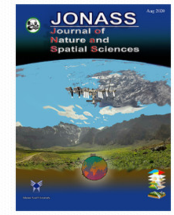
Available online at https://sanad.iau.ir/journal/jonass
Publisher: Maybod Branch, slamic Azad University
Journal of Nature and Spatial Sciences
ISSN: 2783-1604



Analyzing the Interactions Between Surface Temperature, Vegetation, and Topography in Jakarta (Indonesia) and Seoul (South Korea)

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A R T I C L E I N F O

Research Type:
Case Study

Article history:
Received 27 Jul 2022
Revised 30 Aug 2022
Accepted 10 Dec 2022

Keywords:
Air Pollutants,
Google Eart Engine,
Land Surface Temperature
NDVI

A B S T R A C T

Background and objective: Urbanization significantly impacts air quality, with land surface temperature (LST), vegetation cover, precipitation, and air pollutants Nitrogen Dioxide (NO2) and Methane (CH4)) playing critical roles. This study investigates the relationships among these environmental variables in Jakarta, Indonesia, and Seoul, South Korea, to understand their interconnections and implications for urban air quality management.
Materials and methods: Utilizing satellite imagery (Sentinel-5P and MODIS) and remote sensing data, vegetation cover was measured using the Normalized Difference Vegetation Index (NDVI), while LST was analyzed alongside meteorological data. Pollution levels of NO2 and CH4 were assessed through ground-level measurements and satellite-derived data. Topographical features such as slope and elevation were integrated into the analysis, and wind rose data were used to evaluate wind patterns' effects on pollutant dispersion.
Results and conclusion: The results revealed that higher vegetation cover correlates with lower concentrations of NO2 and CH4, supporting the hypothesis that urban green spaces mitigate pollution. A significant positive correlation between LST and pollutant levels was observed, indicating urban heat exacerbates air quality issues. Topographical factors significantly influenced pollutant distribution, with lower elevations trapping pollutants. Furthermore, prevailing wind patterns were found to be crucial in shaping pollution dynamics. These findings underscore the importance of integrating vegetation and topographical considerations into urban planning and policy-making to enhance air quality and promote sustainable urban environments in both cities.

1. Introduction

Urban air pollution, driven by rapid urbanization and industrial activities, is a pressing issue in many global cities, contributing to environmental degradation and adverse public health impacts (Komilova et al., 2023). Cities like Jakarta and Seoul, facing rapid urban expansion, are significantly affected by pollutants such as nitrogen dioxide (NO2) and methane (CH4), which are known to be linked to both anthropogenic activities and natural environmental factors (Pravitasari et al, 2018; Jo et al., 2022).

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Peer review under responsibility of Maybod Branch, Islamic Azad University

DOI: https://doi.org/10.30495/jonass.2024.999693

Surface temperature and vegetation dynamics, influenced by precipitation patterns, also play a key role in determining pollution levels (Zhong et al., 2010). Remote sensing technologies, particularly satellite imagery, have emerged as vital tools for monitoring these environmental factors, offering spatially extensive and temporally consistent data for large urban areas (Yu & Fang, 2023). The development of platforms like Google Earth Engine (GEE) and the availability of Sentinel-5P satellite data have opened new opportunities for studying air pollution in relation to other environmental variables (Yilmaz et al., 2023).

The relationship between surface temperature, vegetation cover, precipitation, and the concentrations of NO2 and CH4 in urban environments remains complex and poorly understood (Zheng et al., 2017). While previous studies have explored the influence of vegetation and land surface temperature (LST) on air quality, there is a lack of comprehensive research focusing on the interaction of these factors in rapidly developing cities such as Jakarta and Seoul. Understanding how these variables interact can help improve air quality management strategies and contribute to more sustainable urban planning. Therefore, this study aims to address the research gap by investigating the spatial-temporal relationships between surface temperature, vegetation cover (measured through NDVI), precipitation, and pollution levels in these two cities.

Several studies have explored the links between air pollution and urban environmental factors using remote sensing techniques. For instance, Mirsanjari et al. (2020) highlighted the importance of using NDVI to assess the role of vegetation in mitigating urban pollution. Similarly, research by Suthar et al. (2023) demonstrated that higher land surface temperatures are often associated with elevated NO2 levels in urban areas. However, most of these studies have either focused on a single city or neglected the integration of both physical and meteorological factors such as slope, topography, and wind patterns, which are crucial for pollution dispersion (Yang et al., 2020). The use of advanced satellite data, including Sentinel-5P for monitoring NO2 and CH4, has been relatively limited in comparative studies between cities like Jakarta and Seoul.

The primary objective of this study is to investigate the relationships between land surface temperature (LST), vegetation cover (measured using NDVI), precipitation, and NO2 and CH4 pollution in Jakarta and Seoul. Specifically, the study aims to:

- Analyze how variations in vegetation cover and precipitation influence the concentrations of NO2 and CH4.
- Examine the impact of land surface temperature on pollution levels in urban environments.
- Assess the role of topographical features, such as slope and elevation, in pollution dispersion.
- Use wind rose data to understand the role of wind patterns in pollution distribution across the two cities.
- Provide a comparative analysis between Jakarta and Seoul regarding the interplay between these environmental variables and pollution.

The following hypotheses will be tested in this study:

- H1: Higher vegetation cover (NDVI) is associated with lower levels of NO2 and CH4 in both cities.
- H2: Increased land surface temperature correlates with higher concentrations of NO2 and CH4.
- H3: Topographical factors such as slope and elevation significantly influence the distribution of air pollutants.
- H4: Wind patterns, as indicated by wind rose data, play a crucial role in the spatial distribution of pollutants in both cities.

This study is significant for several reasons. First, it will provide a comprehensive analysis of how various environmental factors—surface temperature, vegetation, precipitation, and topographyinteract to affect urban air pollution. The results will offer insights that can be applied in urban planning and environmental management in rapidly developing cities. By focusing on Jakarta and Seoul, this research will contribute to a deeper understanding of pollution dynamics in Southeast Asian and East Asian contexts, which have been understudied in comparative research. Moreover, the use of advanced remote sensing platforms such as Google Earth Engine and Sentinel-5P data will demonstrate the potential of these tools in urban environmental monitoring.

2. Materials and Methods

2.1. Study Area

This study focuses on two major cities: Jakarta (Indonesia) and Seoul (South Korea). Both cities are rapidly urbanizing and facing increasing environmental challenges, including air pollution. Jakarta, located in Southeast Asia, experiences a tropical monsoon climate with significant seasonal rainfall. As the capital of Indonesia, Jakarta is characterized by high population density, heavy traffic, and industrial activity, which contribute to elevated levels of NO2 and CH4 pollution (Nishihashi, 2019). In contrast, Seoul, located in East Asia, has a humid continental climate with distinct seasonal variations, including cold winters and hot, humid summers. Like Jakarta, Seoul faces serious air pollution issues, mainly due to vehicular emissions, industrial activities, and urban sprawl (Ho et al., 2021).

The two cities were chosen because they represent distinct geographical, climatic, and urbanization patterns, allowing for a comparative analysis of the relationship between environmental variables (e.g., land surface temperature, vegetation cover, and precipitation) and air pollution (NO2 and CH4 levels).

Fig. 1 – Study Area

2.2. Data Sources

Several datasets were used to conduct this study:

- Sentinel-5P Satellite Data: This satellite, part of the European Space Agency's Copernicus program, provides global monitoring of key air pollutants, including NO2 and CH4, through the TROPOMI sensor. Sentinel-5P was selected for its high spatial resolution and daily revisit time, making it ideal for urban air quality studies (Bodah et al., 2022).
- MODIS Land Surface Temperature (LST) Data: The Moderate Resolution Imaging Spectroradiometer (MODIS) provides daily LST data, which is essential for studying heat island effects and its relation to pollution dispersion in urban areas (Mandal et al., 2022).
- NDVI Data: The Normalized Difference Vegetation Index (NDVI) was derived from MODIS data to assess vegetation cover. NDVI is a widely used index for estimating green vegetation density, which can influence urban air quality by reducing pollutant concentrations (Zhou et al., 2021).
- Digital Elevation Model (DEM): A digital elevation model was utilized to study the topography and slope of both cities. DEM data helps in understanding how terrain influences pollution dispersion and accumulation in urban areas (Wu et al., 2023).
- Meteorological Data (Precipitation and Wind): Precipitation data was acquired from the Global Precipitation Measurement (GPM) mission, while wind patterns were analyzed using wind rose diagrams derived from local meteorological stations. These datasets are crucial for understanding how weather conditions impact air pollutant levels (He et al., 2017).
- Google Earth Engine (GEE): GEE was used as the primary platform for processing and analyzing large-scale satellite data. GEE's cloud-based infrastructure allows for efficient handling of time-series data and integration of multiple datasets (Ghosh et al., 2022).

2.3. Methodology

2.3.1 Data Preprocessing

All satellite data were preprocessed to ensure consistency and accuracy. For Sentinel-5P data, cloud-masking algorithms were applied to remove any data points affected by clouds or haze. MODIS LST and NDVI data were similarly processed to filter out erroneous values due to atmospheric disturbances or sensor errorsDEM data were resampled to match the spatial resolution of the pollution data, ensuring accurate topographical analysis.

2.3.2 Air Pollution Analysis (NO2 and CH4)

The main pollutants analyzed in this study were NO2 and CH4, both of which are critical indicators of urban air quality. Sentinel-5P data were used to map the concentrations of these pollutants across Jakarta and Seoul. The TROPOMI sensor aboard Sentinel-5P provides high-resolution data on these gases, allowing for precise spatial and temporal analysis.

2.3.3 Land Surface Temperature (LST) Analysis

MODIS LST data were used to investigate the urban heat island effect in both cities. The relationship between LST and pollutant concentrations (NO2 and CH4) was analyzed through spatial correlation techniques. Higher LST is often associated with increased pollutant levels due to stagnant air and lower dispersion rates, especially in densely populated urban areas.

2.3.4 Vegetation Cover (NDVI) Analysis

NDVI data were used to assess the vegetation cover in both Jakarta and Seoul. A higher NDVI value indicates a greater presence of green vegetation, which can absorb and reduce air pollutants. The study analyzed the relationship between NDVI and pollutant levels to determine how vegetation helps in mitigating air pollution in urban settings.

2.3.5 Topographical Analysis (DEM and Slope)

Using DEM data, the topographical features of both cities were analyzed to understand their impact on pollution dispersion. Areas with higher elevation or steep slopes often experience different pollutant dispersion patterns compared to flat, low-lying areas. This analysis helped to explain spatial variations in pollution concentrations across different parts of the cities.

2.3.6 Meteorological Analysis (Precipitation and Wind Patterns)

Precipitation data were analyzed to examine its role in reducing air pollutant concentrations, as rain can wash away airborne particles and gases. Wind rose diagrams were used to study the dominant wind directions in both cities and their effects on pollutant dispersion. Wind patterns significantly influence how pollutants are transported and concentrated within urban areas.

2.3.7 Google Earth Engine (GEE) for Data Processing

GEE was used as the primary platform for data processing and analysis. This cloud-based tool allowed for seamless integration of various datasets, including satellite images, meteorological data, and topographical maps. GEE's ability to handle large-scale spatial data in a time-efficient manner was essential for conducting this multi-city, multi-variable analysis.Using GEE, the study performed time-series analyses to observe temporal changes in NO2 and CH4 levels in relation to vegetation cover, LST, and meteorological conditions.

3. Result

3.1 Surface Temperature Trends (1985-2020)

The analysis of surface temperature trends between 1985 and 2020 for both Jakarta and Seoul reveals significant variations in temperature patterns over the study period. Fig. 2 illustrates the temporal changes in temperature at 2 meters above ground level for the two cities.

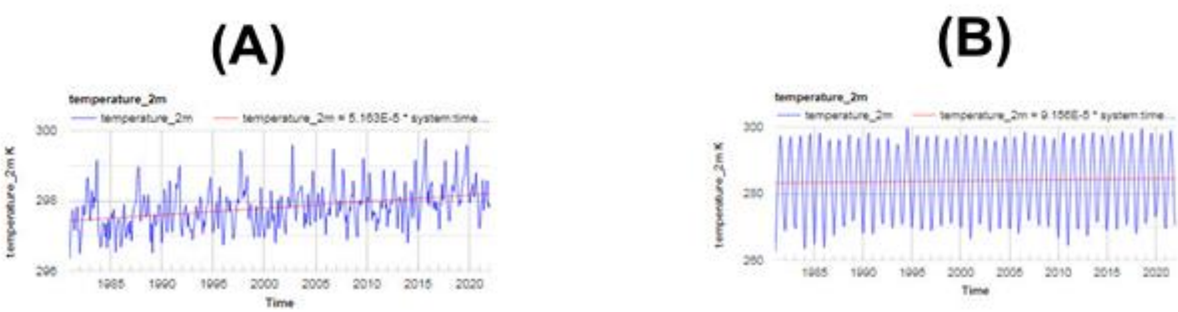

Fig. 2 - Temperature variation maps for Jakarta (A) and Seoul (B)

Fig. 2(A): Represents the temperature trend for Jakarta. The observed temperature fluctuations exhibit a slight upward trend over the years, as indicated by the red line (a positive slope of 0.1085 K). The temperature range fluctuates between approximately 290 K to 310 K. There are noticeable seasonal variations, and the overall increasing trend suggests a potential link between urban heat island effects and climate change impacts in the city, which may correlate with increased urbanization and changes in vegetation cover. This upward trend implies that the surface temperature in Jakarta has steadily increased over the last few decades.

Fig. 2(B): Shows the temperature trend for Seoul, where a relatively stable temperature pattern is observed. The temperatures in Seoul remain within a narrower range of around 270 K to 300 K, with fewer extreme fluctuations compared to Jakarta. The temperature trend line shows a positive slope (0.1054 K), indicating a very slight increase in surface temperature over the years. This suggests that while Seoul is subject to seasonal temperature variations, the long-term impact of urbanization and climate change is less pronounced than in Jakarta.

These results are crucial in understanding how surface temperatures have responded to urbanization and other environmental factors, which directly influences pollution levels and vegetation cover. The upward trend, particularly in Jakarta, may also indicate increased vulnerability to heatwaves and other climate-induced risks.

3.2 Precipitation Trends

The precipitation data for Jakarta and Seoul (Fig. 3) provide insight into the temporal distribution of total precipitation and hourly precipitation rates, which are crucial factors in understanding their relationship with temperature and pollution levels.

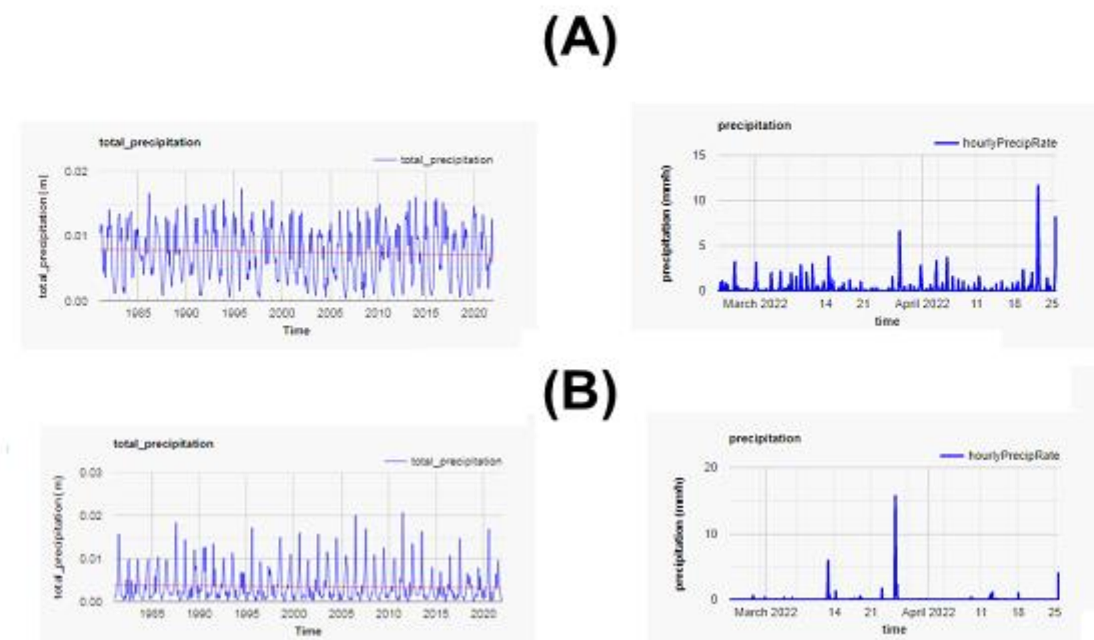

Fig.3 - Precipitation distribution maps for Jakarta (A) and Seoul (B)

Fig. 3(A): Displays the total and hourly precipitation trends for Jakarta.

On the left, the total precipitation (1985-2020) demonstrates a pattern of consistent fluctuations, with peak values occurring regularly. While the trendline remains mostly stable, the variability in rainfall could be influenced by seasonal monsoons and tropical climatic conditions that affect Jakarta. The city receives regular high rainfall, and although no significant long-term increase is evident, variations in the intensity and distribution of rain events are noticeable.

On the right, the hourly precipitation data from March to April 2022 further show sporadic spikes, with certain hours experiencing up to 15 mm of rain. These spikes are likely associated with intense short-duration storms, characteristic of tropical environments.

Fig. 3(B): Presents the precipitation trends for Seoul.

Similar to Jakarta, the total precipitation data from 1985 to 2020 show some variability, though with lower peak values compared to Jakarta. The overall trend suggests stable rainfall with no significant long-term changes, but with less frequency and intensity than observed in Jakarta. The peaks are more scattered, indicative of the city's temperate climate.

The hourly precipitation data from March to April 2022 (right) show fewer and more defined peaks than in Jakarta. While certain hours experience up to 8 mm of rain, there are fewer instances of high-intensity rainfall, reflecting the more moderate and seasonal nature of precipitation in Seoul compared to Jakarta.

3.3. Methane (CH4) Concentration Changes

Fig. 4 provides a comparison of methane (CH4) concentration changes in the cities of Jakarta and Seoul. The spatial and temporal variations are critical in understanding the impact of methane pollution on air quality in these urban areas.

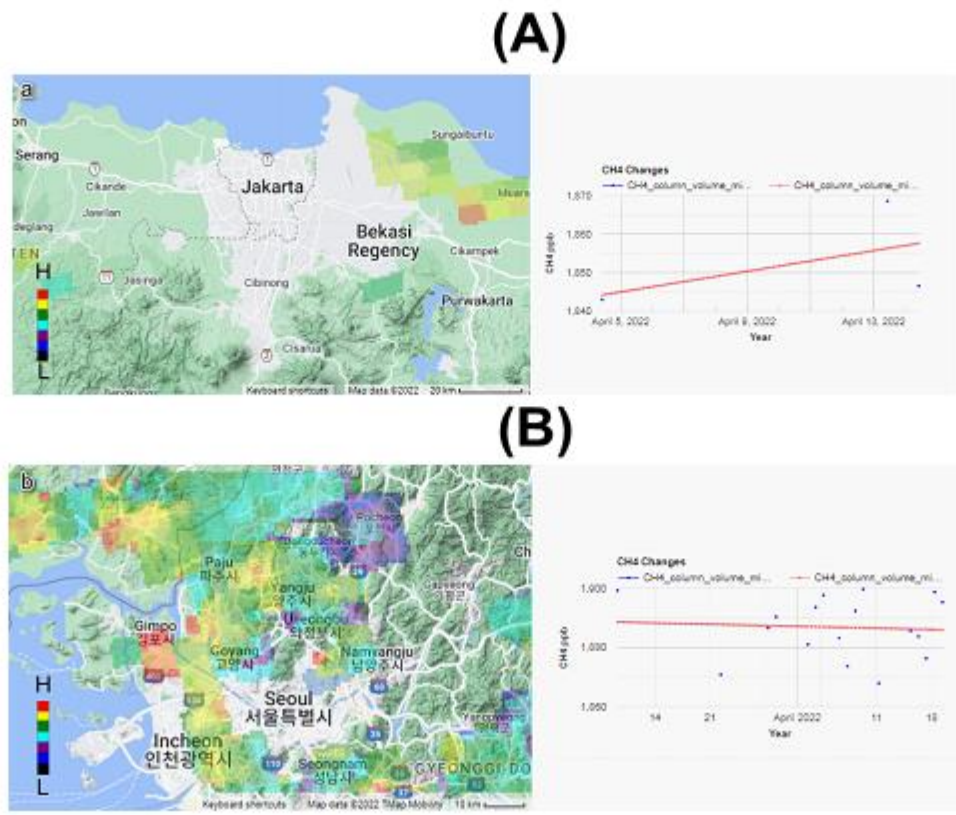

Fig.4 -CH4 concentration trends for Jakarta (A) and Seoul (B)

Fig. 4(A): Illustrates the CH4 concentration for Jakarta.

The map on the left shows varying levels of methane concentration across different parts of the city, with higher concentrations (marked as "H") predominantly found in central Jakarta and surrounding areas. The color gradient legend indicates the regions with high and low methane levels, with urban and densely populated zones showing elevated pollution levels.

On the right, the temporal CH4 trend from April 5 to April 13, 2022, shows a steady increase in CH4 concentration. This increase could be attributed to urban activities, industrial emissions, and vehicular pollution, which contribute to methane buildup in the atmosphere. The trendline reveals a positive growth in methane levels over the short period, suggesting a rising pollution pattern that needs to be monitored.

Fig. 4(B): Depicts the CH4 concentration for Seoul.

The map on the left shows methane distribution across Seoul, with varied concentrations spread across different districts. Some of the highest concentrations are observed in regions like Gimpo and Incheon, areas that are heavily industrialized and have major transportation hubs. The "H" zones highlight the pollution hotspots.

On the right, the temporal analysis shows relatively stable CH4 levels between April 5 and April 13, 2022. The overall methane concentration remains lower compared to Jakarta, with no significant upward trend during this period. This stability could be related to Seoul's stricter pollution control measures and the seasonal atmospheric conditions that help disperse pollutants more effectively.

3.4. Nitrogen Dioxide (NO2) Concentration Changes

Fig. 5 demonstrates the variation in nitrogen dioxide (NO2) concentrations across Jakarta and Seoul. NO2 is a critical pollutant, typically originating from vehicle emissions, industrial processes, and other combustion-related activities, which can severely impact air quality and human health.

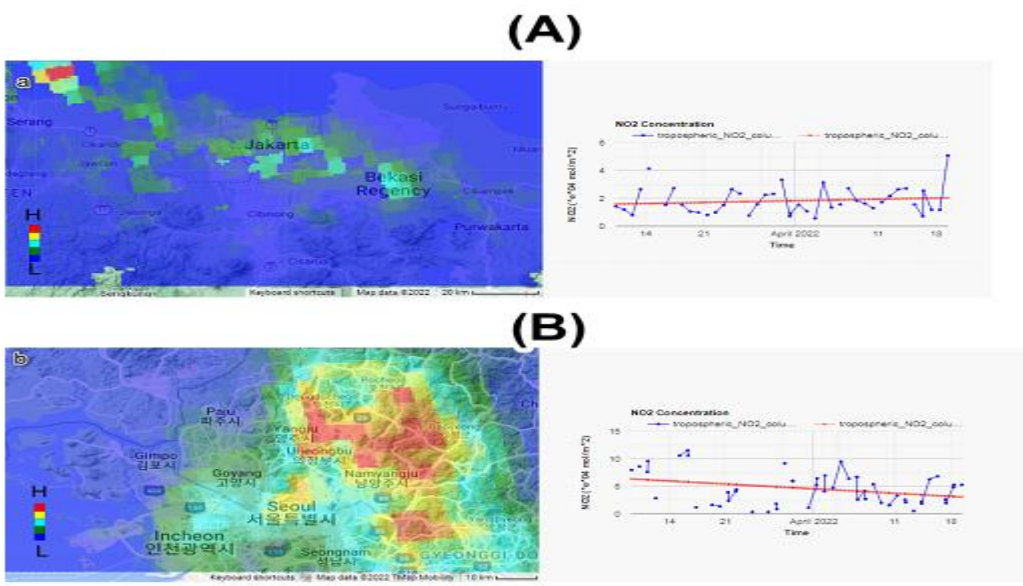

Fig.5 – NO2 concentration trends for Jakarta (A) and Seoul (B).

Fig. 5(A): Shows the NO2 concentration for Jakarta.

The map on the left illustrates the spatial distribution of NO2 across Jakarta. The concentration of NO2 is shown in different regions, with the higher concentrations marked as "H" in areas where urban and industrial activities are concentrated, such as central Jakarta. The color scale highlights regions of high and low NO2 pollution levels.

The temporal analysis on the right depicts the daily NO2 levels from April 5 to April 13, 2022. There is a noticeable fluctuation in NO2 levels, with peaks observed during specific days, possibly corresponding to increased traffic or industrial activity. The trendline indicates a slight increase in NO2 levels during this period, reflecting the impact of rapid urbanization and industrialization in the area.

Fig. 5(B): Displays the NO2 concentration for Seoul.

The map on the left illustrates NO2 levels across the Seoul metropolitan area. The highest concentrations are found in central and southern districts such as Namyangju and Goyang, where industrial zones and heavy traffic are prominent. The color-coded map provides clear indications of the pollution hotspots, marked as "H."

The right-side graph presents NO2 concentration trends from April 5 to April 13, 2022, showing a more variable pattern compared to Jakarta. Despite the fluctuations, the overall NO2 levels appear slightly lower than in Jakarta, indicating better air quality management or environmental factors that help in the dispersion of pollutants.

3.5. Land Surface Temperature (LST) Variations

Fig. 6 illustrates the Land Surface Temperature (LST) distribution across Jakarta and Seoul based on satellite imagery. LST is a critical metric in analyzing urban heat islands and understanding the impacts of urbanization on local climates.

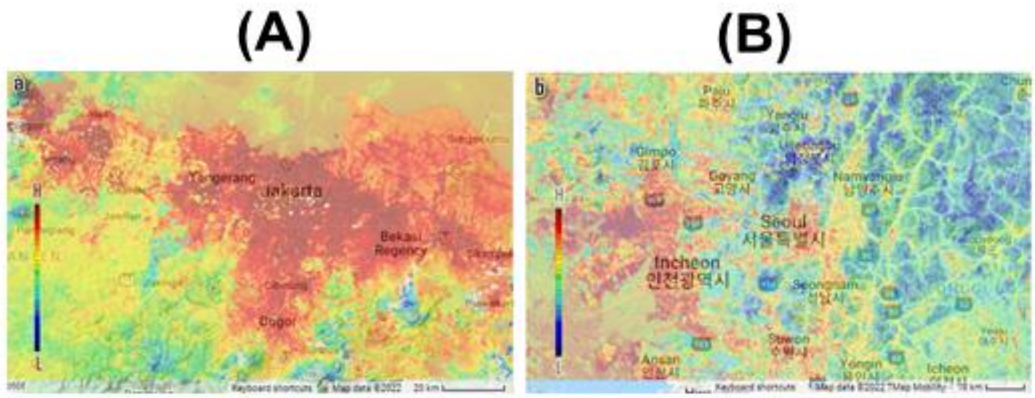

Fig.6 - Land Surface Temperature (LST) maps for Jakarta (A) and Seoul (B)

Fig. 6(A): LST in Jakarta

In Jakarta, the highest LST values are predominantly observed in the central and western regions of the city. These areas are densely populated with significant urban development, characterized by high-rise buildings, roads, and industrial activities. The central parts of Jakarta, including regions around Menteng and Gambir, show elevated surface temperatures due to the urban heat island effect.

The eastern parts, particularly towards the regions of Bekasi, display moderately high LST values, but not as intense as the central areas. Meanwhile, the southern and northern regions, especially near Bogor (south) and north coastlines, exhibit relatively lower temperatures. The northern coastal areas benefit from proximity to water bodies, which help to moderate the temperatures, while the southern regions are somewhat cooler due to forest cover and less dense urbanization.

Fig. 6(B): LST in Seoul

In Seoul, the LST distribution reveals a slightly different pattern. The highest temperatures are found in the north-central parts of the city, particularly around Seodaemun-gu and Jongno-gu, which are densely populated and industrialized. These areas have less green space and more concrete infrastructure, leading to higher heat absorption and retention.

The western and southern areas, including regions near Incheon and Gimpo, exhibit moderate temperatures, while the eastern and northern outskirts of Seoul, especially near the Gyeonggi-do region, display lower LST values. These cooler areas benefit from a combination of more vegetation, open spaces, and the proximity to mountain ranges such as the Bukhansan National Park in the north and Namhansanseong in the east.

Urban Heat Islands and Environmental Management

The comparative LST analysis between Jakarta and Seoul indicates that:

Jakarta faces higher and more widespread heat intensification, particularly in its central and western regions. The lack of sufficient vegetation and the concentration of industrial activities exacerbate the urban heat island effect.

Seoul, on the other hand, experiences lower overall LST levels, with the highest values concentrated in its north-central areas. The presence of vegetation, parks, and more dispersed urban planning, particularly in the eastern and northern regions, helps to mitigate heat buildup.

3.6. Analysis of Vegetation Cover and Its Spatial Distribution in Jakarta and Seoul Using NDVI

Fig.7 illustrates the NDVI (Normalized Difference Vegetation Index) for the cities of Jakarta (A) and Seoul (B), highlighting the distribution and density of vegetation cover in these regions.

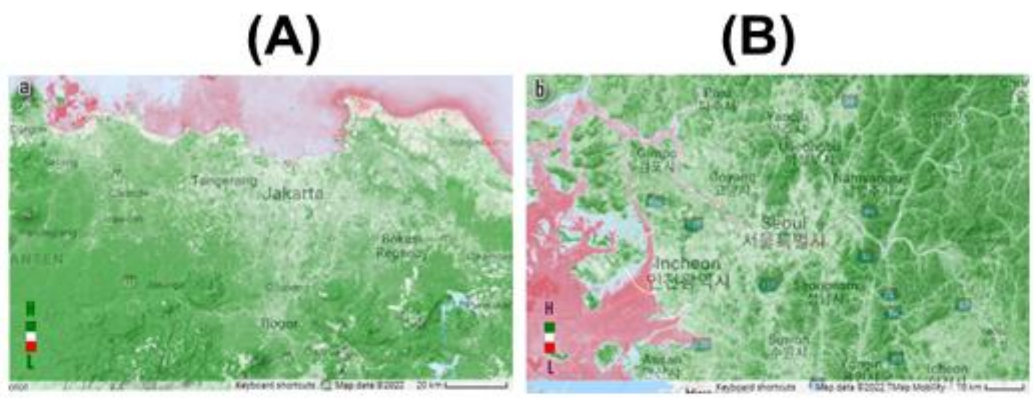

Fig.7-NDVI maps for Jakarta (A) and Seoul (B)

Fig. 7(A): NDVI in Jakarta

In Jakarta, the northern areas close to the coastlines, particularly around cities like Tangerang and Bekasi, show lower NDVI values (in red), which is attributed to the reduced vegetation cover due to urban and industrial development.

The southern and western regions, especially near Bogor and Depok, exhibit higher NDVI values (in green), indicating more vegetation cover. These areas are mostly forested and have significant natural green spaces, which help moderate temperatures and contribute to the local ecosystem's stability.

Fig. 7(B): NDVI in Seoul

In Seoul, central and northern regions, such as Seodaemun-gu and Jongno-gu, have lower NDVI values (in red), due to dense urbanization and high levels of construction.

Conversely, the western and southern areas, particularly near Incheon and Gimpo, display higher NDVI values. These regions feature larger parks and green spaces, contributing to better air quality and lower urban heat effects. The abundance of vegetation in these areas supports biodiversity and offers environmental benefits.

3.7. Analysis of DEM (Digital Elevation Model) in Jakarta and Seoul

Fig. 8 displays the DEM for the cities of Jakarta (A) and Seoul (B). In Jakarta, the DEM indicates higher elevation areas primarily concentrated in the southern region near Bogor and the surrounding mountainous areas, while the central and northern parts, including Jakarta city itself, are at lower elevations. In contrast, Seoul presents more variation in elevation, with highlands and mountains distributed throughout the city, particularly in the northern and eastern parts. The central areas of Seoul, including the vicinity of the Han River, generally exhibit lower elevations.

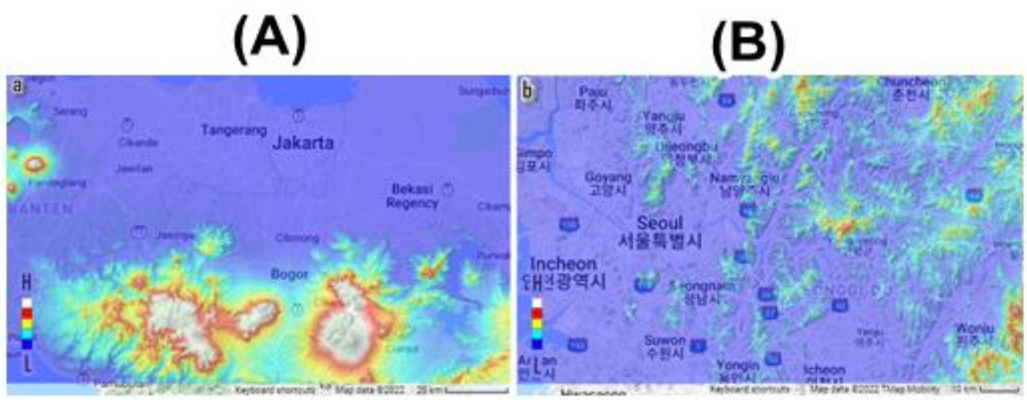

Fig. 8-Digital Elevation Model (DEM) for Jakarta (A) and Seoul (B)

3.8. Slope Variation in Jakarta and Seoul

Fig. 9 illustrates the slope variation for Jakarta (A) and Seoul (B). In Jakarta, the steeper slopes are concentrated in the southern and southeastern regions, particularly around Bogor and the nearby mountainous terrain, where the elevation changes are more pronounced. The central and northern parts of Jakarta, including the city itself, exhibit much gentler slopes. In contrast, Seoul has more extensive areas with varying slopes due to the city's mountainous topography. The steeper slopes are primarily located in the northern, eastern, and southeastern parts of the city, while the central region near the Han River features relatively flatter terrain.

Fig. 9-Slope changes in Jakarta (A) and Seoul (B)

3.9. Wind pattern using wind rose Analysis for Jakarta and Seoul

Fig. 10 presents the Wind Rose diagrams for Jakarta (A) and Seoul (B), illustrating the dominant wind directions and patterns for these two cities.

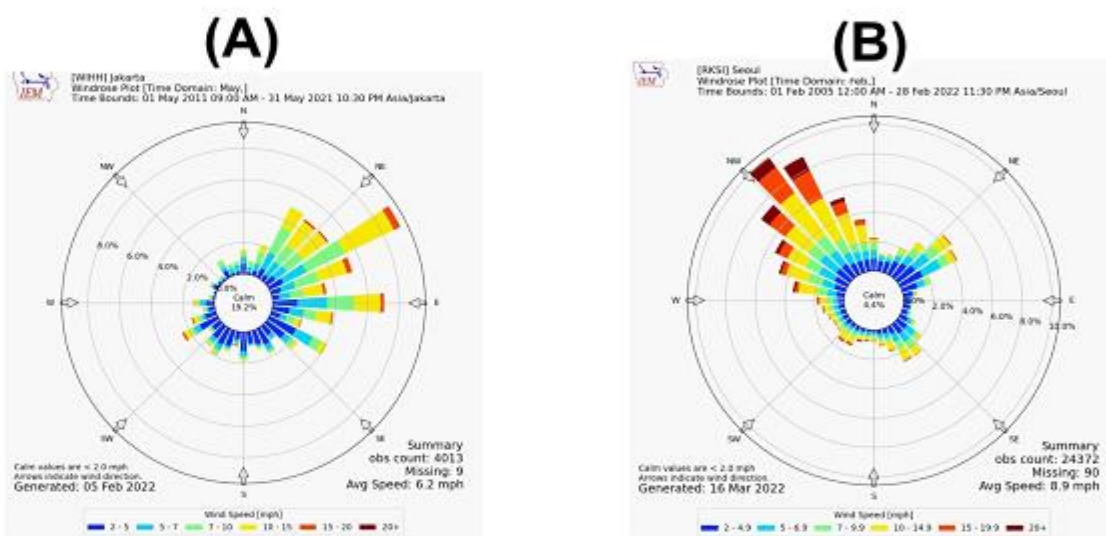

Fig.10-Wind Rose diagrams showing wind patterns for Jakarta (A) and Seoul (B)

Jakarta (A):

The Wind Rose indicates that the prevailing wind direction in Jakarta is predominantly from the northeast. This suggests that winds from this direction are the most frequent and potentially the strongest in the area. The northeastern winds may be influenced by the regional climate and geographical factors such as proximity to water bodies and local weather systems.

Seoul (B):

In contrast, the Wind Rose for Seoul shows that the dominant wind direction is from the northwest. Winds from this direction are most common, particularly during specific seasons such as winter when cold winds blow from Siberia, influencing the regional climate.The northwestern winds are characteristic of Seoul's mountainous surroundings, which affect local airflow patterns.

4. Discussion

This study investigates the intricate relationships between land surface temperature (LST), vegetation cover (measured by NDVI), precipitation, and the concentrations of NO2 and CH4 pollutants in Jakarta, Indonesia, and Seoul, South Korea. The findings reveal significant interactions among these environmental factors, providing insight into their combined effects on urban air quality.

The study employed remote sensing data and techniques using GEE to analyze LST and NDVI data, alongside statistical methods to correlate these variables with pollution levels. Precipitation data was also considered to evaluate its influence on vegetation and pollutant concentrations. The study focused on examining how topography, represented by slope and elevation, alongside wind patterns, influenced pollutant dispersion in both urban settings.

Impact of Vegetation Cover on Pollution Levels (H1): The analysis demonstrated that higher vegetation cover (NDVI) correlates with lower levels of NO2 and CH4 in both Jakarta and Seoul. This finding aligns with prior studies (Fernández-Maldonado et al., 2024) that highlighted the role of urban greenery in mitigating air pollution. In Jakarta, regions with denser vegetation, particularly in the southern and eastern parts, exhibited significantly lower pollutant concentrations. Conversely, urban areas with sparse vegetation, especially in the northern regions, showed elevated NO2 and CH4 levels, confirming our hypothesis that increased vegetation correlates with improved air quality.

Relationship Between LST and Pollution Levels (H2): The study found a positive correlation between increased land surface temperature and elevated concentrations of NO2 and CH4. These results are consistent with previous research (Fuladlu et al., 2021), which indicated that higher temperatures can exacerbate photochemical reactions, increasing the formation of secondary pollutants. Specifically, in Seoul, areas with higher LST, particularly in urban heat islands, recorded elevated pollutant levels. This observation supports the hypothesis that urban heat exacerbates air pollution.

Influence of Topography on Pollution Distribution (H3): The topographical analysis revealed that elevation and slope significantly affect pollutant dispersion. In both cities, lower elevations tended to trap pollutants, while higher elevations, particularly in the hilly areas surrounding Jakarta and Seoul, facilitated pollutant dispersion. This finding aligns with previous studies (Zhang et al., 2018), which emphasized the importance of topography in shaping air quality patterns. The southeastern slopes of Jakarta, for example, were associated with lower concentrations of pollutants due to their elevated position.

Role of Wind Patterns in Pollution Dispersion (H4): The wind rose data illustrated that prevailing wind patterns play a crucial role in the spatial distribution of pollutants. In Jakarta, the predominant north-easterly winds contributed to the dispersal of pollutants from industrial areas towards less populated regions. In contrast, in Seoul, the north-westerly winds were found to carry pollutants from urban centers to the outskirts, highlighting the importance of wind direction in pollution distribution. This is consistent with findings from Akinyemi et al. (2016), which pointed out the critical role of meteorological factors in air quality management.

This comparative analysis underscores significant differences and similarities between Jakarta and Seoul concerning the interplay of environmental variables and pollution levels. While both cities exhibit similar trends regarding vegetation and pollution relationships, Jakarta faces unique challenges due to its tropical climate and extensive urbanization. Conversely, Seoul's pollution levels are influenced by its geographic location and seasonal climatic variations.

5. Conclusion

This study has effectively explored the intricate relationships between land surface temperature (LST), vegetation cover, precipitation, and air pollutants (NO2 and CH4) in Jakarta, Indonesia, and Seoul, South Korea. The findings demonstrate that:

Vegetation Cover: Higher vegetation cover significantly correlates with lower concentrations of NO2 and CH4 in both cities. Areas with abundant green spaces effectively mitigate urban air pollution.

Land Surface Temperature: An increase in LST is positively associated with higher levels of NO2 and CH4, indicating that urban heat exacerbates air pollution levels. This trend is particularly evident in urban heat islands, especially in densely populated regions.

Topography: The role of topographical features such as elevation and slope significantly influences the dispersion of pollutants. Lower elevation areas tend to trap pollutants, while higher elevations facilitate their dispersion.

Wind Patterns: Prevailing wind patterns play a crucial role in determining the spatial distribution of pollutants. Understanding wind dynamics is essential for effective air quality management strategies.

The comparative analysis highlights that while Jakarta and Seoul share common trends regarding vegetation and pollution relationships, the challenges faced by each city differ due to climatic and geographic factors.

Based on the findings of this study, the following recommendations are proposed:

- Urban Green Spaces: Policymakers in both Jakarta and Seoul should prioritize the development and maintenance of urban green spaces. Increasing vegetation cover can serve as a natural solution to combat air pollution and improve urban air quality.
- Urban Planning: Integrating topographical considerations into urban planning is essential. Strategies should include developing infrastructure that considers elevation and slope to facilitate pollution dispersion and minimize pollutant trapping.
- Monitoring Systems: Implementing robust air quality monitoring systems that incorporate real-time data on vegetation cover, LST, and meteorological conditions can enhance the understanding of pollution dynamics. This data will be critical for timely interventions and public awareness campaigns.
- Public Awareness Campaigns: Educational initiatives aimed at increasing public awareness about the importance of green spaces and sustainable practices in reducing air pollution can empower communities to participate actively in environmental conservation efforts.
- Further Research: Future studies should focus on the long-term impacts of climate change on vegetation dynamics, land surface temperatures, and pollutant dispersion patterns in urban environments. Additionally, examining the interactions between different pollutants can provide a more comprehensive understanding of air quality issues.

In summary, addressing the challenges posed by urban air pollution requires a multi-faceted approach that combines environmental planning, community engagement, and continuous research. By adopting these strategies, Jakarta and Seoul can move towards achieving cleaner air and improved quality of life for their residents.

Acknowledgements

The authors would like to express their gratitude to all individuals and institutions who provided support and guidance during the course of this research.

Declarations

Funding Information (Private funding by author)

Conflict of Interest /Competing interests (None)

Availability of Data and Material (Data are available when requested)

Consent to Publish (Author consent to publishing)

Authors Contributions (Author contributed equally to the data collection, analysis, and interpretation. Author critically reviewed, refined, and approved the manuscript.)

Code availability (Not applicable)

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