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Analysis of Air Pollution levels in Padang City with Satellite Imagery Appromixmation

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ABSTRACT

Environmental issues, particularly air pollution, are prevalent in urban areas, often stemming from human activities such as industrial operations and increased vehicle usage, leading to higher energy consumption, emissions, and air pollution. This study focuses on Padang City, Indonesia, where industrial, trade, and transportation sectors significantly contribute to the economy and environmental challenges, especially air pollution. One of the primary pollutants of concern is PM 2.5 (Particulate Matter), which poses severe health risks, including respiratory and cardiovascular diseases, when inhaled over extended periods. This research employs a satellite imagery-based approach, utilizing Sentinel-5P data, to monitor and analyze air pollution levels in Padang City. The study integrates satellite-derived Aerosol Index (AI) with ground-based PM 2.5 measurements to establish a regression model for estimating PM 2.5 concentrations. The research also calculates the Air Pollution Standard Index (ISPU) based on Indonesian environmental regulations to assess air quality. The spatial distribution of air pollution levels was influenced by wind direction and land use, with industrial and mining activities identified as significant contributors to high PM 2.5 levels. In conclusion, this study demonstrates the effectiveness of satellite imagery in monitoring air pollution, providing valuable insights into pollutant sources and distribution patterns. However, the accuracy of PM 2.5 estimation can be further improved by increasing the number of ground-based monitoring stations. This research highlights the importance of integrating satellite data with ground measurements for effective air quality management in urban areas.

Keywords: Air Pollution, PM 2.5, Sentinel 5P, ISPU, Padang City

1. Introduction

Environmental issues are prevailing circumstances engulfing numerous cities. Human activities hold a key role in these issues, such as industrial economic activities, which also contribute to the growth of vehicle usage that causes energy consumption, emissions, and air pollution ultimately increase, resulting in significant consequences [1]. Air pollution is closely related to social, agricultural, transportation, and urban planning issues. According to [2], there are two phases of air quality mitigation. The first phase focuses on emergency responses when pollution and its impacts are visible, while the second phase aims for gradual and sustainable air quality improvement through evidence-based policies guided by scientific research. Major cities in Indonesia, including Padang, are susceptible to these issues. The economy of Padang is supported by the industrial sector, followed by trade and transportation sectors. With these three sectors driving the economy, Padang is also affected by environmental issues, particularly air pollution. Particulate Matter 2.5 (PM 2.5) is one of the pollutants that cause air pollution. PM2.5 particles can be inhaled and settled in the respiratory organs. Long-term exposure to PM2.5 can lead to acute respiratory infections.

The Indonesian government, based on Government Regulation No. 41 of 1999 on threshold limits [3], has set the ambient air threshold limit for PM2.5 at 65 µg/m³ (24-hour average). Research in China has shown that short-term exposure to PM2.5 increases the risk of cardiovascular issues and various physiological respiratory disorders, such as reduced lung function and respiratory tract irritation, especially in individuals with a history of similar diseases [4, 5]. According to the [6], PM2.5 can also cause acute respiratory infections (ARI), lung cancer, cardiovascular diseases, premature death, and chronic obstructive pulmonary disease. Monitoring and analyzing air pollution can be done by satellite imagery approximation. Remote sensing satellite imagery can be used as part of environmental monitoring. Real-time observation and visualization of ongoing events on the Earth's surface are now possible through satellite remote sensing. This innovative technology offers several advantages, including large-scale coverage, long-term study effectiveness, and relatively low costs. Thus, it is considered one of the primary methods for obtaining information on global aerosol distribution [7]. Urban air quality control through regulation will be effective if key areas are thoroughly monitored, allowing for the measurement of emissive pollutants and understanding their chemical processes in the atmosphere. Satellite-based information and ground station measurements are the main components of air quality monitoring systems [8-10]. Multi-spectral remote sensing satellite imagery has several sensors that can be adjusted to meet environmental monitoring needs and offers broad spatial and temporal recording scales [11]. One commonly used satellite for monitoring air quality changes is Sentinel-5P, which focuses on air quality and climate interactions.

Given that air pollution has become a major global concern, Copernicus has introduced the Tropomi instrument, which can map various trace gases affecting air quality and climate, including nitrogen dioxide, ozone, formaldehyde, methane, carbon monoxide, and aerosols [12, 13]. The dataset provides both Near Real-Time (NRTI) and offline (OFFL) versions. With this method, research can be conducted efficiently in terms of time and resources, allowing for the distribution of PM2.5 and analysis of air pollution levels in Padang City.

2. Research method

This research was conducted in Padang City, located at 100°05'05" E – 100°34'09" E and 0°44'00" S – 1°08'35" S. The area of Padang City is 694.337 km², with 11 districts and 104 villages. In this study, 15 sample points were placed at several locations potentially serving as primary sources of PM2.5 pollutants, including industrial areas, steam-power plants, mining sites, and residential areas.

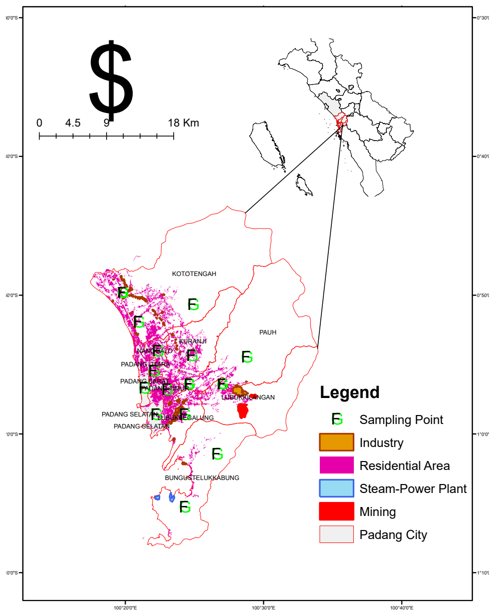


Figure 1. Research Location

The research stages begin with data collection, including Sentinel-5P Aerosol Index data, PM2.5 sample point data, PM2.5, historical data PM2.5 from IQAir, Padang City's land use, wind direction data, and Padang City's land use data. To obtain PM2.5 values from Sentinel-5P satellite imagery, regression analysis between the Aerosol Index and PM2.5 is required. 15 sample points will be regressed with Aerosol Index data. Sentinel-5P raster data needs to be converted into vector data so that the Aerosol Index data can be exported into tabular form and regressed with PM2.5 data. PM2.5 and Aerosol Index data are combined in tabular form, matching XY coordinates and recording dates. This research using following data such as:

Table 1. Data for research

Name	Month/Year	Source
Sentinel 5P Aerosol Index	January,February,March,May,June, November,December 2023	https://browser.dataspace.copernicus.eu
PM 2.5	January,February,March,May,June, November,December 2023	https://ads.atmosphere .copernicus.eu (ECMWF)
Land Use Padang City	2019	ATRBPN Gistaru
Wind Direction	January,February,March,May,June, November,December 2023	ECWMF
Padang City's Boundary	2019	Ina-Geoportal
Historical Data PM 2.5	January-December 2023	IQAir

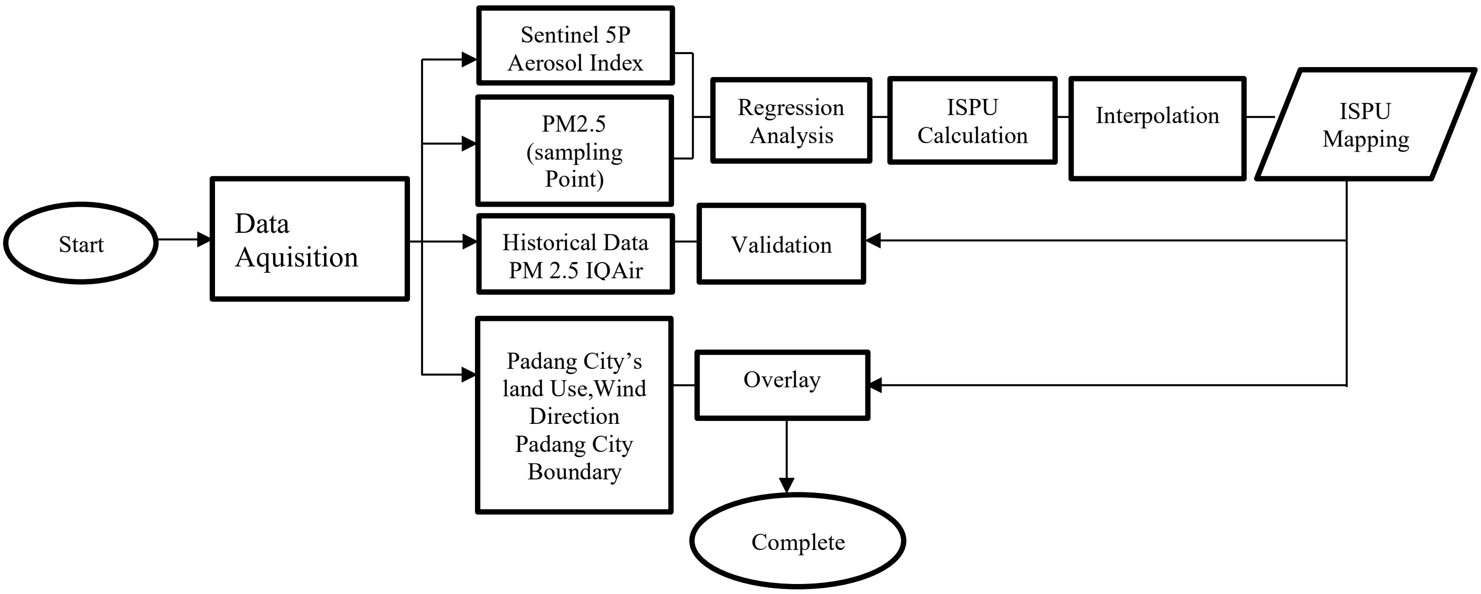


Figure 2. Research Stage

Regression analysis can then be performed. According to [14], regression analysis is needed to investigate the relationship between UVAI and PM2.5. For this purpose, several sample points are prepared and georeferenced with UVAI data. Simple Linear Regression (SLR) is a statistical method used for forecasting or predicting quality and quantity characteristics. The general equation for SLR in this research is:

$$y = a + bx \quad (1)$$

Where a is Intercept of y, b as Regression coefficient or slope of x, Y as Dependent variable (PM2.5), and X as independent variable (Aerosol Index). The regression analysis results provide a formula to calculate PM2.5 using the Aerosol Index values obtained from Sentinel-5P imagery. The PM2.5 values can then be converted into the Air Pollution Standard Index (ISPU) based on the Indonesian Ministry of Environment and Forestry Regulation No. P.14/MENLHK/SETJEN/KUM.1/7/2020. The ISPU can calculate by equation below:

$$I = \frac{Ia - Ib}{xa - xb}(Xx - Xb) + 1b \quad (2)$$

Table 2. ISPU Table

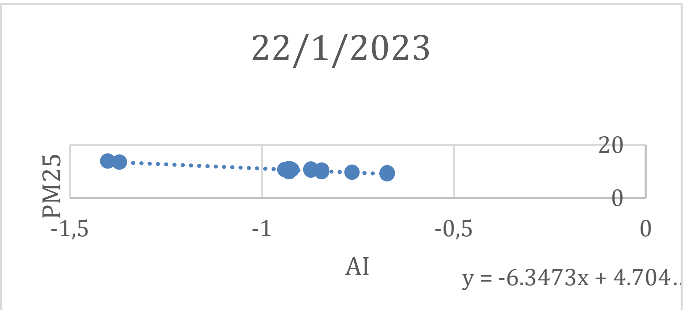
ISPU	24 Hour Particulate (PM 10) $\mu g/m^3$	24 Hour Particulate (PM2.5) $\mu g/m^3$	24 Hour Sulphur Dioxide (SO2) $\mu g/m^3$	24 Hour Carbon Monoxide (CO) $\mu g/m^3$	24 Hour Ozon (O3) $\mu g/m^3$	24 Hour Nitrogen Dioxide (NO2) $\mu g/m^3$	24 Hour Hydrocarbon (HC) $\mu g/m^3$
0-50	50	15,5	52	4000	120	80	45
51-100	150	55,4	180	8000	235	200	100
101-200	350	150,4	400	15000	400	1130	215
201-300	420	250,4	800	30000	800	2260	432
>300	500	500	1200	45000	1000	3000	648

Table 3. ISPU Category

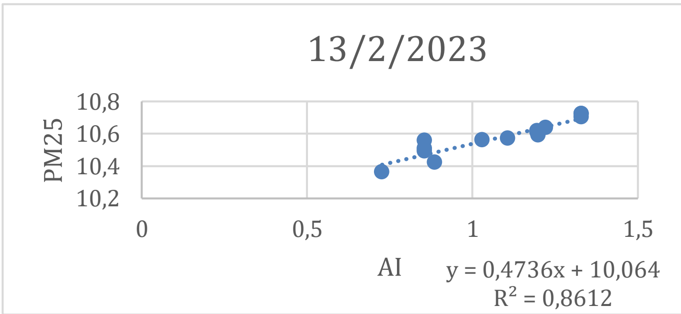
Category	Color	Range
Good	Green	1-50
Moderate	Blue	51-100
Unhealthy	Yellow	101-200
Very Unhealthy	Red	201-300
Dangerous	Black	≥ 301

3. Results and discussion

Results of regression analysis on every date can be seen below:



(a)



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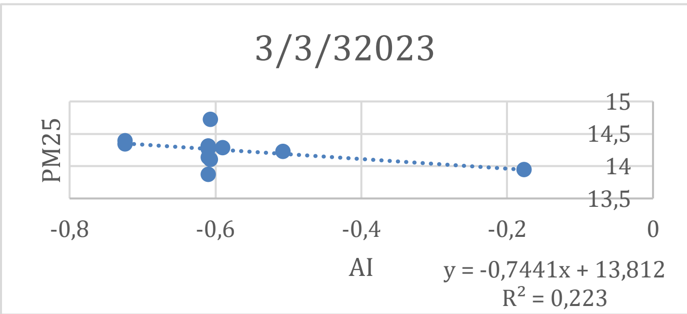
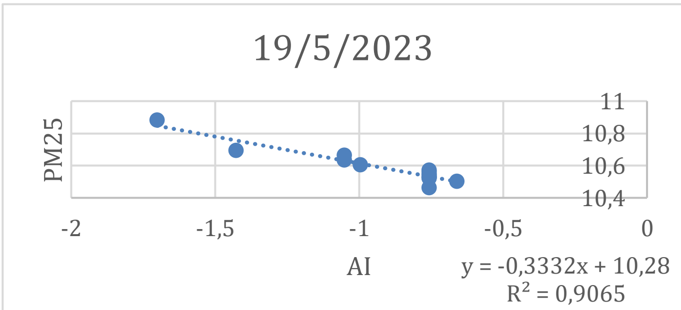


(c)



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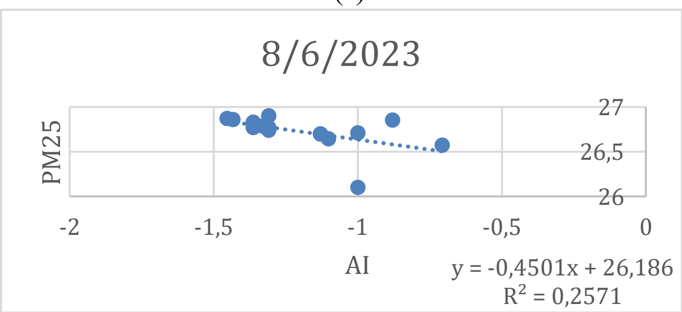
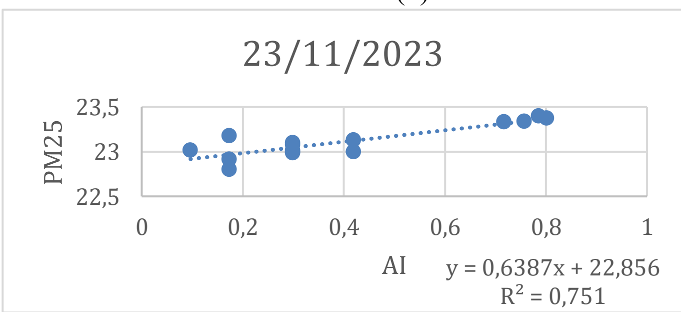
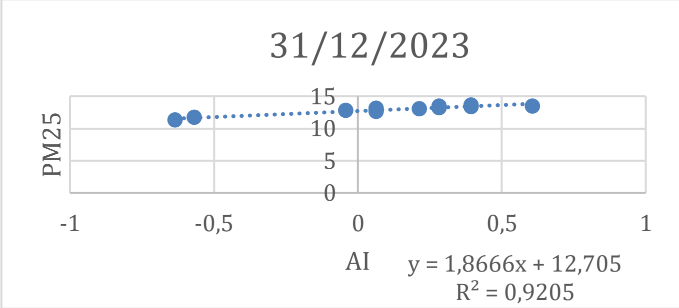


(e)



(f)



(g)

Figure 3. Regression analysis results (a) 22 January 2023, (b) 13 February 2023, (c) 3March 2023, (d) 19 May 2023, (e) 8 June 2023, (f) 23 November 2023, (g) 31 December 2023

Regression Analysis results can be described as:

Table 4. Regreesion Analysis Result

Date	R^2	Relation
22 January 2023	0.9302	Strong
13 February 2023	0.8612	Strong
3 March 2023	0.223	Weak
19 May 2023	0.9065	Strong
8 June 2023	0.2571	Weak
23 November 2023	0.751	Moderate
31 December 2023	0.9205	Strong

With formula retrieved from regression analysis results, PM 25 and ISPU value can be calculated and interpolated. The ISPU map was overlay with wind direction and land use of Padang City's to analyze the level of air pollution from the aspect of pollutant sources and distribution. The overlay results between the RTRW map and the air pollution map indicate that industrial, mining, and other activities contribute to the high levels of PM 2.5 air pollution, such as in Lubuk Kilangan District. However, the distribution of air pollution levels appears to be uneven. For example, in one district, some areas have higher pollution levels, while others have lower levels. On January 22, 2023, areas with high vegetation tended to have low to moderate levels of air pollution. For instance, vegetated areas in Bungus District had lower pollution levels, while vegetated areas in Koto Tangah District had moderate pollution levels. Urban areas had moderate pollution levels, which could be influenced by wind direction. On January 22, 2023, the wind direction was from the northwest and northeast towards the southwest and southeast, which also affected the distribution of pollution levels. On February 13, 2023, urban areas had lower pollution levels compared to areas with high vegetation, such as in Koto Tangah, Pauh, Kuranji, and Lubuk Kilangan Districts. This could be due to wind direction.

On February 13, 2023, the wind direction was from the northwest and northeast, west, and southwest towards the east, northeast, and southwest. On March 3, 2023, the distribution of air pollution levels appeared to be uniform in urban and industrial areas. Vegetated areas in Koto Tangah District had low pollution levels, while vegetated areas in Bungus and South Padang Districts also had low pollution levels. This could be influenced by wind direction. On March 3, 2023, the wind direction was from the northeast and northwest towards the southwest and southeast. On May 19, 2023, the distribution of air pollution levels appeared to be uneven. Highly vegetated areas in Koto Tangah and Bungus Districts had higher pollution levels compared to urban areas. This could be influenced by wind direction, which was mostly towards the south and southwest. On June 8, 2023, the distribution of air pollution levels was almost uniform in vegetated areas in Koto Tangah, Pauh, and Kuranji Districts. Additionally, residential areas had moderate pollution levels. Lubuk Kilangan and Bungus Districts had lower average pollution levels compared to other districts. The wind direction on June 8, 2023, was towards the southwest and southeast. On November 23, 2023, the distribution of air pollution levels was almost uniform in vegetated areas in Koto Tangah, Pauh, Bungus, and Kuranji Districts. Additionally, residential areas had lower pollution levels. Industrial areas and vegetated areas in Bungus District had moderate pollution levels. The wind direction on November 23, 2023, was towards the southwest, west, northeast, and southeast. On

December 31, 2023, the distribution of air pollution levels was almost uniform in residential and industrial areas, which had higher pollution levels. Some vegetated areas also appeared to have higher pollution levels, such as in Koto Tangah, Pauh, and Kuranji Districts. The wind direction on December 31, 2023, was uniform.

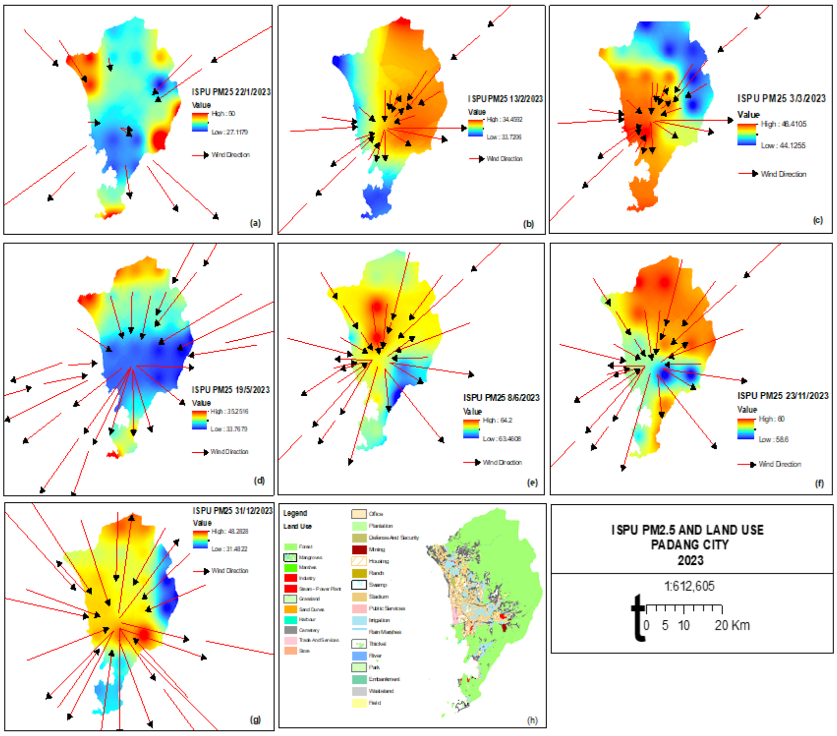


Figure 4. ISPU and Land Use Mapping (a) 22 January 2023, (b) 13 February 2023, (c) 3 March 2023, (d) 19 May 2023, (e) 8 June 2023, (f) 23 November 2023, (g) 31 December 2023,(h) Land Use

Air Pollution Trends and Validation displayed by graph down below

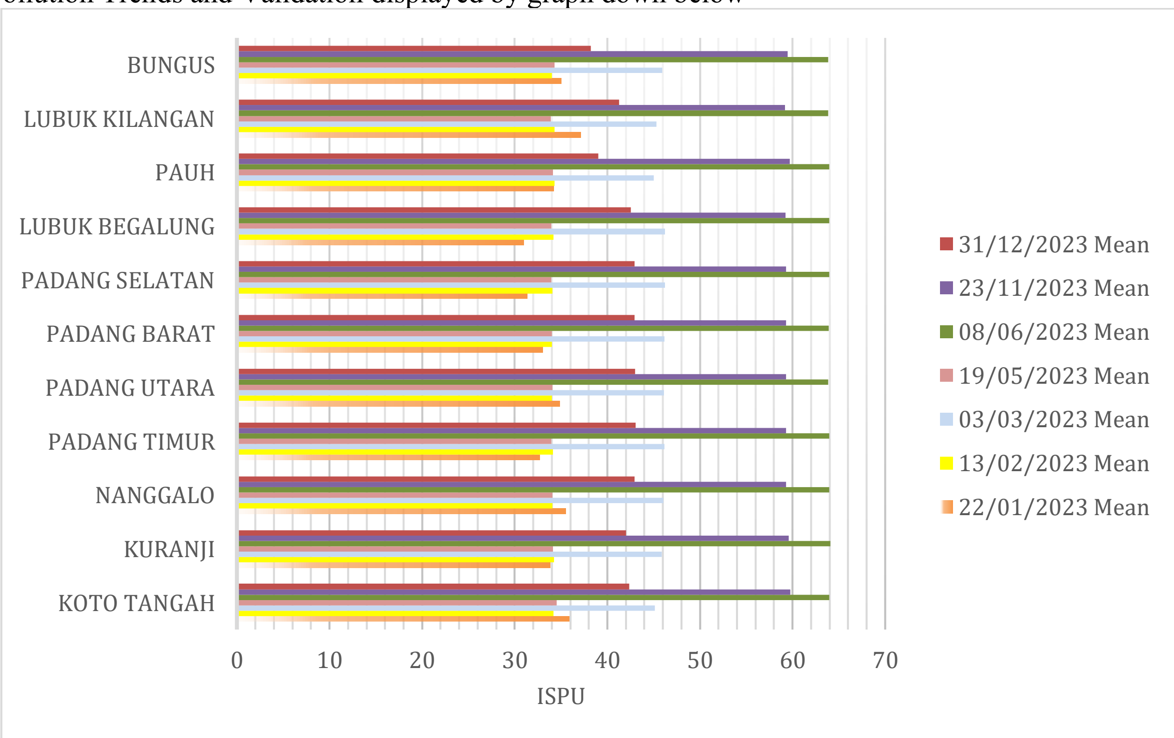


Figure 5. Air Polution Trends in Padang City

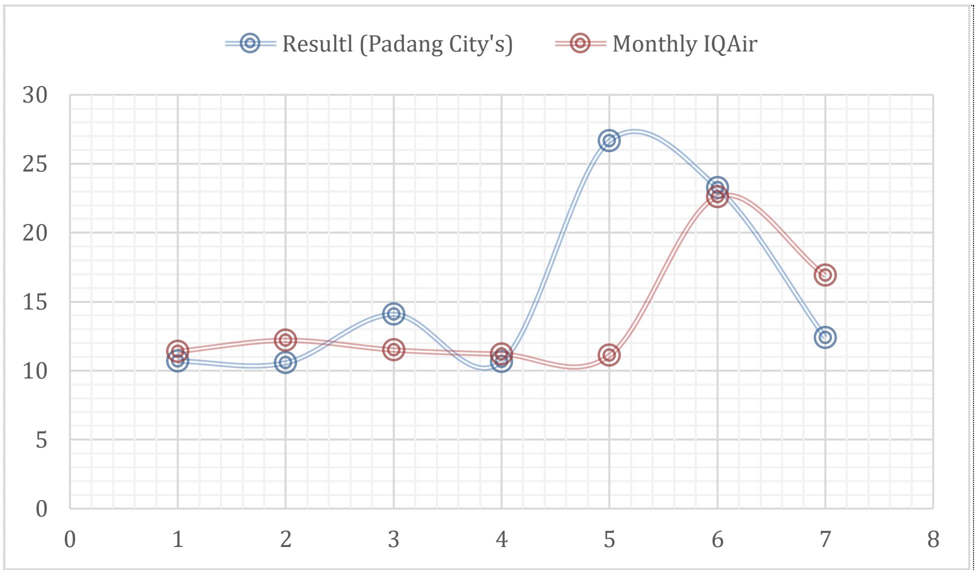


Figure 6. Validation

4. Conclusions

The satellite imagery-based approach for analyzing air pollution levels has strengths and weaknesses. The regression analysis shows that some recording dates have strong relationships between Sentinel-5P imagery and PM2.5, while others show weaker relationships. The ISPU map indicates that industrial, mining, and other activities contribute to high PM2.5 pollution levels. The distribution of air pollution is also influenced by wind direction. In the future, additional ground station data for validation should be increased to improve the accuracy of PM2.5 calculations.

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