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Satellite Observations of Air Quality Dynamics in Türkiye

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ABSTRACT

This paper presents an analysis of air pollution in Turkey over a ten-year period. The study was carried out to determine the concentrations of specific pollutants in the atmosphere by analyzing the Sulfur dioxide (SO_2), Sulfate (SO_4), Organic Carbon Scattering (OCS) and Total Aerosol Angstrom parameter components obtained from MERRA-2 satellite imagery. SO_2 and SO_4 represent the mass densities of sulphate components in the atmosphere, while organic carbon represents atmospheric carbon scattering. The aerosol Angstrom parameter provides important information on particle size and distribution. The most moderate correlation was found between SO_4 and OCS (R value 0.63). Analyzing these parameters is an important step to understand their impacts and changes on air quality in Turkey. Ten years of Land Surface Temperature (LST) data were obtained from Modis images. SO_4 was highly correlated with LST (R value: 0.85) and OCS was moderately correlated with LST (R value 0.58). This study aims to analyze the air pollution profile in depth and identify seasonal/long-term trends, focusing on the analysis of long-term data. This analysis provides an important contribution to provide a scientifically based basis for air quality management and environmental policy development.

Türkiye'deki Hava Kalitesi Dinamiklerinin Uydu Gözlemleri

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ÖZET

Bu makalede, Türkiye'deki hava kirliliğinin on yıllık bir süre boyunca analizi sunulmaktadır. Çalışma, MERRA-2 uydu görüntülerinden elde edilen Kükürt dioksit (SO_2), Sülfat (SO_4), Organik Karbon Saçılması (OCS) ve Toplam Aerosol Angstrom parametre bileşenlerini analiz ederek atmosferdeki belirli kirleticilerin konsantrasyonlarını belirlemek için yürütülmüştür. SO_2 ve SO_4, atmosferdeki sülfat bileşenlerinin kütle yoğunluklarını temsil ederken, organik karbon atmosferik karbon saçılmasını temsil eder. Aerosol Angstrom parametresi, parçacık boyutu ve dağılımı hakkında önemli bilgiler sağlar. En orta düzeyde korelasyon, SO_4 ve OCS arasında bulunmuştur (R değeri 0,63). Bu parametrelerin analiz edilmesi, Türkiye'deki hava kalitesi üzerindeki etkilerini ve değişimlerini anlamak için önemli bir adımdır. On yıllık Kara Yüzey Sıcaklığı (LST) verileri MODIS görüntülerinden elde edilmiştir. SO_4, LST ile yüksek düzeyde korelasyona sahipken (R değeri: 0,85) OCS, LST ile orta düzeyde korelasyona sahiptir (R değeri 0,58). Bu çalışma, hava kirliliği profilini derinlemesine analiz etmeyi ve uzun vadeli verilerin analizine odaklanarak mevsimsel/uzun vadeli eğilimleri belirlemeyi amaçlamaktadır. Bu analiz, hava kalitesi yönetimi ve çevre politikası geliştirme için bilimsel temelli bir temel sağlamak adına önemli bir katkı sağlamaktadır.

1. Introduction

Rapid urbanisation and industrialisation processes are among the important factors triggering environmental problems worldwide. As a result of these processes, especially in big cities, smoke pollution increases, and atmospheric carbon dioxide (CO_2) concentration increases significantly (Aykaç Özen et al., 2023)

Air pollution impacts nearly every habitat, with many having direct consequences for public health and agriculture. Sulfur dioxide (SO_2) is recognized as a primary irritant, posing significant short- and long-term health risks. It primarily affects the respiratory system, but it also impacts the eyes and skin, and laboratory studies indicate that it may influence other bodily systems as well. The effects of these pollutants are dose-dependent, with prolonged exposure potentially leading to reactive airway dysfunction syndrome. Some studies have suggested that sulfur dioxide could be a potential carcinogen through its interaction with other substances and might also contribute to the development of ischemic stroke in the brain. Sulfates (SO_4) can form a substantial component of fine particulate matter, contributing to acid rain, which contaminates surface water and soil. This acid rain also damages forests and disrupts the broader ecosystem (Maynard et al., 2007; Nan, 2010; CAS 7446-09-5, 2004).

Sulfur originates from precursor emissions due to fossil fuel combustion, volcanic eruptions, and biological ocean activity. Carbonaceous aerosols, on the other hand, come from both natural and anthropogenic sources. Human-induced emissions include controlled and incomplete combustion of fossil fuels and biofuels, as well as uncontrolled biomass burning. Organic carbon is also released from plants and debris and is secondarily produced in the atmosphere by gaseous compounds. Since the pre-industrial era, concentrations of all these aerosol types have risen considerably, now exerting a significant radiative force on the climate (Manning & Solomon, 2007).

The wide range of estimates for the direct radiative forcing of aerosols reflects the intricate nature of these particles and the challenges associated with accurately assessing their impact on the Earth's climate. Aerosols, such as sulphate, black carbon, and organic carbon, exhibit short lifetimes and considerable variability in their distribution across different regions and time periods. Moreover, the limited availability of comprehensive measurement data on a global scale adds further complexity to the evaluation process. This variability in estimates suggests significant uncertainty in our understanding of aerosol effects on the Earth's radiation balance. It underscores the need for more extensive and precise measurements, as well as improved modeling approaches, to better grasp the role of aerosols in climate dynamics. Despite the challenges, efforts such as those outlined in the IPCC Fourth Assessment Report contribute valuable insights, albeit within a range of potential outcomes (Ramaswamy et al., 2001; Takemura et al., 2005, Charlson et al., 1992; Schulz et al., 2006, Sato et al., 2003; Manning & Solomon, 2007). Therefore, ongoing research and advancements in observational techniques and modeling capabilities are essential to refine our understanding of aerosol impacts and their implications for climate change mitigation and adaptation strategies.

This study aims to analyze air pollution in Turkey using various parameters. The focused parameters are SO_2, SO_4, OCS and Total Aerosol Angstrom Parameter. Thematic maps were created using MERRA-2 satellite data based on data between 2022-2013. In the study, temporal and spatial trends of air pollution in the selected region were investigated. This study is an important step towards a deeper understanding of the air quality problem in Turkey and identifying its potential sources. The analyzed parameters will help to reveal the different sources and impacts of air pollution. Furthermore, thematic maps will help to identify problematic areas and develop air quality management strategies by visualizing the temporal and spatial distribution of air pollution. The results of this study may pave the way for the development of more effective policies to improve Turkey's air quality and protect public health.

2. Materials and Methods

2.1. Materials

Satellite records can be used as a very valuable and effective tool for estimating air pollution (Sierra-Porta et al., 2023). Satellite records can observe a large geographical area simultaneously and are therefore an important data source for monitoring and analyzing the distribution of air pollution.

MERRA-2 is a modern reanalysis developed at NASA. Compared to its predecessor, MERRA-2 offers improved representation of processes involving the hydrological cycle, cryosphere, stratosphere, particularly enhancing atmospheric ozone-related processes, and benefits from joint assimilation of aerosols and meteorological fields. It also considers the interaction of atmospheric aerosols with radiation effects (Gelaro et al., 2017). Furthermore, MERRA-2 enables a more comprehensive analysis of atmospheric interactions and processes by exploiting the joint assimilation of aerosol and meteorological data fields. This leads to increased accuracy in weather and climate modelling. In addition, by considering the complex relationship between atmospheric aerosols and radiation, MERRA-2 provides valuable information on the mechanisms driving changes in Earth's radiation balance and climate. MERRA-2 is a significant advance in atmospheric reanalysis capabilities. It provides researchers with a powerful tool to better understand and predict changes in Earth's atmosphere, which is essential for addressing pressing environmental challenges such as climate change.

The aerosol assimilation system in MERRA-2 incorporates aerosol optical depth (AOD) measurements from satellite instruments such as MODIS, MISR, AVHRR, and stations within the AERONET network. The GOCART module is used to model atmospheric aerosols, including the simulation of sources, sinks, and dynamics for five different aerosol types: dust, sea salt, sulfates, black carbon (BC), and organic carbon (OC) (Randles et al., 2017; Butchard et al., 2017). It considers emissions from fossil fuel combustion and biomass burning, with sources identified through AeroCom inventories and various other biomass burning inventories. Since 2010, daily emissions of BC and OC from biomass burning have been estimated using the Quick-Fire Emissions Dataset (QFED), which is based on fire radiative power (FRP) data from MODIS instruments (Darmenov & da Silva, 2015; Freeborn et al., 2014).

For hydrophilic carbonaceous aerosols, the decay coefficients are adjusted according to moisture levels. The model also accounts for factors such as hygroscopic growth of particles, rates of aerosol deposition, and the optical properties when calculating aerosol mass and AOD, with data being corrected based on observations. The GOCART model's capability in analyzing observed aerosol characteristics has been validated in numerous studies (Colarco et al., 2010; Bian et al., 2013; Shikwambana, 2019).

Land Surface Temperature (LST) is a critical parameter in understanding land surface processes on both regional and global scales, as it reflects the outcomes of surface-atmosphere interactions and the exchange of energy between the ground and the atmosphere (Mannstein, 1987; Sellers et al., 1988). A decade of LST data was acquired from MODIS imagery.

2.2. Methods

Satellite data is an effective and reliable tool for analyzing air pollution over large geographic areas (Sierra-Porta et al., 2023). While analyses supported by ground-based measurements yield higher accuracy, satellite data offers a critical solution when ground data is lacking. In this study, the Pearson correlation method was employed to determine the relationships between air pollution parameters and Land Surface Temperature (LST). Using MERRA-2 data, various air pollution parameters such as SO_4 and OCS were selected, and correlation analyses were performed between each parameter and LST. These analyses, conducted with the Pearson correlation method, represent a significant step in evaluating the accuracy of MERRA-2's air pollution data and its interactions with related variables.

The data provided by MERRA-2 enables monitoring of atmospheric pollution parameters over vast geographic areas, while data processing and analysis processes were conducted using the Google Earth Engine (GEE) platform. With its high data processing capacity, GEE allows for the generation of high-resolution results. In the coding steps, MERRA-2 data was first imported, parameters were selected, and suitable datasets were prepared for correlation analysis. These steps were coded on GEE, enabling efficient and fast analysis processes.

This study utilizes MERRA-2 data to analyze the temporal changes of air pollution components over Turkey. Analyses were conducted on the Google Earth Engine (GEE) platform, covering the period from 2013 to 2022, and examined the distribution of important atmospheric parameters such as SO_4, SO_2, Organic Carbon Scattering, and the Aerosol Angstrom Parameter.

For each parameter, a time-series analysis was conducted by taking monthly average values across Turkey. To visualize the analysis results, time-series charts were generated using GEE's graphing tools. These charts, prepared on a specific scale and with axes arranged according to dates and units, illustrate how each parameter changed over certain time periods. The graphs obtained from this study provide a comprehensive view of the temporal changes in air pollution components across Turkey. The analyses conducted on the GEE platform demonstrate the contribution of remote sensing data to air pollution monitoring over large geographic areas and highlight the advantages of the MERRA-2 dataset in such environmental monitoring and analysis studies.

Although there are some limitations in using coarse-resolution data, MERRA-2 data provides a unique advantage, particularly for air pollution parameters such as SO_4, SO_2, OCS, and Total Aerosol Angstrom. These parameters are crucial for analyzing the movement and regional distribution of atmospheric pollutants. Pollutants such as SO_4 and SO_2 are provided by MERRA-2 with a level of detail that is not available in other satellite datasets, offering high reliability in atmospheric modeling and air pollution analysis (Randles et al., 2017; Butchard et al., 2017). These data allow for a detailed understanding of processes affecting air quality and serve as a reliable alternative when local measurement data is unavailable.

In conclusion, although the resolution of the satellite data used in this study may be a limiting factor, the significance of the parameters offered by MERRA-2 largely compensates for these limitations. The analysis of parameters such as SO_4, SO_2, OCS, and Aerosol Angstrom plays a critical role in revealing the regional variations in atmospheric pollution. Therefore, the detailed aerosol and meteorological data provided by MERRA-2 make a unique contribution to research on air pollution.

2.3. Study Area

Air pollution poses significant environmental and health challenges in Turkey, particularly in its densely populated urban centers. In Figure 1, Google Earth image of Turkey is given. Air pollution is an important issue in Turkey. Especially in big cities, factors such as industrial activities, heavy traffic and energy production affect air quality. For example, air pollution is frequently on the agenda in metropolises such as Istanbul, Ankara and Izmir. In this study, Turkey's air pollution was analyzed in detail with various parameters. These parameters include SO_2, SO_4, OCS and Total Aerosol Angstrom parameters. Between 2022 and 2013, thematic maps were created for different regions of Turkey using MERRA-2 dataset. MERRA-2 data were processed on the Google Earth Engine platform and graphics and visuals were obtained. Time-varying air pollution trends and spatial distributions in various geographical regions of Turkey were analyzed in detail.

Figure 1. Google Earth image of Turkey

3. Result and Discussion

In this study, the temporal and spatial variations of key air pollution indicators in Turkey were analyzed over a decade, utilizing thematic maps and graphical representations. By examining parameters such as SO_2, SO_4, OCS, and the Total Aerosol Angstrom parameter, significant trends and patterns were identified across different regions. The analysis revealed notable fluctuations in air pollution levels, with distinct peaks and troughs corresponding to specific years and regions. The findings provide a comprehensive understanding of how air quality has evolved over time in Turkey, highlighting critical areas and periods of concern that may warrant further investigation and policy intervention.

Figure 2a shows the thematic maps of SO_4 value between 2022-2013. It was observed that the highest values were reached in 2019. It is observed that SO_4 density is higher especially in coastal regions and the highest density is in the Marmara region. Figure 2b shows the thematic maps of SO_2 value between 2022-2013. It was observed that the highest values were reached in 2017. Especially around the Marmara Sea, Izmir, Ankara, Adana, Kahramanmaraş SO_2 intensity is higher. Figure 2c shows the thematic maps of OCS value between 2022-2013. The highest value was observed in 2017. The lowest values were observed in 2022. It was observed most intensely on the coasts of the Marmara and Black Sea. Figure 2d shows the thematic maps of the Total Aerosol Angstrom parameter value between 2022-2013. The highest value was observed in 2020. It was observed that the lowest values were reached in 2021. The Central Anatolia region was observed most intensely.

Figure 3(a) shows SO_4 value graphs between 2022-2013. The highest level was seen in October 2015 and the lowest level was seen in March 2020. Figure 3(b) shows SO_2 value graphs between 2022-2013. The highest level was seen in August 2017 and the lowest was in March 2020. Figure 3(c) shows OCS demonstration charts from 2022-2013. The highest level was seen in August 2021 and the lowest was seen in November 2016. Figure 4(d) shows the Total Aerosol Angstrom parameter value graphs between 2022-2013. The highest level was seen in December 2015 and the lowest level was seen in April 2022.

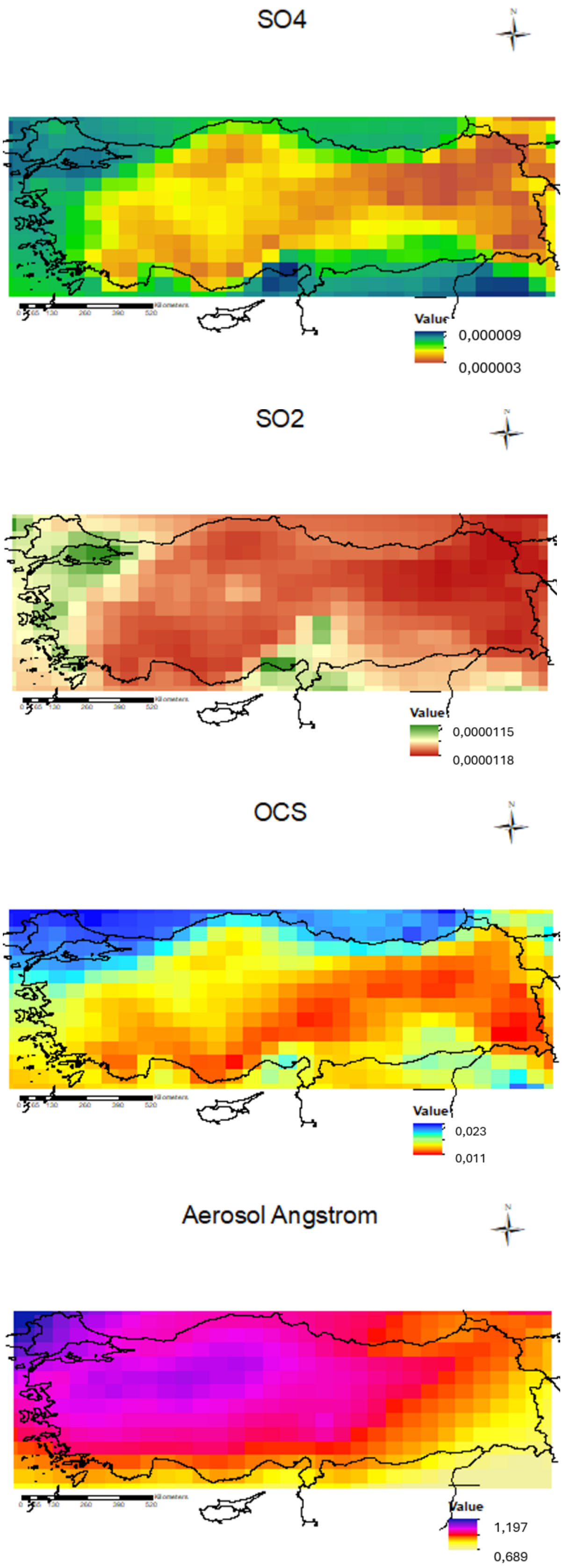
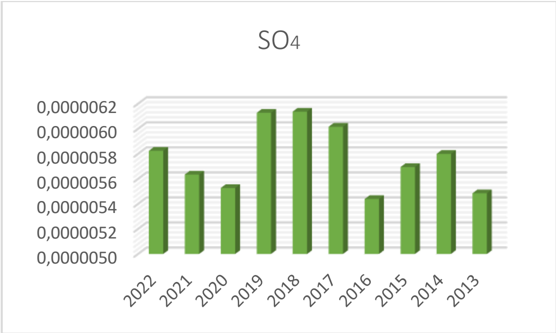
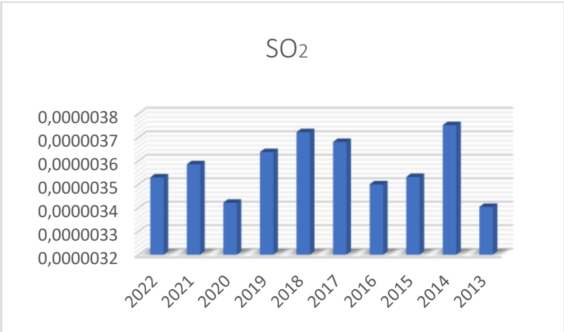


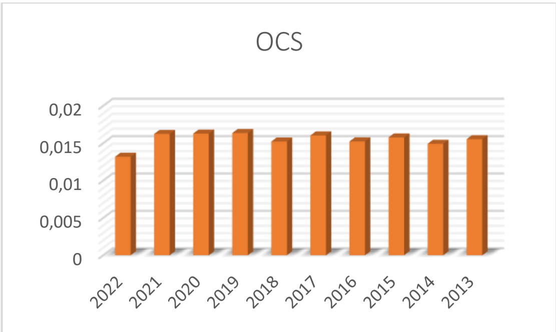
Figure 2. (a) Dated thematic maps of SO_4 value in 2022-2013, (b) Dated thematic maps of SO_2 value in 2022 - 2013, (c) Dated thematic maps of 2022-2013 OCS value, (d) Dated thematic maps of 2022-2013 Total Aerosol Angstrom parameter value



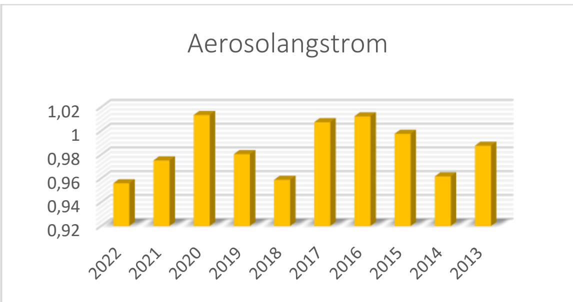
(a)



(b)



(c)



(d)

Figure 3. (a) 2022-2013 of SO_4 value (b) 2022-2013 of SO_2 value (c) 2022-2013 charts of OCS value (d) Total Aerosol Angstrom parameter value charts dated 2022-2013

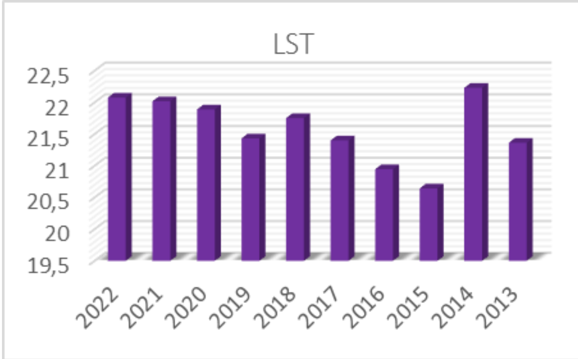


Figure 4. 10-year Lst values table

10-year LST values are given in Figure 4. It was created by averaging the monthly average values. It was observed that the highest average was reached in 2014, and the lowest average was reached in 2015.

4. Conclusion

Recently, there has been a noticeable deterioration in environmental conditions, with air pollution emerging as one of the most pressing issues. This degradation has had a profound impact on public health worldwide. One of the most concerning consequences is the significant increase in respiratory tract inflammation, directly attributable to poor air quality (Santosa et al. 2008). More efforts are still needed worldwide because air pollution poses a serious threat to human health and adversely affects environmental quality.

Recently, air pollution has begun to emerge as a serious problem in Turkey, and this situation is increasingly at the center of the policy agenda. The social and economic costs of air pollution are likely to be large for Türkiye. The OECD's environmental performance review estimated that excessive sulfur dioxide emissions could significantly increase mortality rates (Kaygusuz 2007; MEF 2007; Say 2006). It is recommended that Turkey take serious steps in the fight against air pollution and that this issue be addressed urgently.

The analysis based on the obtained data shows the importance of MERRA-2 satellite data in analyzing the air quality in various regions of Turkey. Studies on parameters such as SO_2, SO_4, Organic Carbon Scattering and Total Aerosol Angstrom reveal that there are significant differences between different regions. Especially in the Marmara region, SO_2 and SO_4 levels are higher than in other regions. It is emphasized that population density and industrialisation may be one of the important factors affecting air quality. Likewise, it is stated that Organic Carbon Scattering is intense in the Black Sea and Marmara Sea coasts, while Total Aerosol Angstrom parameters are concentrated in the Central Anatolia region.

Table 1. Regression results

Parameters	Correlation (R Value)	Correlation Strength
SO_4 and OCS	0.63	Moderate
Other Parameters	<0.5	Weak
SO_4 and LST	0.85	High
OCS and LST	0.58	Moderate

Table 1 presents the regression results. Regression was performed between all parameters with the Statistica programme. The most correlation was moderate between SO_4 and OCS (R value: 0.63) and the correlation between the other parameters was weak. Regression analysis was performed between all parameters and LST values. A high correlation was found between SO_4 and LST (R value: 0.85). A moderate correlation was found between OCS and LST (R value: 0.58).

The annual analysis conducted on the Google Earth Engine platform has shown that MERRA-2 satellite data is an important tool in formulating environmental policies more effectively and improving air quality. It was emphasized that the use of satellite imagery for continuous monitoring of air quality in Turkey is of great importance and this study is an important step in terms of environmental protection, public health and sustainability.

Air pollution is a significant environmental issue in the present day. To monitor and control air pollution more effectively, advanced and comprehensive methods are required due to its global impact. Satellites have become an important tool in this regard. NASA's MERRA-2 (Modern-Era Retrospective Analysis for Research and Applications, Version 2) is an atmosphere modelling and data assimilation system that plays a vital role. MERRA-2 is utilized to estimate the concentration of aerosols and other particles present in the atmosphere, providing information on the spatial and temporal distribution of air pollution. Other satellites, such as Sentinel-5P, TROPOMI and VIIRS, are also employed for air pollution monitoring. These satellites provide data in different spectral bands and at higher resolutions, enabling a more detailed analysis of air pollution. Supporting satellite data with ground measurements is crucial for accurate and reliable air pollution monitoring. Ground measurement stations verify and calibrate satellite data and provide information on air pollution in areas beyond satellite reach. The combination of satellite and ground-based measurements enhances understanding of air pollution sources and impacts. This information can aid in the development of policies and regulations to control air pollution.

The use of various satellites for air pollution monitoring has both advantages and disadvantages. MERRA-2 is suitable for monitoring long-term trends in air pollution due to its wide area coverage and long data history. Satellites such as Sentinel-5P and TROPOMI provide higher resolution data, enabling more detailed analyses of air pollution. It is important to support satellite data with ground-based measurements for more accurate and reliable air pollution monitoring. Ground measurement stations are used to verify and calibrate satellite data. They are also important for obtaining information on air pollution in areas beyond satellite reach. The combination of satellite and ground-based measurements can provide a better understanding of the sources and impacts of air pollution. This information can aid in the development of necessary policies and regulations to control air pollution.

This analysis presents important findings that may represent a new approach and paradigm in the field of air quality monitoring. In terms of environmental protection and public health, it emphasizes the importance of continuing detailed analyses and states that these data can play a critical role in taking various measures. Such analyses can provide guidance in combating environmental threats and in policy making for a healthy environment.

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Conflict of Interest Statement

Author of the present study does not have any conflicts of interest.

Declaration of Contribution of Researchers

The author Investigation, Analysis, Writing- Review & Editing.

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