unchanged under rescaling of the time axis, up to a corresponding change in amplitude, typically characterized by a scaling exponent (**the Hurst exponent H**).

A **sliding monitoring** approach for fractal characteristics is proposed and implemented. The original time series is analyzed in sequentially shifted windows of fixed length with a specified overlap step. In each window, the **detrended fluctuation analysis (DFA) method** is applied to compute Hurst exponent. The resulting estimates form new time series of local Hurst exponent reflect the dynamics of the correlation structure and scaling properties of the original data

## Results and Interpretation of H Dynamics

Time series	H(t) variation range	Dominant dynamic regime	Interpretation of fractal structure	Structural features
PM <sub>2.5</sub>	~0.30-0.70	close to random and moderately persistent	H is often around 0.5-0.6, indicating moderate long-term correlations	H changes smoothly; periods of increase/decrease align with PM <sub>10</sub> dynamics
PM <sub>10</sub>	~0.30-0.70	close to random and moderately persistent	H is often around 0.5-0.6, indicating moderate long-term correlations	High consistency with PM <sub>2.5</sub> ; changes occur synchronously
NO <sub>2</sub>	~0.25-0.70	often anti-persistent	Many H(t) values < 0.5, indicating chaotic dynamics and weak long-term memory	Changes do not coincide with PM <sub>2.5</sub> /PM <sub>10</sub> ; more abrupt fluctuations

The results show that tracking the Hurst exponent provides information about air pollution time series beyond concentration levels. Its variations reflect transitions between dynamical regimes and **may indicate structural changes in pollution formation processes.**

A key application of fractal analysis is early detection of regime shifts: **abrupt changes in the Hurst exponent can signal changes in pollution dynamics before critical concentration levels** are reached. When the Hurst exponent exceeds 0.5, the presence of long-term dependence makes future values more predictable, allowing fractal analysis to complement traditional forecasting approaches.

**Monitoring the Hurst exponent also enables detection of anomalies** based on changes in dynamics rather than concentrations alone. Even moderate pollution levels combined with irregular behavior may indicate unusual conditions. In addition, long-term patterns of the Hurst exponent provide insight into system stability, distinguishing between predictable and highly sensitive environmental dynamics.