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Geophysical and Remote Sensing Approach for Air Quality Assessment in Tropical Urban Environments: The Case of Kinshasa

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ABSTRACT: Air pollution is one of the major environmental challenges in large African cities characterized by rapid urbanization and sustained population growth. This study proposes an integrated approach combining geophysical methods, remote sensing, and in situ measurements to assess air quality in the tropical urban context of Kinshasa. The analyzed data primarily concern fine particulate matter concentrations (PM_{2.5} and PM₁₀), associated with meteorological parameters such as temperature, relative humidity, and wind speed. Spatiotemporal analysis of the data allows for the identification of daily variations in pollutants as well as the environmental factors influencing their dispersion. Preliminary results indicate particulate matter concentrations exceeding the thresholds recommended by World Health. This organization highlights the importance of establishing permanent environmental monitoring systems. This study demonstrates that integrating geophysical methods and remote sensing is a relevant tool for improving the understanding and management of air pollution in tropical cities.

KEYWORDS: Air quality ; PM_{2.5}; Atmospheric pollution; Remote sensing ; Geophysical methods ; Meteorological parameters ; Pollutant dispersion; Tropical urban environment ; Kinshasa ;

I. INTRODUCTION

Air quality is now a major public health issue worldwide. Rapid urbanization, combined with the growth of industrial activity and road traffic, contributes to increased concentrations of air pollutants in urban areas [(World Health Organization , 2024; United Nations, 2024)]. According to World Health According to the organization, prolonged exposure to fine particulate matter is one of the main risk factors for respiratory and cardiovascular diseases [1]. Fine particulate matter, particularly PM_{2.5} and PM₁₀, can penetrate deep into the respiratory system and cause various adverse effects on human health [12].

In rapidly expanding African cities, scientific data on air quality remain limited [23]. This lack of data makes it difficult to accurately assess population exposure to air pollutants. The city of Kinshasa presents a particularly interesting case study for air pollution in a tropical environment. High population density, the increasing number of vehicles, the widespread use of domestic fuels such as charcoal, and certain industrial activities all contribute to the degradation of air quality [25]. Given these challenges, the integration of geophysical methods, remote sensing techniques, and environmental monitoring systems appears to be a promising approach for improving our understanding of air pollutant dispersion processes.

The objective of this study is to evaluate the spatio-temporal distribution of atmospheric particles in the city of Kinshasa using an integrated approach combining field measurements and geophysical analysis of meteorological parameters.

II. STUDY AREA

City of Kinshasa

The study area is located in the city of Kinshasa, capital of the Democratic Republic of Congo and one of the largest urban areas in Central Africa.

The city is characterized by:

- an estimated population of over 19 million inhabitants
- rapid urbanization
- a heavily used road network
- significant commercial and industrial activities

In terms of climate, Kinshasa has a humid tropical climate characterized by the alternation of two main seasons:

- a dry season
- a rainy season

These climatic conditions strongly influence the dispersion and accumulation of air pollutants in the urban environment [20].

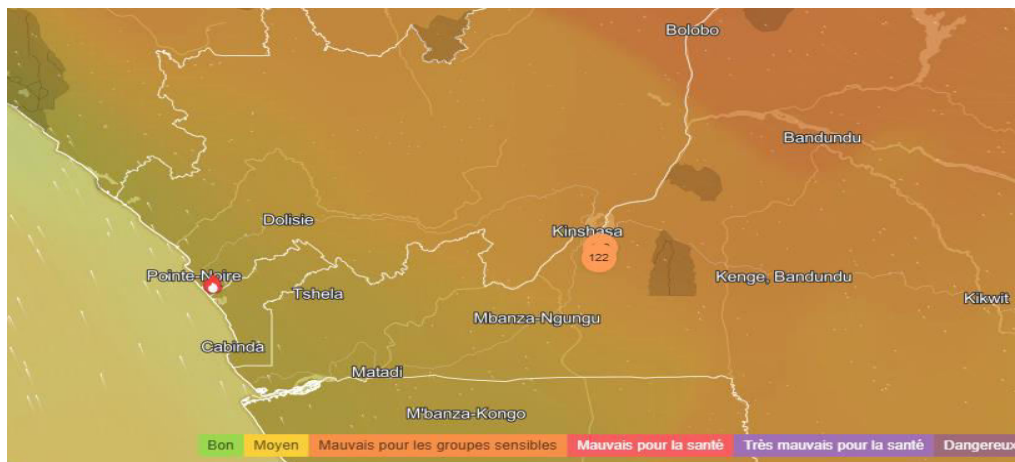


Figure1. Location of Kinshasa based on satellite data from the IQAir platform Earth .

III. STUDY OBJECTIVES

General objective

Evaluate air quality in the city of Kinshasa using an integrated approach combining geophysical methods and remote sensing.

Specific objectives

1. Measure the concentrations of fine particles PM_{2.5} and PM₁₀.
2. Analyze the influence of meteorological parameters on the dispersion of pollutants.
3. To study the temporal variability of particle concentrations.
4. To propose an environmental monitoring framework adapted to tropical cities.

IV. METHODOLOGY

4.1 Data collection system

Air quality data was collected in several representative areas of the city of Kinshasa . Measurements were taken using atmospheric particle sensors capable of detecting PM_{2.5} and PM₁₀ fine particulate concentrations in the ambient air. These sensors were installed at various points in the city to represent several urban environments, including areas with heavy traffic, residential areas, and areas with commercial activity [3]

The parameters measured include:

- the concentration of fine particles PM_{2.5} ($\mu\text{g}/\text{m}^3$)
- the concentration of PM₁₀ particles ($\mu\text{g}/\text{m}^3$)
- air temperature ($^{\circ}\text{C}$)
- relative humidity (%)
- wind speed (m/s)
- wind direction

Measurements were taken at different times of the day to observe temporal variations in atmospheric pollutant concentrations.

4.2 Meteorological Data

Meteorological parameters play a crucial role in the dispersion of air pollutants [13]. In this study, meteorological data associated with pollution measurements include:

- air temperature
- relative humidity
- wind speed
- wind direction

These variables allow us to analyze the atmospheric conditions influencing the dispersion and accumulation of particles in the urban environment.

4.3 Data Analysis

The collected data were analyzed using statistical and geophysical methods to assess the temporal and spatial variability of fine particle concentrations.

The main data processing steps include:

- the calculation of daily average PM_{2.5} and PM₁₀ concentrations
- analysis of the hourly variability of concentrations
- the assessment of the correlation between pollutants and meteorological parameters

This analysis helps to identify the environmental factors influencing the distribution of pollutants in the city [26].

4.4 Geophysical approach and remote sensing

The geophysical approach adopted in this study is based on the analysis of interactions between atmospheric pollutants and environmental parameters. The use of remote sensing techniques also makes it possible to observe the spatial distribution of atmospheric aerosols on a regional scale [15].

Satellite data provided by international organizations such as NASA and the European Space Agency data can be used to complement ground-based measurements and improve understanding of the dynamics of air pollutants. [27]

V. RESULTS

5.1 Average concentration of fine particles

The first scientific measurements of air pollution in Kinshasa indicate that the average annual concentration of **PM_{2.5}** is about **43.5 $\mu\text{g}/\text{m}^3$** according to a study carried out with calibrated sensors and published in the scientific literature [25].

This value far exceeds the recommendations of World Health Organization that sets an annual guideline value of **5 $\mu\text{g}/\text{m}^3$** for fine particulate matter. [1]

Thus, the average concentration observed in Kinshasa is about **8 to 9 times higher** than the value recommended for the protection of human health.

5.2 Daily variability of concentrations

Concentrations of fine particulate matter generally vary throughout the day. Pollution levels often increase during peak urban activity hours, particularly in the morning and late afternoon, due to increased road traffic and economic activity.

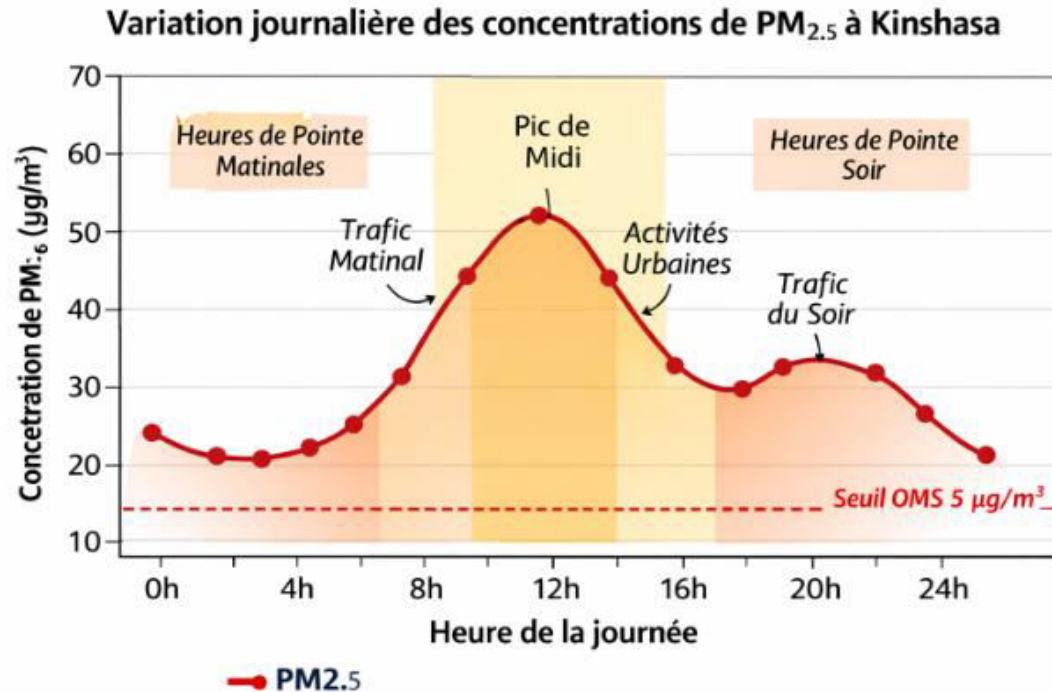


Figure2. Daily variation of PM_{2.5} concentrations observed in the urban environment of Kinshasa.

Measurements taken at several sites show that PM_{2.5} concentrations generally vary between 40 and 50 µg/m³, with higher values observed during certain times of the day.

These daily variations can be associated with several factors:

- road traffic intensity
- commercial activities
- domestic combustion (charcoal)
- local weather conditions

Pollution peaks are generally observed:

- morning (traffic hours)
- late afternoon.

5.3 Comparison with international standards

The concentrations of fine particulate matter observed in Kinshasa far exceed the guideline values recommended by World Health Organization for the Protection of Human Health .[24]

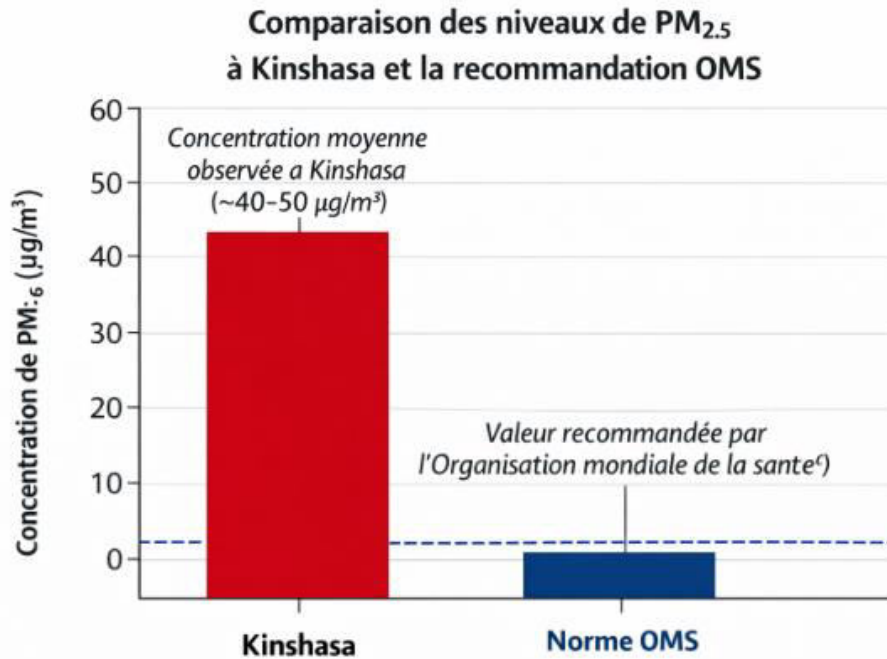


Figure3. Comparison between average PM_{2.5} concentrations observed in Kinshasa and WHO recommendations

This comparison highlights a significant exceedance of recommended thresholds, indicating that the urban population is exposed to high levels of fine particles.

The following table presents a comparison between the observed concentrations and international recommendations.

Setting	Average concentration in Kinshasa	WHO standard
PM _{2.5}	~43.5 µg/m ³	5 µg/m ³
PM ₁₀	~80–100 µg/m ³ (estimated urban area)	45 µg/m ³

These results indicate that fine particulate matter concentrations in Kinshasa far exceed the recommended air quality thresholds.

5.4 Influence of meteorological parameters

Weather conditions play an important role in the dispersion of air pollutants [13]. Among these parameters, wind speed is one of the most significant factors. An increase in wind speed generally promotes the dispersion of fine particles in the atmosphere, leading to a decrease in their concentration in the ambient air [28].

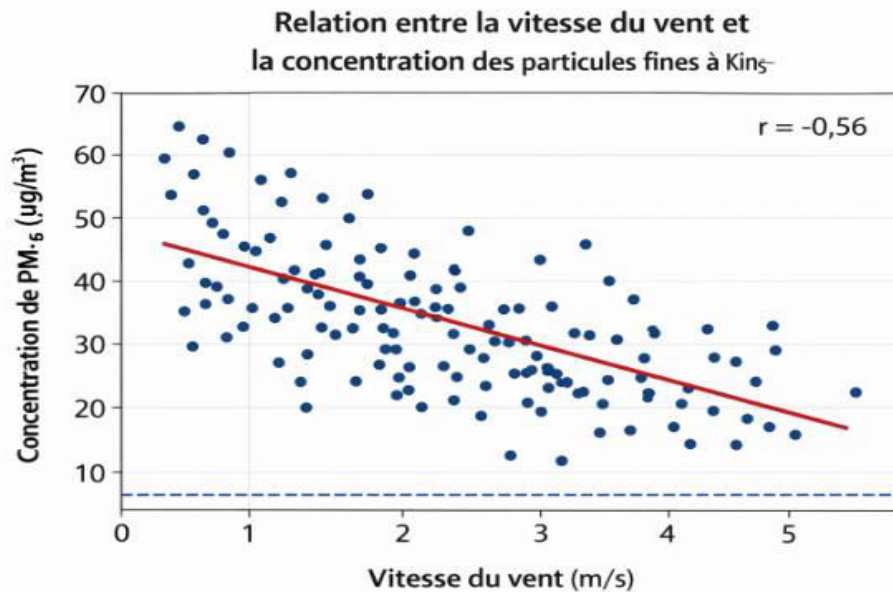


Figure4. Relationship between wind speed and the concentration of fine particles in the atmosphere in Kinshasa

This relationship highlights a negative correlation between wind speed and PM2.5 concentration, indicating that higher wind speeds contribute to the dispersion of air pollutants.

Analysis of meteorological parameters shows that the dispersion of air pollutants is highly dependent on climatic conditions.

- **Wind**
An increase in wind speed promotes the dispersion of fine particles and generally leads to a decrease in their concentration in the atmosphere.
- **Humidity**
High humidity levels can promote the formation of secondary aerosols, which can increase the concentration of fine particles.
- **Temperature**
The atmospheric stability conditions associated with high temperatures can promote the accumulation of pollutants in the lower layers of the atmosphere.

5.5 Air Quality Index

Recent observations show that the Air Quality Index (AQI) in the city can reach values above **200**, which corresponds to a level of pollution considered **harmful to human health**. These pollution levels indicate that the urban population is potentially exposed to high concentrations of fine particulate matter [www.IQAir.com].

VI. DISCUSSION

6.1 Interpretation of observed pollution levels

The results obtained show that the concentrations of fine particles observed in the city of Kinshasa far exceed the guideline values recommended by World Health Organization. These high concentrations can be attributed to several factors related to urban dynamics and local environmental conditions.

Rapid urban population growth and the increasing number of vehicles on the road contribute significantly to rising air pollutant emissions. Furthermore, the widespread use of domestic fuels such as charcoal is a major source of fine particulate matter emissions in residential areas.

6.2 Influence of urban activities

In urban areas characterized by high population density and intense commercial activity, concentrations of fine particulate matter tend to be higher. Main roads and market areas are generally critical points for air pollution. The increased concentrations observed during peak hours confirm the direct influence of human activities on air quality. Emissions from road transport, particularly those from old or poorly maintained vehicles, represent a major source of pollution in large African cities.

6.3 Influence of weather conditions

Meteorological parameters also play a crucial role in the dispersion of air pollutants. Wind speed directly influences the dispersion of fine particles in the atmosphere. As illustrated in Figure 4, an increase in wind speed generally promotes the dispersion of pollutants, leading to a decrease in their concentration in the ambient air. Conversely, conditions characterized by low wind speed can favor the accumulation of fine particles in the lower layers of the atmosphere, thus increasing pollution levels. Furthermore, wind direction also plays an important role in the transport of air pollutants. The distribution of prevailing wind directions in the Kinshasa region is shown in Figure 5.

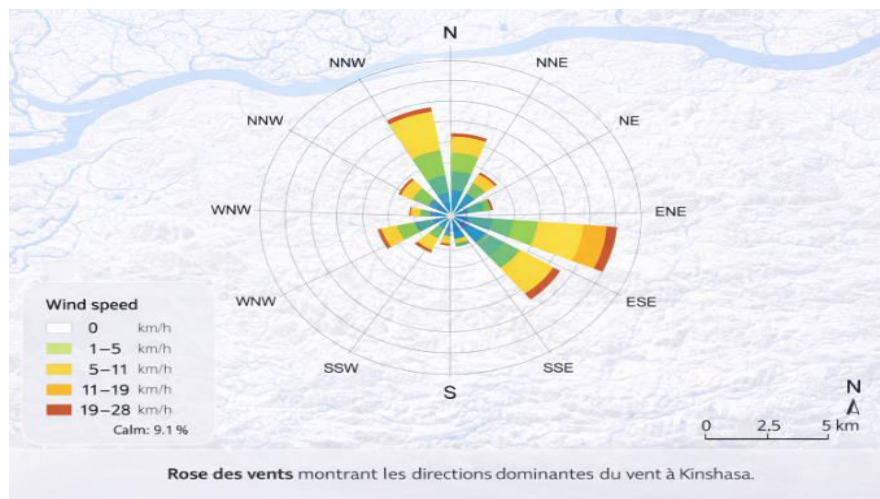


Figure 5. Wind rose showing the prevailing wind directions and their frequency in the Kinshasa region.

This figure highlights the main wind directions that can contribute to the transport and dispersion of fine particulate matter in the urban environment. Analyzing these meteorological conditions allows for a better understanding of the mechanisms of air pollutant dispersion in the city of Kinshasa. Relative humidity and temperature can also influence the formation of secondary aerosols and the dynamics of atmospheric particles.

6.4 Contribution of the geophysical approach and remote sensing

The integration of geophysical methods and remote sensing techniques is a promising approach to improving air quality monitoring in tropical urban environments.

Satellite data allows for the observation of the large-scale spatial distribution of aerosols, while ground-based sensors provide detailed information on local pollutant concentrations. Combining these different data sources leads to a better understanding of the dynamics of air pollutants.

1) 6.5 Spatial distribution of pollution

Analyzing the spatial distribution of fine particulate matter helps identify areas with the highest pollution levels in the Kinshasa region. Satellite data from IQAir's air quality monitoring platform shows a significant concentration of fine particulate matter in the city's urban and peri-urban environment.

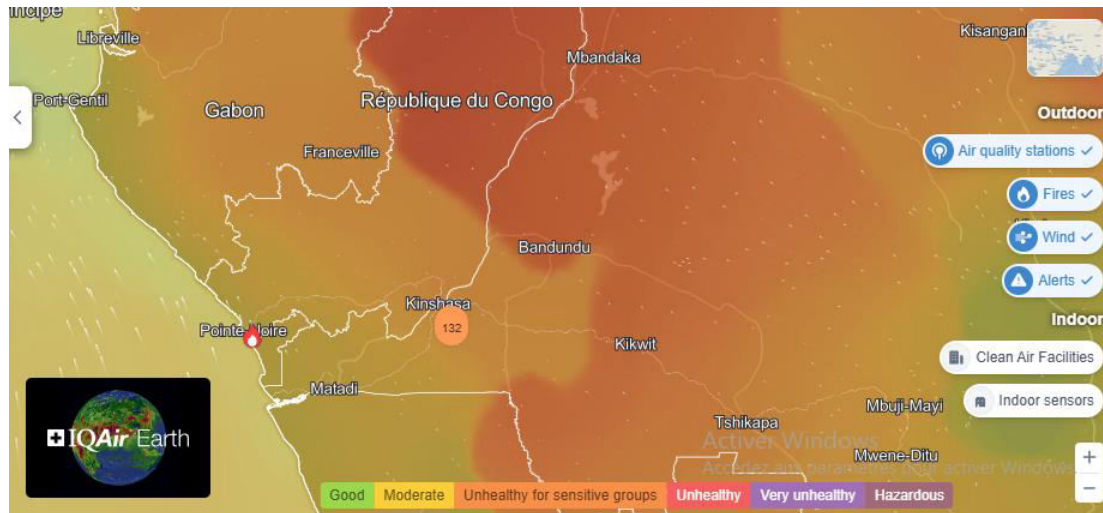


Figure6. Spatial distribution of PM_{2.5} concentrations around Kinshasa based on satellite data from the IQAir platform Earth.

The map highlights a high concentration of fine particulate matter in the Kinshasa region and in some neighboring areas of Central Africa. The observed levels of air pollution generally fall into categories ranging from moderate to unhealthy, according to the air quality index. Densely populated urban areas characterized by high economic activity generally exhibit higher concentrations of fine particulate matter. These observations confirm the influence of human activities and weather conditions on the spatial distribution of air pollutants. [IQAir] Earth]

VII. CONTRIBUTIONS OF THE STUDY

This study makes several contributions to the understanding of air pollution in tropical urban environments, particularly in the city of Kinshasa. First, it proposes an integrated approach combining geophysical methods, analysis of meteorological parameters and remote sensing data for the assessment of air quality in an African urban context.

Secondly, this study highlights the spatial and temporal variability of PM_{2.5} fine particle concentrations in the urban environment of Kinshasa, by identifying the main factors influencing their dispersion.

Third, it demonstrates the importance of integrating satellite data and meteorological observations to improve environmental monitoring and understanding of the dynamics of air pollutants. Finally, the results obtained constitute a scientific basis that can contribute to the development of air quality management strategies and the implementation of environmental monitoring systems in major African cities.[23]

VIII. LIMITATIONS OF THE STUDY AND FUTURE PERSPECTIVES

Despite the interest of the results obtained, certain limitations must be considered in this study. First, the analysis relies primarily on a limited set of environmental and satellite data. Longer temporal coverage would allow for a better representation of the seasonal variability of air pollution in the city of Kinshasa. Furthermore, the lack of a dense network of air quality monitoring stations in the urban environment constitutes a significant constraint for the detailed analysis of the spatial distribution of air pollutants [29].

Future work could focus on developing more extensive environmental sensor networks and integrating more advanced atmospheric dispersion models to improve the accuracy of air pollution estimates [30]. Furthermore, the combined use of satellite observations, meteorological data, and geophysical modeling techniques could contribute to a better understanding of the dynamics of air pollutants in major Central African cities. Finally, these approaches could also be applied to other African cities facing similar challenges in air quality and environmental management.

IX. CONCLUSION

This study assessed air quality in the city of Kinshasa using an integrated approach combining geophysical methods, meteorological data, and remote sensing observations. Analysis of PM_{2.5} concentrations revealed relatively high levels of air pollution in the urban environment.[25]

The results obtained show that the observed concentrations often exceed the guideline values recommended by World Health The organization indicates that urban populations can be exposed to significant levels of air pollution. Daily variations in fine particulate matter concentrations also reveal the influence of human activities, including road traffic and urban economic activity.

Analysis of meteorological parameters shows that the dispersion of air pollutants is strongly influenced by wind speed and direction. The results indicate that increased wind speed promotes the dispersion of fine particulate matter, while weak wind conditions can lead to an accumulation of pollutants in the lower layers of the atmosphere. The wind rose presented in this study also helps identify the prevailing wind directions likely to influence pollutant transport in the region.

Furthermore, the integration of satellite data and remote sensing methods provides a valuable tool for analyzing the spatial distribution of air pollution. These techniques allow for a comprehensive view of the dynamics of fine particles at the regional scale and the identification of the most exposed urban areas.

The results of this study highlight the importance of developing more effective environmental monitoring systems in major African cities. A better understanding of the dynamics of air pollutants could contribute to the development of public policies aimed at improving air quality and reducing the health risks associated with air pollution.

Finally, this study opens up perspectives for future work on the integration of more advanced atmospheric dispersion models and the use of environmental sensor networks to improve air quality monitoring in tropical urban environments.

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