Application of satellite technology in air pollution monitoring analysis of carbon monoxide measurements, pm10, pm2.5 levels and weather index

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Abstract: *The use of satellite technology in monitoring air pollution has become increasingly important for understanding and managing environmental health. This article explores the advancements in satellite-based monitoring of air pollutants, specifically focusing on the measurements of carbon monoxide (CO), particulate matter (PM10 and PM2.5), and weather indices. Satellite remote sensing provides extensive spatial and temporal data, addressing the limitations of ground-based monitoring networks [1]. Recent studies show that geostationary satellites have great potential for continuous and wide-ranging monitoring of air quality. These satellites enable accurate estimation of surface concentrations of pollutants, allowing for real-time assessment and trend analysis [2]. The integration of satellite data with ground measurements improves the reliability of air quality monitoring systems [3]. The analysis also highlights the usefulness of satellite data in understanding the dynamics of air pollution, including the dispersion patterns and the impact of weather conditions on pollutant levels. The use of advanced satellite instruments, such as those on the Sentinel-5P satellite, has shown significant improvements in detecting and quantifying CO and particulate matter concentrations [4]. Overall, the application of satellite technology in air pollution monitoring not only provides valuable insights into pollutant levels but also supports the development of effective mitigation strategies and policies to protect public health [5].*

KEY WORDS: *AIR QUALITY, SENTINEL-5P SATELLITE, POLLUTANT GASES, CARBON MONOXIDE*

1. Introduction

The increasing awareness of environmental health and the pressing need to address air pollution have driven significant advancements in the methods used to monitor and analyze atmospheric pollutants. Among these advancements, satellite technology has emerged as a powerful tool for providing comprehensive data on air quality over large geographical areas. This study leverages satellite data from the Sentinel-5P mission and meteorological data from OpenWeatherMap to examine air pollution levels, focusing on key pollutants such as carbon monoxide (CO), particulate matter (PM10 and PM2.5), and related weather indices.

Sentinel-5P, part of the European Space Agency's (ESA) Copernicus program, is specifically designed to monitor atmospheric composition with high spatial resolution and temporal frequency. Equipped with the Tropospheric Monitoring Instrument (TROPOMI), Sentinel-5P provides detailed measurements of various atmospheric gases, including carbon monoxide, ozone, nitrogen dioxide, and methane. The high precision and global coverage of Sentinel-5P make it an invaluable resource for studying air pollution trends and identifying pollution sources. Data from Sentinel-5P enable researchers to conduct detailed spatial and temporal analyses of air quality, offering insights into how pollution levels fluctuate over time and across different regions [6].

In addition to satellite observations, meteorological data play a crucial role in understanding the dispersion and concentration of air pollutants. Weather conditions such as temperature, humidity, wind speed, and direction significantly influence the behavior of pollutants in the atmosphere. To incorporate these factors, this study utilizes data from OpenWeatherMap, a widely used platform providing real-time and historical weather data. OpenWeatherMap offers a robust API that delivers accurate and up-to-date weather information from numerous weather stations around the world. By integrating meteorological data from OpenWeatherMap with satellite data from Sentinel-5P, this study aims to create a comprehensive framework for analyzing air pollution.

The combination of these datasets allows for a more holistic approach to air quality monitoring. Satellite data provide a broad overview of pollutant concentrations, while ground-based weather data add context and depth to the analysis, helping to explain variations in pollution levels [7]. This integrated methodology enhances our ability to monitor and model air quality, ultimately supporting the development of more effective strategies for pollution control and public health protection. In this study, we will first describe the datasets used and the methodology for data integration. Next, we will present the results of our analysis, focusing on the spatial and temporal patterns of carbon monoxide, PM10, and PM2.5 levels. Finally, we will discuss the implications of our findings for air quality management and future research directions.

By leveraging the advanced capabilities of Sentinel-5P and the comprehensive meteorological data from OpenWeatherMap, this research aims to contribute to the ongoing efforts to monitor and mitigate air pollution. The insights gained from this study will not only enhance our understanding of atmospheric pollutants but also provide valuable information for policymakers and environmental agencies tasked with protecting public health and the environment [8].

2. Results and discussion

The study focuses on Poland as the geographic area of interest. Poland, located in Central Europe, faces significant challenges with air pollution, particularly in urban areas where industrial activities and vehicular emissions are prevalent. The research aims to analyze air quality across various regions within Poland to identify patterns and sources of pollution.

The time frame for this study encompasses the entire year of 2023. This period allows for a comprehensive examination of seasonal variations and long-term trends in pollutant levels. By covering all four seasons, the study captures the impact of different weather conditions and human activities on air quality. Data collected throughout the year provide a robust dataset for assessing the effectiveness of current pollution control measures and identifying areas needing further intervention.

The Sentinel-5P satellite, part of the European Space Agency's Copernicus program, is equipped with the Tropospheric Monitoring Instrument (TROPOMI). This advanced instrument provides high-resolution data on various atmospheric gases. For this study, we specifically focus on the measurements of carbon monoxide (CO) obtained from Sentinel-5P. Carbon monoxide is a significant pollutant with serious implications for human health and the environment, making it an important parameter for air quality assessment.

In addition to the satellite data, the OpenWeatherMap Weather API provides essential ground-based measurements that enhance the overall understanding of air pollution. The Weather API offers real-time and historical data on several key pollutants, including:

- Carbon Monoxide (CO): Complements the satellite data, providing a more granular view of CO levels at ground level.
- Particulate Matter (PM2.5 and PM10): These fine particles are particularly harmful to respiratory health and are important indicators of air quality.
- Air Quality Index (AQI): A composite index that takes into account the concentrations of various pollutants to provide a clear and understandable measure of overall air quality.

The first step in data integration involves matching the geographic coordinates from both data sources. Sentinel-5P provides satellite data with high spatial resolution, capturing atmospheric measurements over large areas. These measurements are mapped to specific geographic locations within Poland. Similarly, the OpenWeatherMap Weather API provides ground-level data from numerous weather stations distributed throughout the country. By aligning the geographic coordinates of satellite and ground-based data, we ensure that the information from both sources corresponds to the same locations.

The second step in the integration process involves synchronizing the data based on the time of measurement. Sentinel-5P continuously captures atmospheric data, providing temporal coverage that includes daily and even hourly measurements. The OpenWeatherMap Weather API also offers real-time and historical data with timestamps. By aligning the timestamps of satellite and ground-based measurements, we can accurately compare and combine the data from both sources.

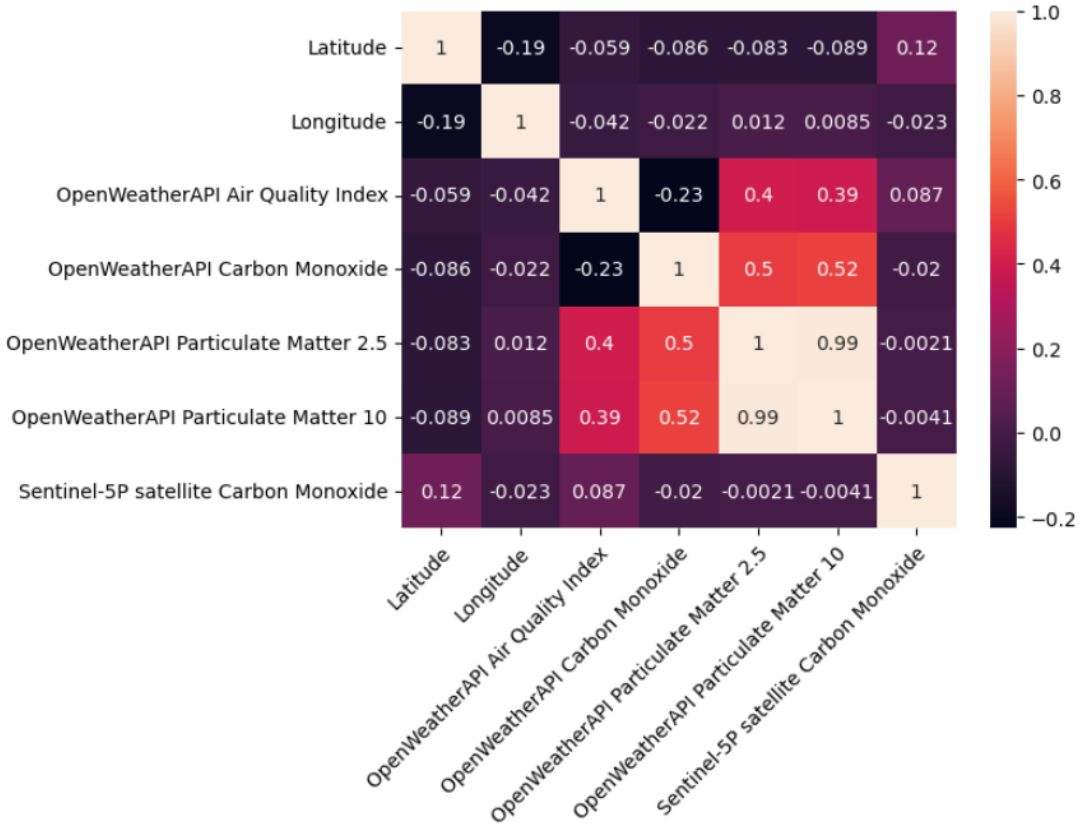

Figure 1 *Correlation matrix.*

This combined approach allows for a detailed analysis of air quality by providing a multi-dimensional perspective. The satellite data offers broad coverage and high-altitude measurements, while the Weather API data provides precise, ground-level observations. Together, they create a comprehensive dataset that enhances the accuracy and depth of our analysis.

In the following sections of this study, specific abbreviations will be used to differentiate between the sources of data for carbon monoxide (CO) measurements. Understanding these abbreviations is essential for interpreting the results accurately.

- Weather CO: This abbreviation refers to the carbon monoxide data recorded by the OpenWeatherMap Weather API. These measurements are taken at ground level by various weather stations distributed across Poland.
- Satellite CO: This abbreviation indicates that the carbon monoxide data were obtained from the Sentinel-5P satellite. The measurements provided by Sentinel-5P are collected from the atmosphere at a higher altitude and offer a broad spatial coverage.

The provided correlation matrix (Figure 1) displays the relationships between various environmental variables. Latitude shows a weak negative correlation with longitude (-0.188788), AQI (-0.059035), Weather CO (-0.086040), PM2.5 (-0.083310), and PM10 (-0.088942). It has a weak positive correlation with Satellite CO (0.123106).

Longitude has a very weak negative correlation with AQI (-0.041640), Weather CO (-0.021636), and Satellite CO (-0.023325). It has a very weak positive correlation with PM2.5 (0.011748) and PM10 (0.008463). AQI exhibits a moderate negative correlation with Weather CO (-0.226235). It has a moderate positive correlation with PM2.5 (0.404642) and PM10 (0.388478). There is a very weak positive correlation between AQI and Satellite CO (0.087329). Weather CO shows a moderate positive correlation with PM2.5 (0.498754) and PM10 (0.517268). It has a very weak negative correlation with Satellite CO (-0.019941). PM2.5 has a very strong positive correlation with PM10 (0.993529). There is a very weak negative correlation between PM2.5 and Satellite CO (-0.002102). PM10 shows a very weak negative correlation with Satellite CO (-0.004113). Satellite CO has very weak correlations with all other variables, indicating it is not strongly related to any of the measured weather parameters. The strongest positive correlation is between PM2.5 and PM10 (0.993529), suggesting that these two air pollution indicators are very strongly related to each other. Other variables generally have weak correlations with each other, indicating no clear relationships among them.

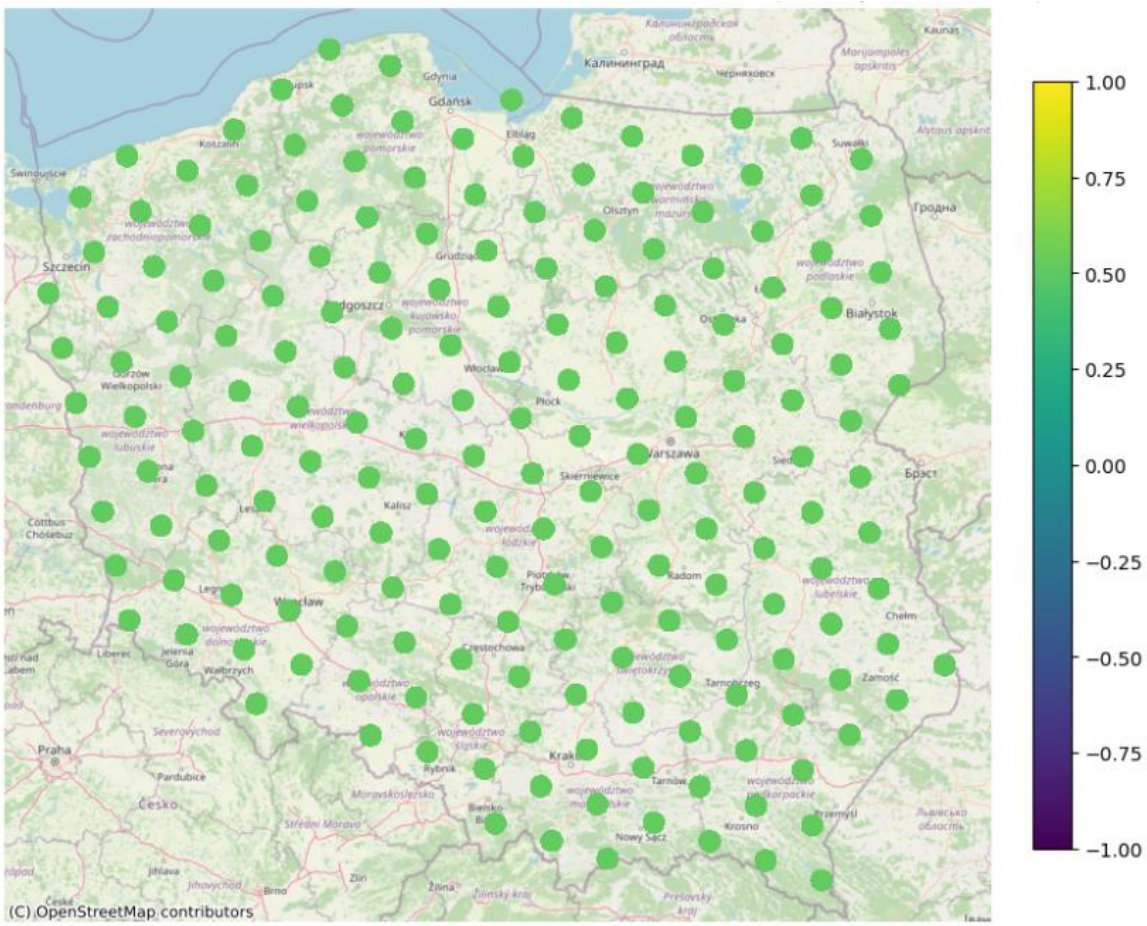

Figure 2 *Correlation Visualization of Carbon Monoxide and Particulate Matter 10 (both OpenWeatherAPI).*

The analysis of the correlation matrix reveals significant relationships between Carbon Monoxide (OpenWeatherAPI CO) and particulate matter (PM10 and PM2.5) as shown in Figure 2. The correlation between OpenWeatherAPI CO and PM10 is 0.517268, indicating a moderate positive correlation. This suggests that higher levels of carbon monoxide in the weather data are associated with higher levels of PM10. When carbon monoxide concentrations increase, PM10 levels also tend to increase, indicating that areas with higher carbon monoxide pollution are likely to also have higher concentrations of coarse particulate matter. Similarly, the correlation between OpenWeatherAPI CO and PM2.5 is 0.498754, also indicating a moderate positive correlation. This implies that higher levels of carbon monoxide are associated with higher levels of PM2.5, suggesting that fine particulate matter levels are also influenced by carbon monoxide pollution, although the correlation is slightly weaker compared to PM10.

These positive correlations highlight that areas experiencing higher carbon monoxide levels, possibly due to vehicular emissions, industrial activities, or other sources, are likely to also have higher particulate matter pollution. Monitoring and controlling carbon monoxide levels could potentially help in managing particulate matter pollution, as these pollutants often coexist and have common sources. Overall, the correlations between OpenWeatherAPI CO and particulate matter underscore the importance of comprehensive air quality management strategies that address multiple pollutants simultaneously.

3. Conclusion

The correlation analysis between various environmental variables revealed significant relationships between carbon monoxide and particulate matter PM10 and PM2.5. The correlation between OpenWeatherMap data for CO and PM10 is 0.517268, indicating a moderate positive correlation. This means that higher levels of carbon monoxide in meteorological data are associated with higher levels of PM10. Similarly, the correlation between CO and PM2.5 is 0.498754, also indicating a moderate positive correlation. This suggests that higher levels of carbon monoxide are associated with higher levels of PM2.5, although the correlation is slightly weaker compared to PM10.

These positive correlations indicate that areas with higher levels of carbon monoxide, likely due to vehicular emissions and industrial activities, also have higher concentrations of particulate matter. Monitoring and controlling carbon monoxide levels can potentially help in managing particulate matter pollution, as these pollutants often coexist and have common sources. These correlations highlight the importance of comprehensive air quality management strategies that address multiple pollutants simultaneously.

Satellite technology, combined with meteorological data, is a powerful tool for monitoring and analyzing air pollution. High-resolution data from the Sentinel-5P satellite, supplemented with precise ground-based measurements from OpenWeatherMap, enable detailed spatial and temporal analyses of air pollution. Correlations between carbon monoxide and particulate matter PM10 and PM2.5 indicate common sources of these pollutants, suggesting that air quality management strategies should consider controlling various pollutants simultaneously.

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