Air Quality Monitoring During Diwali

Location: Gurgaon, Haryana (Delhi NCR)

Time Duration: October 18 – October 22

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Air Quality Monitoring During Diwali in Gurgaon: Data Collection, Calibration, Cleaning, and Analysis

Contents

1 Introduction

Air quality monitoring is especially important in regions where pollution levels fluctuate rapidly due to human activity. Gurgaon experiences some of the highest pollution peaks in India, particularly during the days surrounding Diwali. Firecrackers, increased vehicle movement, and stagnant weather conditions all contribute to sharp rises in particulate matter and harmful gases during this time.

This project focuses on measuring five key air-quality parameters - CO_2, NO_2, PM ($PM_{2.5}$/PM_{10}), temperature, and humidity - using a low-cost sensor system based on the ESP32 microcontroller. Data was collected across multiple days before, during, and after Diwali in order to capture short-term pollution spikes and observe how quickly air quality deteriorates and recovers.

The report outlines the system design, describes the collected dataset, and provides analysis of trends across the different pollutants. Visualizations and comparisons across the measurement periods highlight how Diwali-related activities influence Gurgaon's air quality and how environmental factors interact with pollutant levels.

2 System Design

2.1 Hardware Setup Used

- ESP32 Dev Module
- MiCS-2714 (NO_2 sensor)
- ACD10 (CO_2 sensor)
- Nova SDS011 (PM sensor)
- AHT10 (Temperature + Humidity)

3 Data Collection Methodology

3.1 Deployment Setup

- Height: ∼2–3 m above ground to represent the breathing zone and to reduce road splash/ground dust influence.
- Location: Residential area in Gurgaon, Haryana (Delhi NCR) (coordinates: 28.456392, 77.056818) in a balcony (open air).
- Shelter: Ceiling above the node to prevent direct sunlight and rain.
- Sampling cadence: 15 seconds raw samples.
- Data being sent to our dashboard using MQTT as MQTT uses significantly less power than HTTP.

- Deployment timeframe: Diwali Time — October 18 to October 22.

4 Sensor Specifications

4.1 Ranges of Each Sensor

Sensor	Range
SDS011 (PM2.5 and PM10)	0 to 999 μg/m^3
MiCS-2714 (NOx MOS Sensor)	0.05 to 10 ppm
ACD10 (NDIR CO_2 Sensor)	400 to 5000 ppm
AHT10 (Temperature & Humidity)	Temp: 5°C to 45°C; Humidity: 20–95%

5 Sensor Calibration

5.1 Calibration Process for SDS011

Accurate sensor calibration is essential to ensure that the readings from the air quality monitoring system are precise. This section outlines the calibration methods used for the SDS011 PM sensor.

To calibrate the SDS011 PM sensors, the system used an Aeroqual sensor as a reference device. The following steps outline the calibration procedure:

- **Reference Device:** The Aeroqual sensor, known for its high accuracy, was used as the benchmark for comparison.
- **Setup and Duration:**
  - The SDS011 sensors and the Aeroqual device were placed in the same controlled environment to minimize external influences on the readings.
  - The calibration period lasted for 24 hours to allow the sensors to stabilize and provide consistent data.
  - Data were recorded at one-minute intervals throughout the entire duration.
- **Data Collection:**
  - Both the SDS011 sensors and the Aeroqual sensor collected PM2.5 and PM10 readings every minute.
  - The data were compiled and analyzed using a linear regression approach to derive calibration parameters.
- **Calibration Results:**
  - PM2.5 Calibration:
    * Slope: 1.15

    - Intercept: -0.69
  - PM10 Calibration:
    - Slope: 1.05
    - Intercept: -1.08
- **Error Percentages:**
  - PM2.5 error: 12.4%
  - PM10 error: 1.17%

6 Data Cleaning and Processing

After collecting the raw sensor data during the Diwali deployment in Gurgaon, we performed systematic preprocessing to ensure the dataset was reliable, free of corrupt entries, and suitable for further analysis. The cleaning process involved timestamp validation, removal of impossible physical readings, elimination of sensor warm-up artefacts, and discarding values outside the manufacturer-specified operational ranges.

6.1 Timestamp Validation

- Removed records with missing timestamps, duplicated timestamps, or incorrect format.
- Dropped entries where timestamps were out of chronological order (caused by resets or power drops).
- Removed values collected during the first 2–3 minutes after boot (sensor warm-up period).

6.2 SDS011 (PM2.5 & PM10) Data Cleaning

Physical and specification-based rules applied:

- Valid PM2.5/PM10 range: 0–999 $\mu g/m^3$.
- Removed negative PM values.
- Removed PM10 $<$ PM2.5 (physically inconsistent).
- Removed sudden spikes $> 800\ \mu g/m^3$ lasting one record.
- Removed long periods of exactly 0.0 values (fan/laser dropout).

6.3 MiCS-2714 (NOx) Data Cleaning

- Removed raw ADC < 0 V or $>$ supply voltage.
- Removed Rs $< 100\ k\Omega$ or Rs $= 0$.
- Removed readings showing impossible sudden factor changes ($5\times$ within 1 second).

6.4 ACD10 (CO_2) Data Cleaning

- Removed $CO_2 < 350$ ppm.
- Removed $CO_2 > 10{,}000$ ppm.
- Removed single-step jumps $>$3000 ppm.
- Removed flatlined outputs lasting too long.

6.5 AHT10 (Temperature & Humidity) Data Cleaning

- Removed temperature $<$ –40°C or $>$ 85°C.
- Removed humidity $<$ 0% or $>$ 100%.
- Removed sudden unrealistic jumps (±10°C / s).
- Removed long 0% or 100% humidity periods.

6.6 Outlier Removal Using Statistical Checks

- Values beyond $3 \times$ IQR or outside mean $\pm\, 4\sigma$ were flagged.
- Points kept only if similar consecutive values occurred (real event).

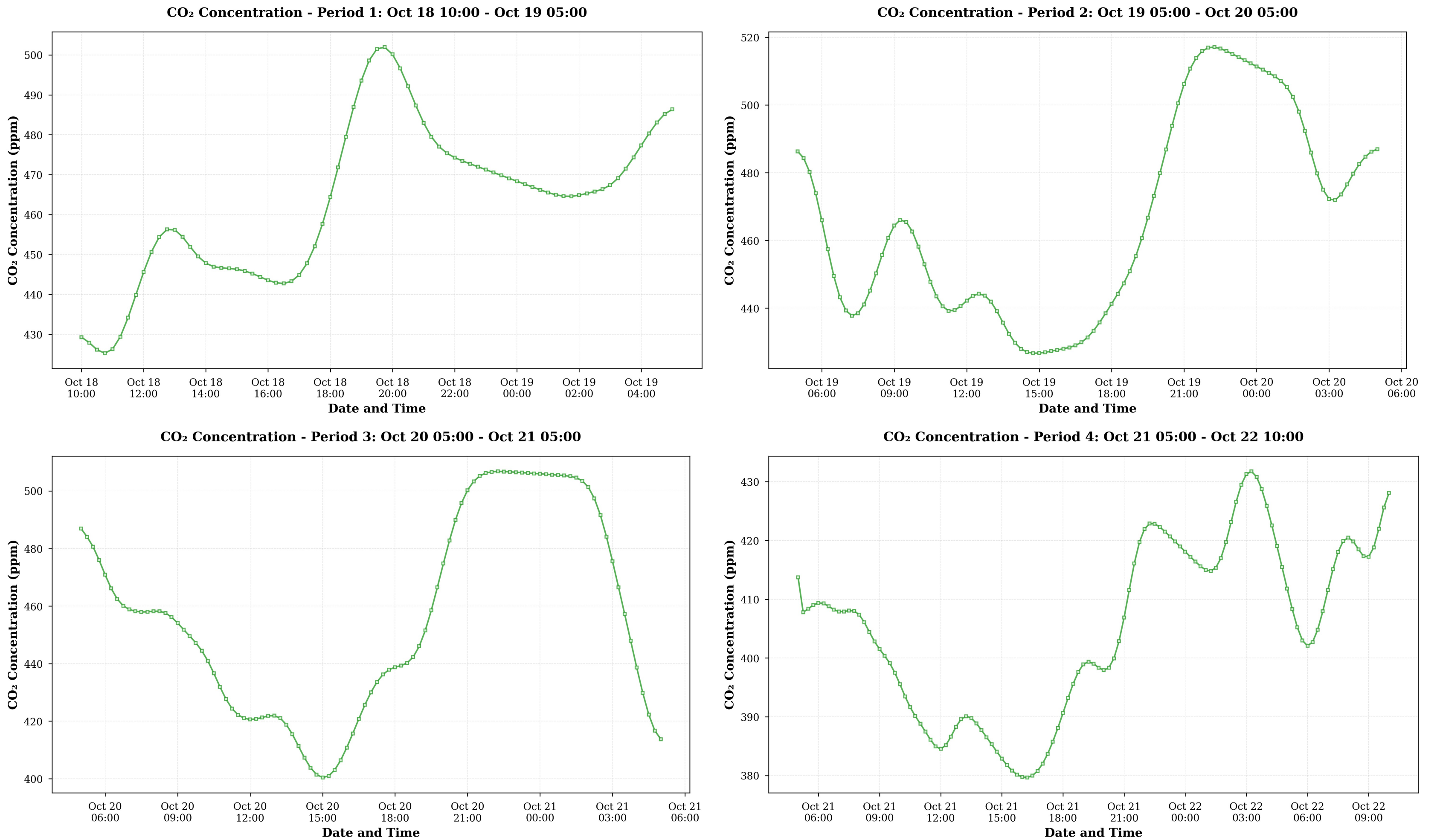
7 Data Analysis and Visualisation

This section presents plots for each pollutant across the four measurement periods:

- Period 1: 18–19 October
- Period 2: 19–20 October
- Period 3: 20–21 October
- Period 4: 21–22 October

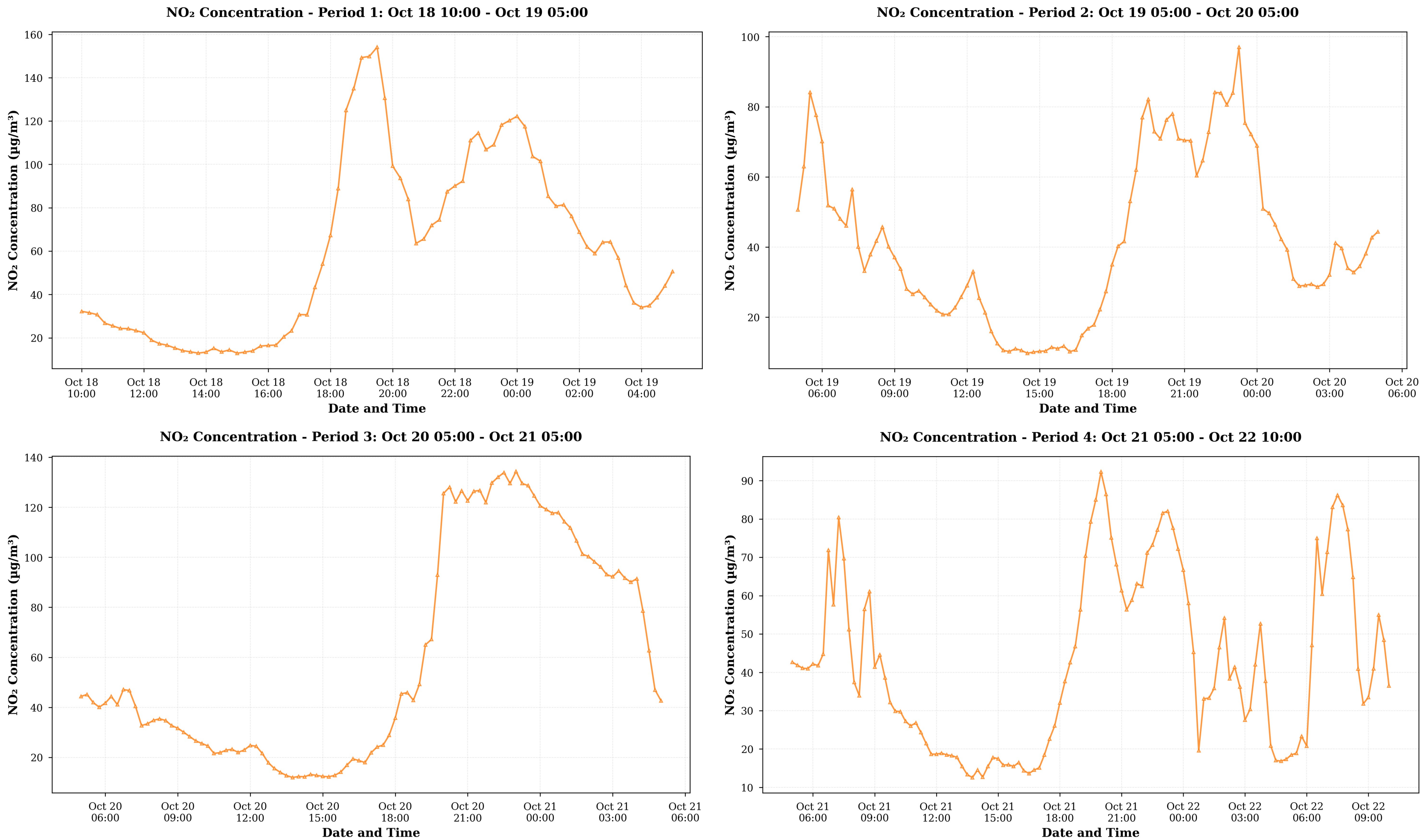
Each pollutant is displayed in landscape mode on a dedicated page.

CO_2 Trends Across All Periods



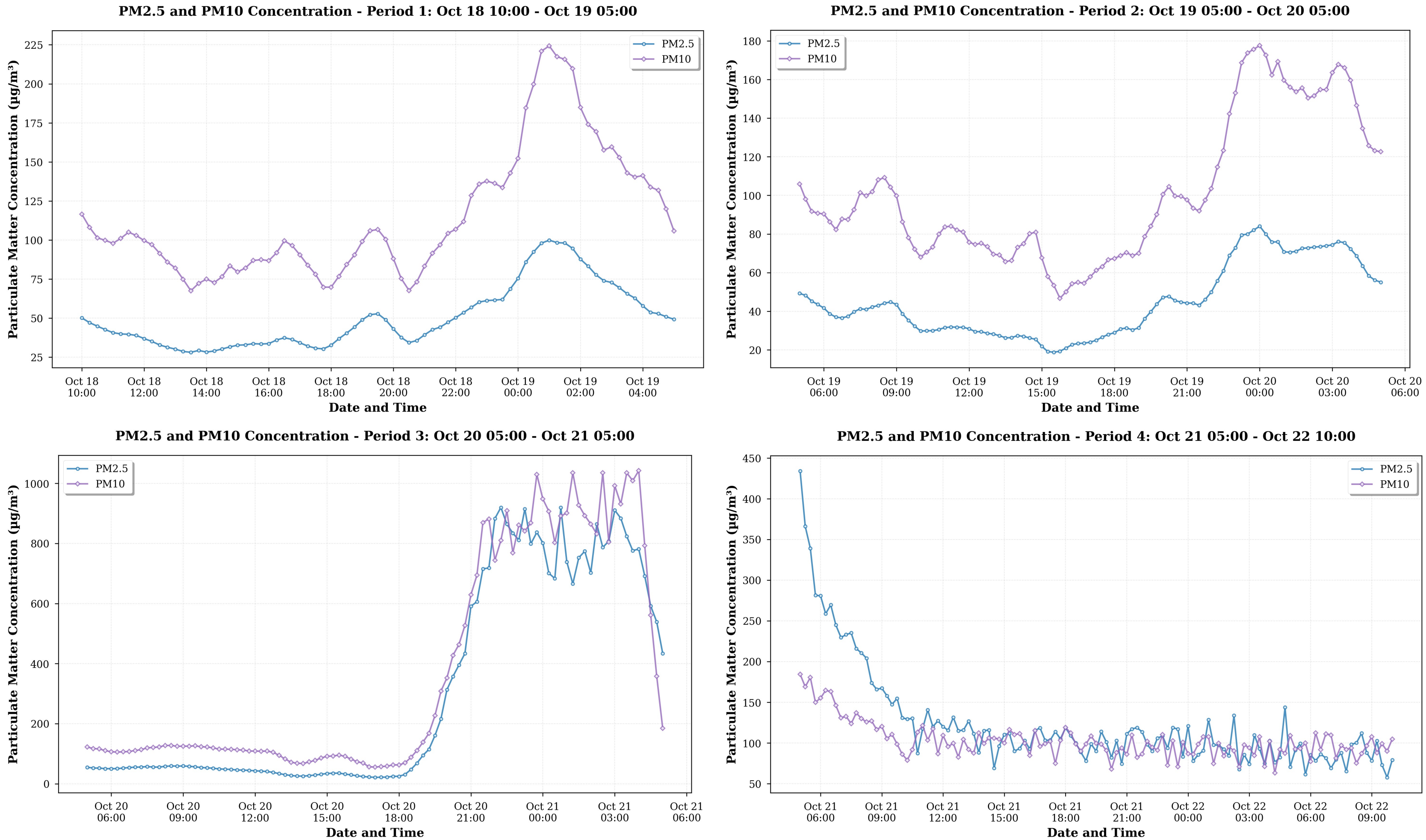
CO_2 concentration plots for Periods 1–4 (period1 = 18–19 Oct, period2 = 19–20 Oct, period3 = 20–21 Oct, period4 = 21–22 Oct).

NO_2 Trends Across All Periods



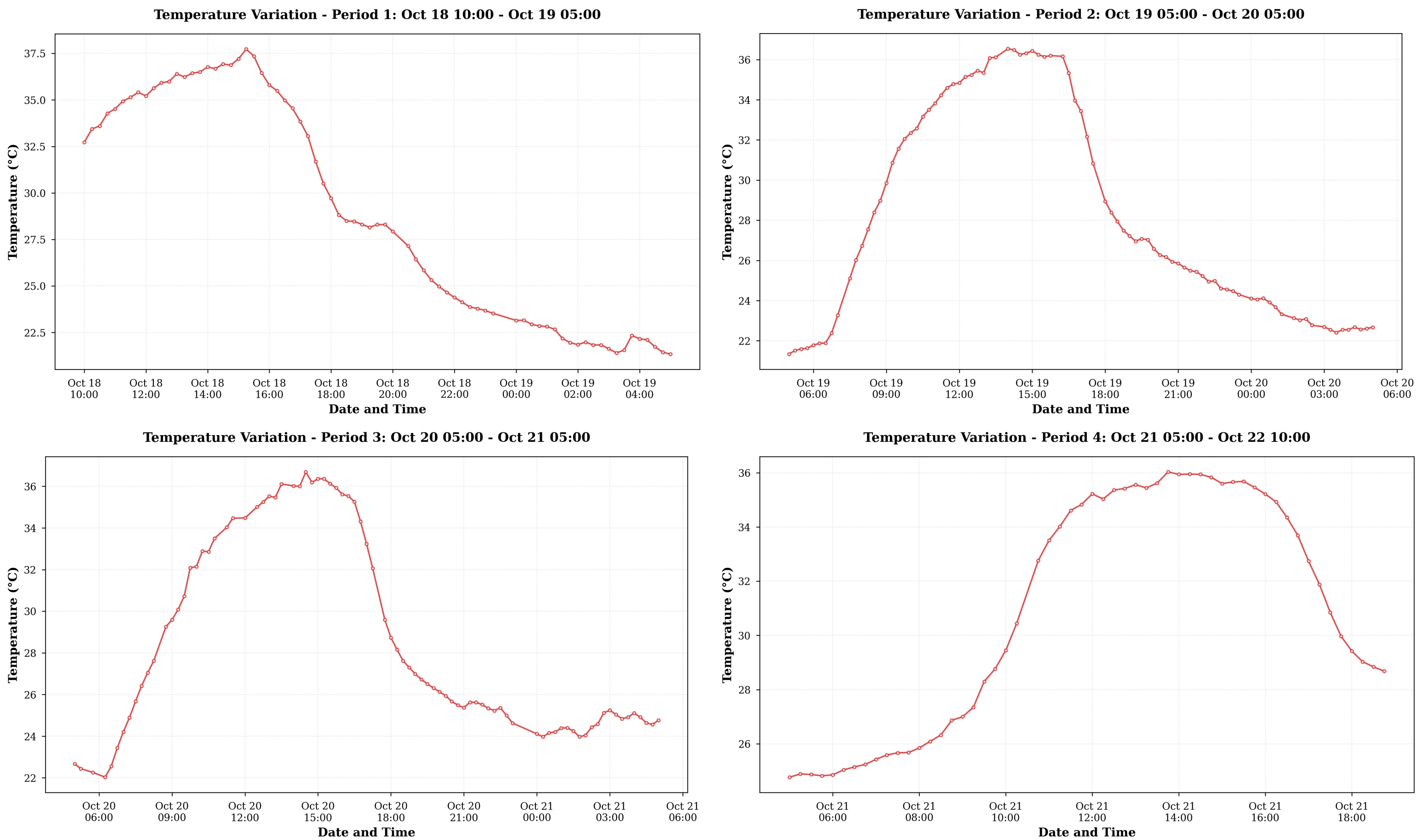
NO_2 concentration plots for Periods 1–4.

PM Trends Across All Periods



PM2.5/PM10 plots for Periods 1–4. Values are in μg/m^3.

Temperature Trends Across All Periods



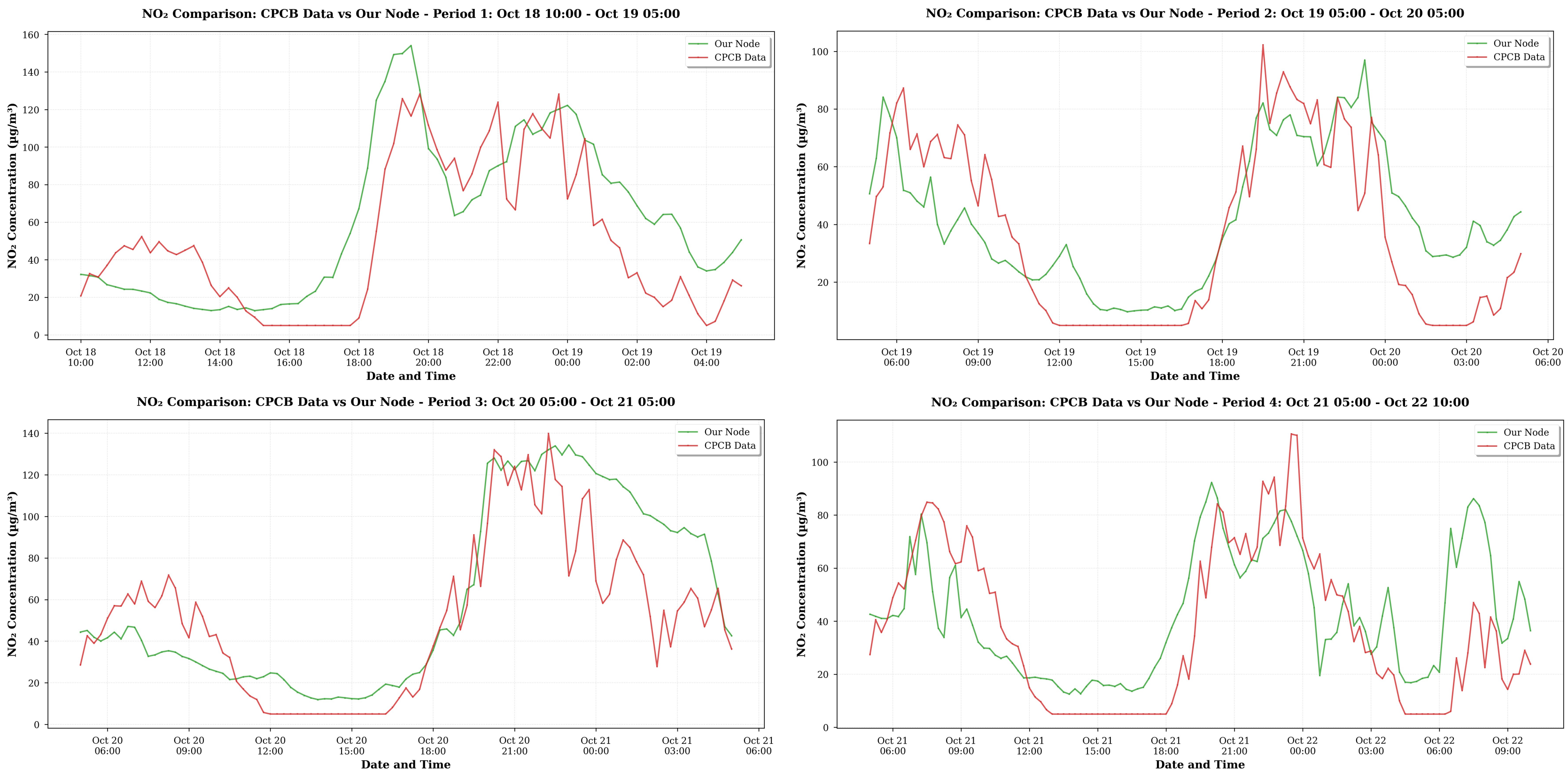
Temperature plots for Periods 1–4 (units: °C).

8 Comparison with CPCB Sector 51 Monitoring Station (Gurgaon)

To validate the measurements from our low-cost sensor node, we compared our collected data with official air quality readings obtained from the CPCB (Central Pollution Control Board) monitoring station located in Sector 51, Gurgaon. The CPCB data for NO_2 and $PM_{2.5}/PM_{10}$ was downloaded for the same Diwali periods.

The plots below show a period-wise comparison between our sensor readings and the CPCB reference data.

NO_2 Comparison with CPCB Sector 51



Comparison of NO_2 levels between our sensor node and CPCB Sector 51 for Periods 1–4.

PM Comparison with CPCB Sector 51

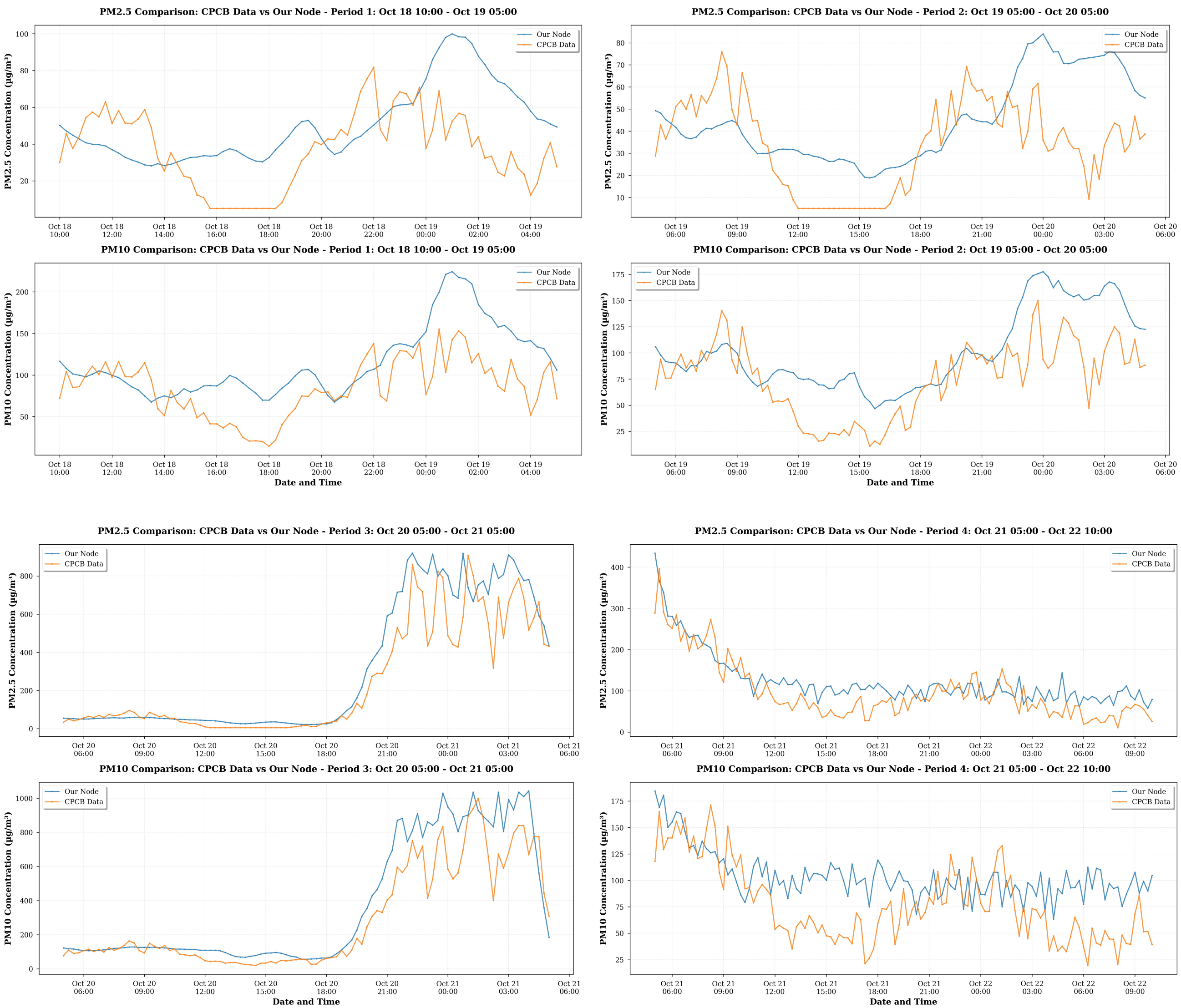
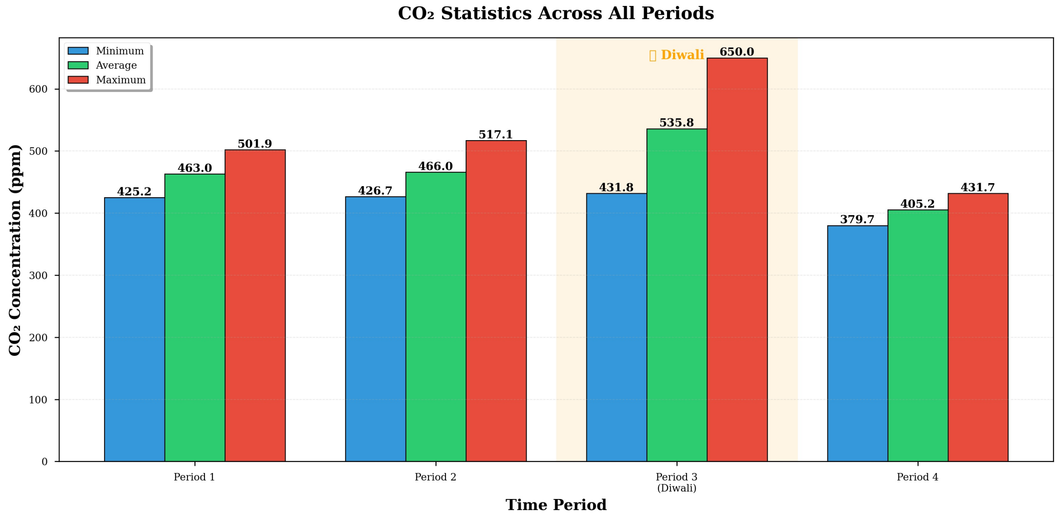


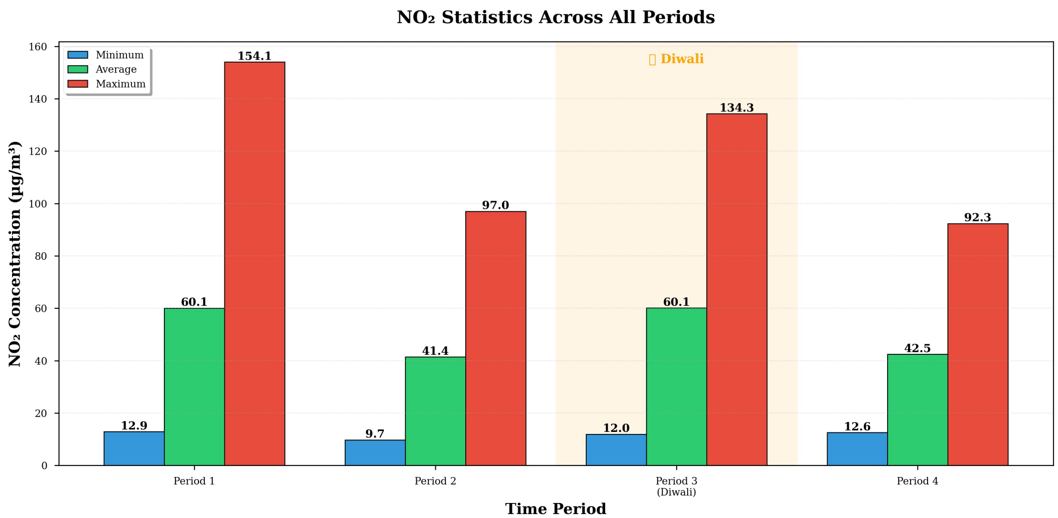
Figure 1: Comparison of PM concentrations between our sensor node and CPCB Sector 51 for Periods 1–4.

9 Descriptive Statistics and Comparative Analysis

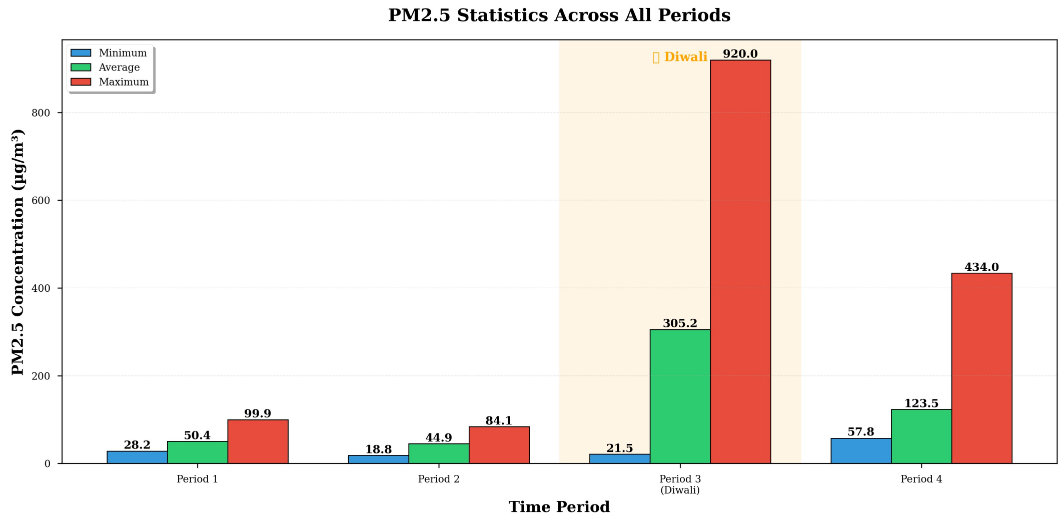
This section presents descriptive statistics for each pollutant across the four measurement periods. For every parameter (CO_2, NO_2, $PM_{2.5}$, PM_{10}, and temperature), we computed the mean, minimum, and maximum values. The following bar charts summarize the trends and allow visual comparison across pre-Diwali, Diwali, and post-Diwali periods.

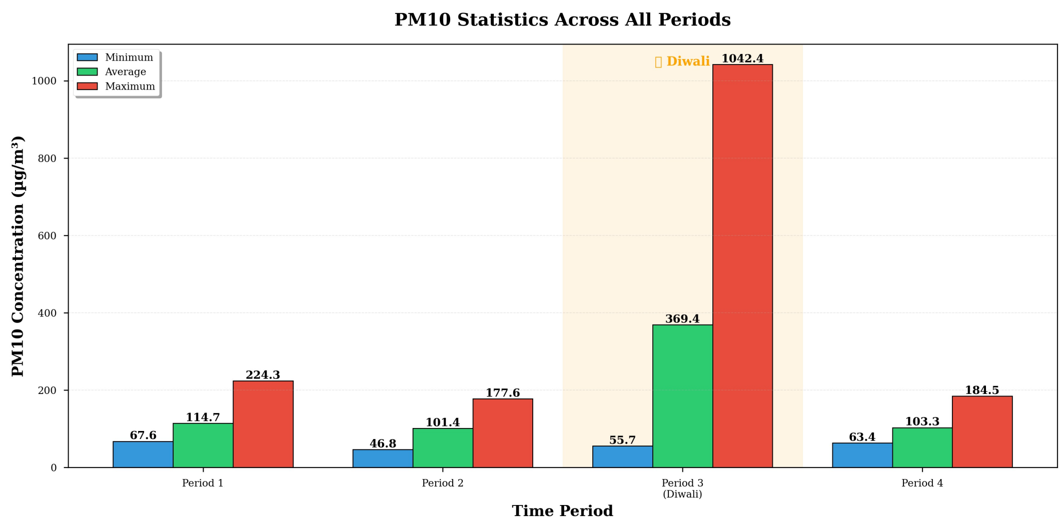
Descriptive Statistics: CO_2 and NO_2



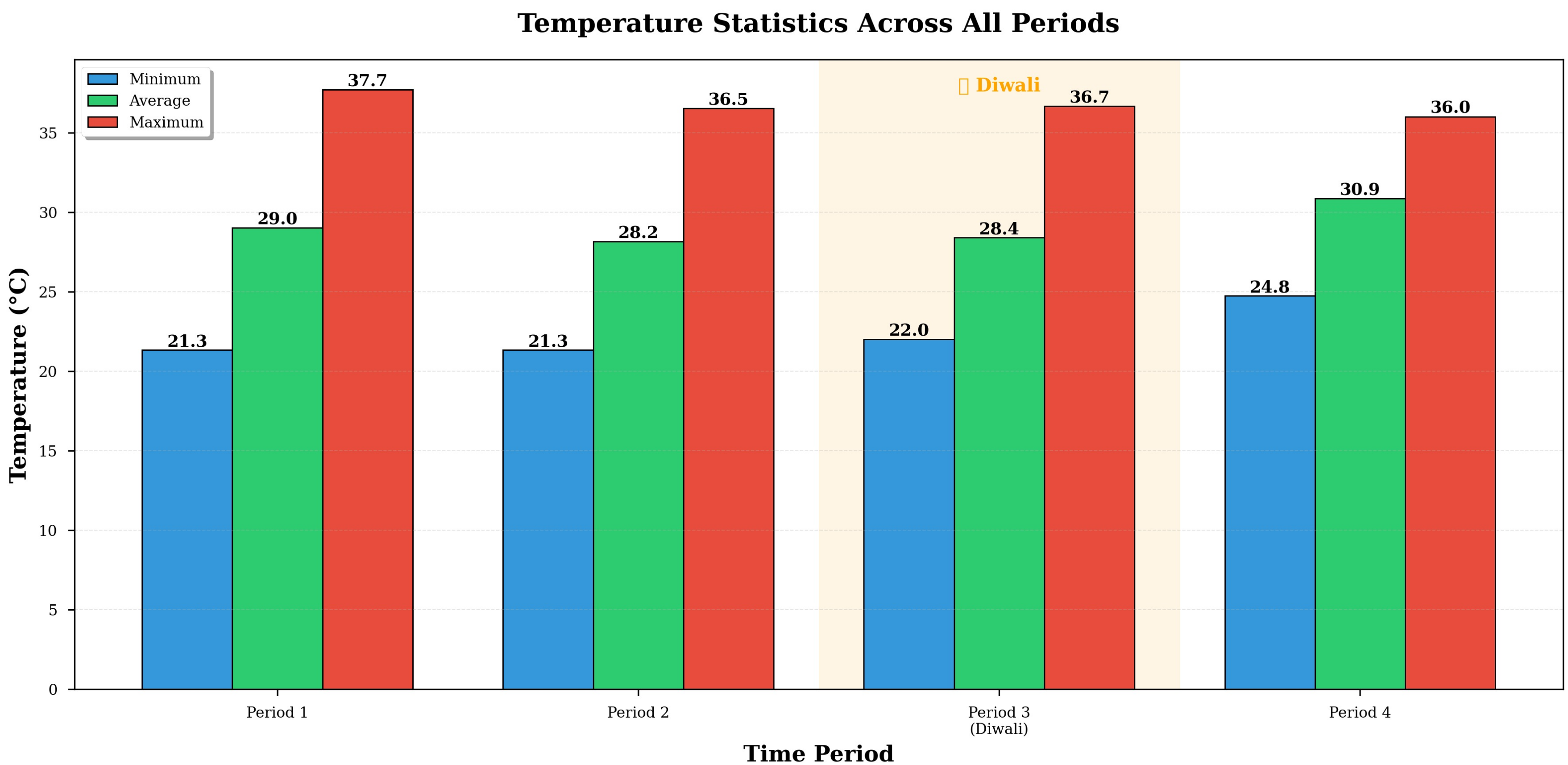


Descriptive Statistics: $PM_{2.5}$ and PM_{10}





Descriptive Statistics: Temperature



10 Discussion

10.1 NO_2 Rise During Diwali

Findings:

- NO_2 increased by **61%** (36.5 μg/m^3 to 58.8 μg/m^3) during Diwali.
- Peak value reached **154 μg/m^3**, which is approximately 2.35× the WHO recommended limit of 25 μg/m^3.

Reasons:

1. **Firecracker combustion:** Oxidizers such as potassium nitrate and barium nitrate produce nitrogen oxides upon ignition.
2. **Increased traffic:** Festival shopping and family visits caused a spike in vehicular emissions.
3. **Poor atmospheric dispersion:** Lower wind speeds and cooler temperatures reduced pollutant dispersion, trapping NO_2 near the surface.

10.2 Dramatic PM Increase on Diwali

Findings:

- $PM_{2.5}$: **506% increase** (50.1 μg/m^3 to 305.2 μg/m^3) — nearly 20× the WHO limit.
- PM_{10}: **222% increase** (114.7 μg/m^3 to 369.4 μg/m^3) — about 8× the WHO limit.
- Peak $PM_{2.5}$: **920 μg/m^3** (61× the WHO guideline).

Reasons:

1. **Firecracker residue:** Metallic compounds and unburnt carbon form large quantities of fine particulate matter.
2. **Secondary aerosol formation:** Interactions between NO_2, SO_2, and moisture generate secondary particles.
3. **Temperature inversion:** Evening temperatures (22–26°C) created a stable atmospheric layer that trapped PM near the surface.
4. **City-wide celebrations:** Simultaneous bursting of firecrackers produced a pollution dome across the region.
5. **Slow atmospheric clearance:** Fine particles remained suspended for 24–48 hours post-Diwali.

10.3 Rise in CO_2

Findings:

- CO_2 ranged from **379–650 ppm** across all periods.
- Period 3 showed the highest average: **535.8 ppm**.

Reasons:

1. **Firecracker combustion:** Produces CO_2 that can drift indoors.
2. **Human respiration:** Family gatherings increased indoor occupancy (8–12 people vs. usual 4–6).

10.4 Comparison with WHO Standards

Parameter	WHO Limit	Diwali Average	Exceedance
$PM_{2.5}$	15 μg/m^3	305.2 μg/m^3	**20.3**×
PM_{10}	45 μg/m^3	369.4 μg/m^3	**8.2**×
NO_2	25 μg/m^3	58.8 μg/m^3	**2.4**×

Comparison of pollutant levels during Diwali against WHO standards.

These results align with prior research, which typically reports a 3–10× increase in PM concentrations during Diwali.

11 Conclusion

11.1 Main Findings

1. **Severe PM pollution:** $PM_{2.5}$ increased by 506%; PM_{10} increased by 222%.
2. **Gaseous pollutants:** NO_2 rose 61%; CO_2 showed a 17% elevation.

11.2 Air Quality Safety Assessment

Overall Classification: HAZARDOUS

- **Diwali peak (9–11 PM):** AQI exceeded 400 (severe category).
- **Diwali day average:** AQI between 250–350 (very unhealthy).
- **Post-Diwali:** AQI remained 150–200 for more than 24 hours.
- **Baseline periods:** Already 3–4× WHO limits due to urban background pollution.

Health impact: Air quality during Diwali was unsafe for all groups, especially children, the elderly, and individuals with respiratory or cardiovascular conditions.

11.3 Impact of Festival Pollution

Quantified impact:

- 5–6× baseline PM increase within 6–8 hours.
- 20× exceedance of WHO $PM_{2.5}$ guidelines during the peak.
- Pollution equivalent to 30–40 days of normal urban emissions concentrated into one night.
- Health effects persisted for up to 3–5 days after the event.

Key conclusion: Diwali firecracker activity leads to severe, preventable air quality degradation with notable public health risks. The findings support the need for eco-friendly celebration alternatives and policy measures to balance cultural traditions with environmental protection.