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Can aerosol optical depth unlock the future of air quality monitoring and lung cancer prevention?

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Abstract

This "Policy Brief" explores the potential integration of Aerosol Optical Depth (AOD) into the United Kingdom's air quality and public health monitoring frameworks, highlighting its potential to enhance existing air pollution control strategies. Amid growing concerns over air pollution's impact on health, particularly the link between particulate matter and lung cancer, this brief presents a focused investigation into how AOD can be leveraged alongside traditional monitoring methods to provide a more nuanced understanding of air quality trends. By correlating AOD data with lung cancer incidence rates within the UK, the brief aims to uncover potential associations and inform public health decisions. Furthermore, it discusses the advantages and limitations of employing AOD in air pollution and respiratory disease monitoring, advocating for a strategic enhancement of the UK's air pollution monitoring efforts. This approach seeks to complement and refine current monitoring practices with advanced remote sensing techniques, aiming to inform policy innovations that prioritize environmental health and public welfare. Through a comprehensive review of existing data and policies, the brief underscores the urgency of adopting multidimensional air quality management strategies that respond to technological advancements and emerging public health needs.

Keywords Environmental health, Air quality, Remote sensing, Public health

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Main text

Amid the rapid progression of industrialization and urban expansion, air quality has emerged as a focal point of global concern. Many developed nations are shifting their attention towards the intrinsic connection between air quality and public health. Harmful pollutants, such as particulate matter, ozone, sulfur dioxide, nitrogen dioxide, and various organic compounds, have been evidenced to adversely impact the respiratory system. Chronic exposure to these pollutants can lead not only to respiratory conditions like chronic bronchitis and asthma, but also escalate the risk of lung cancer [1].

The UK, with its early onset of industrialization, has shown pronounced attention to this issue. The compounding effects of urban transportation and industrial emissions have rendered air pollution increasingly problematic in certain regions, posing significant challenges to public health. This situation underscores the imperative for continuous air quality monitoring, reporting, and forecasting. Accurate predictions and timely reports serve dual purposes: equipping the public with vital information to make informed health decisions and providing policymakers with a foundation for decision-making.

The Air Quality Index (AQI) is a tool developed by government agencies to inform the public about the level of air pollution and its potential health risks [2]. It enjoys widespread coverage in the UK, becoming the most significant and widely used air quality monitoring indicator in the country. The greatest advantage of the AQI is its ability to simplify complex air quality data into an easily understandable format, enabling the public to make informed decisions about their activities based on air quality. It employs a color-coded "traffic light" system to categorize air quality levels, making it comprehensible even to those without a background in environmental science. While the AQI provides valuable information to the public, it also has limitations. For instance, the accuracy and comprehensiveness of the monitoring data used to calculate the AQI can impact its effectiveness. The index may not fully capture the nuances of air quality in all areas, especially where monitoring is sparse or where various pollutants pose significant health risks not adequately reflected by the AQI. Therefore, relying solely on the AQI as a standard for monitoring air quality and as an index for preventing air pollution is insufficient. It necessitates the introduction of additional standards and indices to refine the overall framework.

In recent years, environmental remote sensing has offered a novel perspective for observing and assessing air quality. These remote sensing parameters can effectively capture the overall environmental conditions. For instance, the Aerosol Optical Depth (AOD) provides a certain level of insight into regional air quality [3]. This parameter, derived from satellite imagery processing and computations, offers a preliminary assessment of air quality without necessitating comprehensive pollutant sampling—particularly useful for gauging particulate matter concentrations. If this approach can be accepted and integrated into the existing framework for monitoring and preventing air pollution, it will undoubtedly demonstrate its value. Particularly, its sensitivity to variations in particulate matter makes it an excellent reference tool for assessing final particulate pollution levels.

This paper serves as a “Policy Brief”, aiming to explore the potential viability of using Aerosol Optical Depth (AOD) in the monitoring of air pollution and respiratory diseases. In the forthcoming sections, we will initially examine the UK as a preliminary case study. Our focus will be on correlating the variations in the UK’s AOD with the incidence rates of lung cancer within the country to investigate their potential association. Based on the findings, we will delve deeper into discussing the potential advantages and shortcomings of employing AOD in the realms of air pollution and respiratory disease monitoring. This discussion will be complemented by an analysis of the UK’s air pollution control policies, aiming to shed light on the future role of AOD and potential policy innovations in air pollution management.

According to the World Health Organization, nearly the entire global population (99%) breathes air exceeding WHO air quality limits, posing a health threat [4]. There’s a potential correlation between air pollution and lung cancer, especially concerning particulate matter. Studies indicate that exposure to air pollutants, particularly $PM_{2.5}$ particles, significantly increases the risk of lung adenocarcinoma in non-smokers with EGFR mutations, also revealing potential mechanisms through which air pollutants promote tumor growth, including DNA damage, inflammation, and altered gene expression [5]. A review by the American Cancer Society suggests that 14.1% of all lung cancer deaths globally are directly linked to air pollution, including non-smokers [6]. These findings underscore the importance of reducing air pollution to protect public health. While an increasing number of studies have delved into the correlation between air quality (especially pollutant concentrations) and various respiratory ailments, exploration using environmental remote sensing parameters, notably AOD, remains limited. A significant reason is the reliance on MODIS satellite data, which only began collection in 2000. Hence, the existing data might not be sufficient to firmly establish the link between AOD and respiratory diseases, especially lung cancer. Nevertheless, as time progresses, the momentum to uncover these connections remains unabated.

In the quest to uncover the relationship between air quality and lung cancer incidence, particularly as indicated by the AOD, one faces several challenges, especially with the inconsistency and gaps in relevant data collection. For instance, official lung cancer statistics for the UK present disparities across regions: England boasts data from 2013 to 2020, while Wales offers figures from 2011 to 2019. Scotland and Northern Ireland adopt a different approach, with the former tallying total cases biennially (e.g., 2011–2012) (as shown in Fig. 1A) and the latter opting for five-year intervals (e.g., 2015–2019). These discrepancies complicate the task of discerning a direct correlation between AOD and lung cancer cases or incidence rates.

While the link between the overall AOD (Fig. 1B), representing air quality, and lung cancer may not be immediately apparent, a closer examination of the available data reveals subtle hints of a connection. Some studies

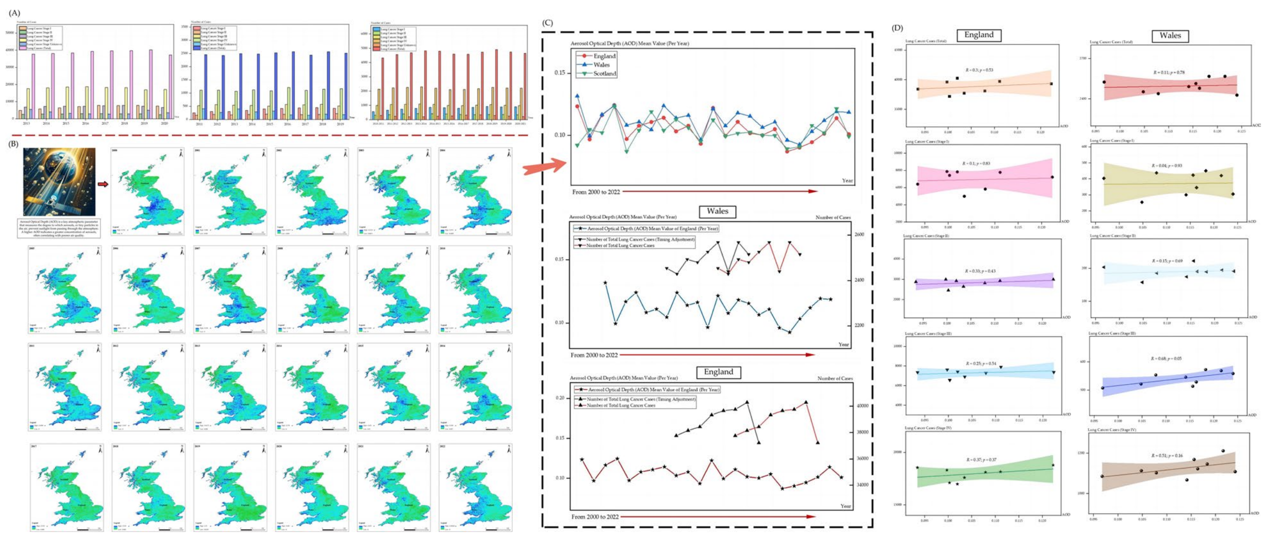

Fig. 1 **A** Lung cancer cases in England, Wales, and Scotland. **B** Maps of AOD changes in England, Wales, and Scotland from 2000 to 2022. **C** AOD statistics in England, Wales, and Scotland from 2000 to 2022; Lung cancer total cases and the curves timing adjusting (England and Wales). **D** Spearman's correlation analysis.

suggest that the influence of air quality shifts on lung cancer might manifest with a lag of 2–5 years, or possibly even longer [3]. By adjusting the lung cancer data curve for England and Wales five years forward, certain parallels emerge with the annual average AOD trend for these regions (Fig. 1C). We found similarities in the trends between AOD and lung cancer rates for lag years ranging from 2 to 5. However, in our graphical representations, we chose to specifically showcase the data for a 5-year lag to streamline our analysis and focus on the most pronounced correlation observed during this period. The choice to contrast the annual average AOD with total cases stems from two factors: the unavailability of precise incidence rate data and the fact that the annual AOD changes embody the overall state of air quality, paralleling the same meaning of the trend seen in cumulative lung cancer cases. In essence, using the year-over-year change in newly diagnosed cases would require a comparison with the yearly AOD fluctuation, which is essentially akin to comparing the annual average AOD with total cases.

Therefore, when Spearman's correlation analysis was executed between the annual average AOD for England and Wales and the variations in their respective lung cancer cases five years hence (spanning total cases and stages I to IV), a positive correlation consistently emerged across the board (Fig. 1D). The coefficients are persuasive enough to suggest that a higher AOD, indicating poorer air quality, might precipitate an uptick in lung cancer cases some years down the line, say five years later. However, out of the ten correlation analyses conducted, only one yielded statistically significant results. This is likely attributed to the limited data pool but still underscores the subtle ties between AOD and lung cancer. Moving forward, a deeper dive into this subject necessitates a more comprehensive collection of both statistical and AOD data.

Overall, the preliminary analysis presented faces several potential challenges, making the results less than definitive. For instance, the lack of comprehensive data makes it difficult to rule out other factors (like smoking rates) that might account for changes in cancer case numbers [7]. Furthermore, the diagnosis data available are somewhat fragmented and scant, compromising the precision of the analysis. Additionally, we approach the analysis of the correlation between overall lung cancer cases, as well as cases at various stages of development, and AOD with a degree of caution. When directly comparing these factors, particularly when examining cases at different stages, there may exist potential uncertainties and biases. The statistical discrepancies and challenges posed by the progression of cases through different stages warrant careful consideration. It is essential to acknowledge that the nuances of disease progression can introduce variability into the data, potentially influencing the outcome of correlation analyses. However, a broad outline can be discerned from this discussion, suggesting a potential correlation between the Aerosol Optical Depth (AOD) as a reflection of air quality, and the number or even incidence rates of lung cancer cases. If future research gradually confirms this link, the implications for public health policy could be profound. The AOD offers a distinct advantage: it can be obtained without exhaustive sampling, relying simply on satellite imagery, rendering the results easily interpretable by the general public. This means citizens can more readily grasp changes in air quality. Most crucially, if the changes and predictions based on AOD can be acted upon, they may provide timely interventions in lung cancer prevention.

Building on the aforementioned potential of AOD, its application as a viable environmental remote sensing indicator offers promising avenues for air quality monitoring. By weaving AOD into the fabric of public health strategies, especially in combatting respiratory diseases and lung cancer, a more holistic approach to these health challenges becomes conceivable. The strength of AOD extends beyond its capability to mirror atmospheric conditions [8]; it also serves as a window into instantaneous air quality shifts. Such real-time insights could be instrumental in fostering timely health interventions and advisories. As our comprehension deepens regarding the complex interplay between air quality and health repercussions, embracing sophisticated tools like AOD may emerge as a cornerstone for devising robust and adaptive health policies. Incorporating Aerosol Optical Depth (AOD) into the air quality monitoring framework significantly strengthens the entire monitoring and regulatory system. However, AOD also has its clear drawbacks. Firstly, as an emerging remote sensing data source, most AOD data are available only post-2000, limiting our ability to conduct more extensive research, particularly in applying advanced technologies like machine learning to analyze the correlation between AOD and respiratory diseases. Secondly, while AOD can track particulate matter pollution, it may not fully reflect the extent of air pollution. Factors such as climate change can influence AOD readings, and due to the prolonged lifespan of aerosols, the generation of secondary aerosols, and non-urban aerosol sources, AOD distributions tend to be more uniform and less correlated with pollution source locations, highlighting a limitation of AOD as an air pollution monitoring method. Lastly, from a disease statistics perspective, there is a significant gap between the available disease data and reality in many regions. The UK is among the best in public health management, yet inaccuracies in disease statistics remain. Under such circumstances, it becomes challenging to meaningfully explore the correlation between AOD and related diseases. While not a drawback of AOD itself, this represents one of the most significant barriers to formally integrating AOD into air pollution monitoring and public health prevention frameworks. Should these limitations be resolved in the future, the feasibility of incorporating AOD into the air quality monitoring framework will significantly increase.

Considering the current focus and policies of air pollution monitoring in the UK, expanding the existing air monitoring methods and tools appears to be a promising measure, especially by incorporating remote sensing of air into the monitoring and regulatory framework.

Air quality monitoring in the UK is managed by the Department for Environment, Food & Rural Affairs (DEFRA) along with devolved administrations [9]. The UK boasts approximately 300 national monitoring sites organized into various networks. Each network, through designated methods, gathers specific types of information. These networks, designed to measure air quality, are categorized into automatic and non-automatic types, based on the pollutants measured and the methods employed. This setup facilitates a comprehensive approach to air quality monitoring across the UK, catering to diverse objectives and data usage needs. Furthermore, DEFRA provides a suite of data tools on its UK Air Information Resource website to facilitate access to air quality data. These resources are intended to simplify the process for professionals and the public to access and understand air quality data, ensuring that information is readily accessible and understandable. Additionally, for daily updates and forecasts regarding air quality, DEFRA's website offers the latest air quality data, forecasts, and health advice related to air pollution levels.

The air quality monitoring initiatives and implementations by DEFRA are not only highly effective, but also serve as a commendable model for other nations. Incorporating remote sensing data as an additional reference could potentially elevate these efforts. Remote sensing technology has the distinct advantage of detecting changes in air quality even before ground-based monitoring stations, offering a preemptive glimpse into potential air quality variations. This capability could enhance the comprehensiveness and responsiveness of air quality monitoring systems. By integrating remote sensing data, we could achieve a more dynamic and predictive approach to air pollution management, facilitating earlier intervention measures and more accurately targeted actions. This integration would represent a significant advancement in our ability to understand and combat air pollution on a global scale, offering a more proactive stance in protecting public health and the environment.

From a policy perspective, the UK could explore enhancing its air pollution monitoring efforts, particularly concerning particulate matter. In this context, Aerosol Optical Depth (AOD) emerges as a promising tool for particulate monitoring, especially valuable in localized assessments.

The National Air Pollution Control Programme (NAPCP) meticulously outlines the UK's commitments to reducing emissions of five key pollutants by 2020 and

2030 [10]: nitrogen oxides, ammonia, non-methane volatile organic compounds, particulate matter, and sulfur dioxide. Particulate matter is a focal point of this pollution control plan, which is crucial for the UK to meet its legal obligations and contribute to improved air quality and public health outcomes.

Moreover, the Clean Air Strategy 2019 delineates a comprehensive plan involving various sectors of government and society to enhance the UK's air quality [11]. It aims to safeguard national health, the environment, and foster clean growth and innovation. Air quality monitoring plays a critical role within this strategy, aligning with broader efforts such as the Industrial Strategy, the Clean Growth Strategy, and the 25 Year Environment Plan.

Overall, by strengthening air pollution monitoring, particularly for particulate matter, and considering the integration of AOD as a monitoring reference, the UK can further solidify its commitment to environmental health and public welfare. These efforts underscore the importance of a multi-faceted approach to air quality management, leveraging both traditional monitoring networks and innovative remote sensing technologies to provide a comprehensive understanding of air pollution dynamics and inform effective policy interventions.

In conclusion, this paper, serves as a "Policy Brief", aims to present a focused exploration rather than an exhaustive study or comprehensive review. It specifically examines the potential for integrating Aerosol Optical Depth (AOD) into the UK's air quality and public health monitoring frameworks, advocating for the enhancement of current air pollution control strategies. The brief underscores the significance of AOD as a valuable tool for monitoring particulate matter, highlighting its utility in capturing air quality trends and its potential role in informing public health decisions. Finally, the brief advocates for a strategic enhancement of air pollution monitoring efforts in the UK, incorporating advanced remote sensing techniques like AOD. This approach aims to complement traditional methods, providing a more nuanced understanding of air quality dynamics. The ultimate goal is to inform and guide policy innovations that prioritize environmental health and public welfare, ensuring that air quality management evolves in line with technological advancements and emerging public health needs.

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Availability of data and materials
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Declarations

Ethics approval and consent to participate
Not applicable.

Competing interests
The authors declare no competing interests.

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