Analysis of PM_{10} Air Quality Parameters Based on Satelite Images in The Cement Industrial Area

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Abstract *Industry is one of the main causes of global warming and a significant source of emissions. Growth in production rates in a cement industry sector can cause an increase in pollutant emission loads into the air, which has the potential to affect pollutant concentrations in ambient air. This study aims to analyze* PM_{10} *concentrations and the Air Pollution Index (API) category based on satellite imagery in the X Cement Industry.This research was conducted with Sentinel-2 and Landsat 8 OLI/TIRS satellite image data using algorithm calculations of* PM_{10} *air quality parameters, data used in this study are Sentinel 2 on October 16, 2023, and Landsat 8 on October 16, 2023. The highest* PM_{10} *concentration for Sentinel-2 occurred in the operational area (Coal Stock Pile Unit 2/3/4), whereas Landsat 8 detected its highest value in a residential area (in front of Kampung Sela Mosque). The results of the ambient air concentration analysis from satellite imagery were converted into the Air Pollution Standard Index (ISPU) with the Average* PM_{10} *ISPU results of 60,10 (Moderate). With an RMSE test of 93,06 for Residential Area and for the Operational 123,47. confirming that* PM_{10} *is the dominant pollutant of concern. These findings highlight the significance of particulate matter monitoring in emission prone zones using satellite based approaches.*

Keywords:Sentinel 2, Landsat 8, Cement Industry, ISPU, Remote Sensing

1. INTRODUCTION

Industry is one of the main causes of global warming and a significant source of emissions. With the increasing number of new products being manufactured every day, industry produces various types of waste that have an impact on the environment (Panigrahy, 2021). Emissions produced by the cement industry contain various hazardous chemicals that can harm human health and the environment, such as carbon monoxide and particles, as well as several micropollutants (Caronge, 2018). Dust is a type of solid aerosol formed by the mechanical separation of a material, such as crushing, grinding, and blasting. Dust is considered to be finely divided solid particles ranging in size from 0.1 µm to 100 µm. PM_{10} refers to particulates smaller than 10 µm (Wangsa et al., 2022).

In industrial and mining areas, sources of PM_{10} include wind erosion in mining areas, which causes the spread of particulates to receptor areas, emissions from rock blasting, the release of pollutants during material transport using vehicles such as trucks, and emissions caused by wind and blasting activities. Additionally, PM_{10} can also originate from the use of heavy machinery, construction processes, road dust generated by motor vehicles, and combustion from various sources (Ramdhana., 2022)

One method used to estimate air quality is by utilizing remote sensing satellite imagery, particularly for identifying emissions from industrial pollution sources. According to (Somvanshi et al., 2019), the advantage of remote sensing is that we can measure natural conditions and obtain information about the entire contamination system from satellites, even in very large areas. Satellite measurements provide a wide range when combined with field measurement models, helping to determine air quality in an easier and more cost-effective manner. Some common satellite images used to coordinate air quality changes include Landsat and Sentinel.

According to (Lin et al., 2019), remote sensing satellite images not only provide information on air quality changes but also present spatial and temporal variations that can be combined with field measurement data, yielding satisfactory results. One of the satellites used for air quality monitoring is Sentinel-2, and Landsat 8, which provides free image data with moderate spatial accuracy and high spectral resolution. This enables fast, economical, and easy-to-apply mapping methods (Lopes et al., 2020). Based on the background explained above, this study was conducted with the aim of analyzing PM_{10} concentrations and the ISPU (Air Pollution Standard Index) category based on Sentinel 2 and Landsat 8 satellite imagery in the X Cement Industry.

2. LITERATURE REVIEW

Remote sensing is the science of obtaining data on objects, areas, or events without direct contact. According to Idris (2019), there are three main stages in recognizing objects in images: detection (finding objects), identification (assigning characteristics such as shape, size, and location), and analysis (exploring further information). According to Noor (2012) in Herwanda (2016), every remote sensing application requires sensors with spatial, spectral, and temporal resolutions tailored to the needs of the coverage area, frequency, and type of energy detected.

The cement industry in Indonesia has a production capacity of up to 74 million tons per year. Cement is produced from a mixture of limestone, clay, and other additives. Limestone contains calcium oxide (CaO), while clay contains silicon oxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), and magnesium oxide (MgO) (Rahmadhani, 2017). The cement production process is a series of complex stages aimed at transforming raw materials into cement that is ready for use in construction activities. Caronge et al., 2018

Sentinel-2 is part of the European Space Agency's Copernicus program, designed for Earth observation with high spatial and spectral resolution. It captures multispectral imagery across 13 bands (10 m–60 m) and revisits the same location every 5 days. Sentinel-2 is commonly used for land cover analysis, environmental monitoring, and air quality studies due to its free access and consistent data.

Landsat 8, launched by NASA and USGS, provides multispectral imagery with spatial resolutions of 15 m (panchromatic), 30 m (visible/NIR/SWIR), and 100 m (thermal). With a 16-day revisit cycle, it supports long-term environmental monitoring. Its OLI and TIRS sensors enable analysis of land surface characteristics, including estimation of PM_{10} and CO concentrations.

PM_{10} are airborne particles with a diameter of less than 10 microns that can be inhaled into the lower respiratory tract and have an impact on health (Fahrisa, 2017). Sources include natural activities such as volcanic eruptions and forest fires, as well as human activities such as industry, vehicles, construction, demolition, and certain gas reactions (KLHK, 2013). In industrial and mining areas, PM_{10} is also produced by wind erosion, rock blasting, material transportation, heavy equipment use, road dust, and burning (Ramdhana, 2022). In addition to impacting health, high concentrations of PM_{10} affect the climate by absorbing or reflecting energy and reducing atmospheric visibility.

3. METHODOLOGY

3.1 Research Location

Cement Industry X is the largest cement producer in Eastern Indonesia, located in Biring Ere Village, Bungoro Subdistrict, Pangkep Regency, approximately 68 km from Makassar City. The industry has five factory units and clay mining areas spread across Bungoro, Tondong Tallasa, and Minasatene subdistricts. Air quality monitoring points cover both industrial work areas and residential areas spread across nine subdistricts and several surrounding villages. The monitoring is designed to obtain accurate data on potential air quality issues caused by industrial activities or external factors, while ensuring that air quality standards in work areas remain maintained.

Table 1: Ambient Air Measurement Location

No	Area	Location	Code
1	Operational	Bontoa Clay Mine (Kehati Park)	UA1

No	Area	Location	Code
2		Limestone Mine	UA2
3		Packer Unit 5	UA3
4		Cement Mill Unit 5	UA4
5		Kiln Unit 2/3	UA5
6		Coal Stock Pile Unit 2/3/4	UA6
7		Biringkassi Cement Silo	UA7
8		Biringkassi 1 Steam Power Plant	UA8
9	Residential Area	Residential Area Near the Tabo-Tabo Mine	UA9
10		Residential Area Near Bulutellue Mine	UA10
11		Residential Area Near Tonasa Clay Mine 1	UA11
12		Taraweang Village	UA12
13		In front of Sela Village Mosque	UA13
14		Biringere Village Office	UA14
15		Bungoro Intersection	UA15

Source: Industry Cement X

3.2 Research Tools and Data

This study used several supporting software programs, namely Google Earth for location mapping, Copernicus Data Space and USGS Earth Explorer to obtain Sentinel-2 and Landsat 8 images, ArcGIS 10.8 for spatial analysis of pollutant distribution and QGIS 3.40.4 for image correction.

Table 2: Satellite Image Acquisition Data

Components	Sentinel-2	Landsat 8
Satelit	Sentinel-2 Level 2A Surface Reflectance	Landsat 8-9 OLI/TIRS C2 L2
Sensor	MSI (Multispectral Instrument)	OLI (Operational Land Imager) + TIRS (Thermal Infrared Sensor)
Acquisition Date	16 October 2023 and 20 October 2024	16 October 2023 and 18 October 2024
Resolusi Spasial	10 m (Band 2, 3, 4, 8)	30 m (Band 1–7, 9)
	20 m (Band 5, 6, 7, 8A, 11, 12)	15 m (Band 8)
	60 m (Band 1, 9, 10)	100 m (Band 10 dan 11)
Number of Bands	12 band	11 band
Revisit Time	5 day	16 day
Orbital Period	100,6 minute	99 minute
Cloud Conditions	25%	25%
Coverage Width	290 km	185 km

Source: USGS Earth Explorer dan Copernicus Data Space

3.3 Research Flow Chart

This research was conducted through several interconnected stages, from preparation and data collection to analysis and presentation of results. These stages are systematically illustrated in the following research flowchart to provide a clearer picture of the research process.

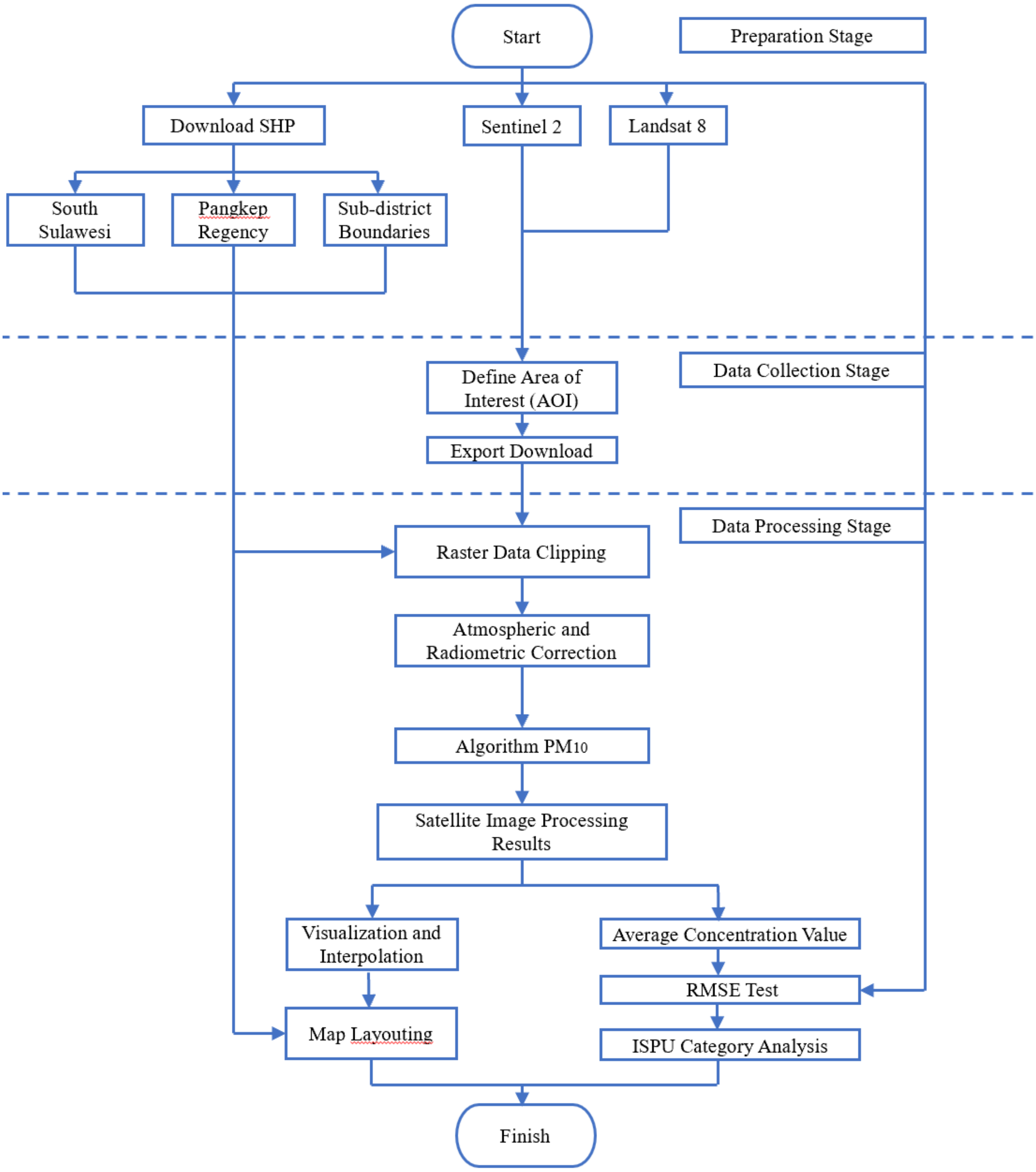


Figure 1: Research Flowchart

This research began with a preparatory stage in the form of collecting SHP data (South Sulawesi, Pangkep Regency, and sub-district boundaries) as well as Sentinel-2 and Landsat 8 satellite imagery. Next, the study area (AOI) was determined and the raster data was cut and atmospheric and radiometric corrections were performed. The data were then analyzed using the PM_{10} algorithm to generate pollutant concentration information. The results of satellite image processing were used in spatial visualization, interpolation, and analysis of average concentration values, RMSE tests, and ISPU categories. Finally, the results were presented in map form through a layout process.

3.3.1 Preparation Stage

The preparation stage was carried out by downloading the administrative boundaries of the research area through shapefile (SHP) clipping covering South Sulawesi Province, Pangkep Regency, up to the sub-district boundaries. Next, Sentinel-2 and Landsat 8 satellite images were downloaded. Secondary data on PM_{10} concentrations were obtained from direct measurements taken by pt global quality analitical at monitoring points in the working area and residential areas of the X Cement Industry Environmental Monitoring Program.

3.3.2 Data Collection Stage

The preparation stage was carried out by determining administrative boundaries, namely by cutting the boundaries of the area to be used as the Area of Interest in the form of a shapefile taken from geospatial data.

3.3.3 Data Processing Stage

Data processing is carried out in several sequential steps. First, the downloaded Sentinel-2 and Landsat 8 raster images are cropped according to the Area of Interest (AOI) to focus only on the research area. Next, atmospheric and radiometric corrections are applied to reduce atmospheric interference and adjust the spectral reflectance values of the images, ensuring the data obtained is more accurate and consistent with field conditions. The subsequent step involves applying image processing algorithms to estimate PM_{10} pollutant concentrations. The multispectral regression algorithm developed in Othman et al. (2010) to reflect PM_{10} concentrations in the Mecca region using Landsat 7 ETM+ satellite image data shows very promising results.

$$PM10 = (396 \times BB\rho) + (253 \times BG\rho) - (194 \times BR\rho) \quad (1)$$

Where: BBρ – Band Blue, BGρ – Band Green, BRρ – Band Red, SWIRρ - Short Wave Infrared Band.

According to Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. 14 of 2020, the ISPU calculation procedure uses the following equation:

$$I = \frac{(Ia - Ib)}{(Xa - Xb)}(Xx - Xb) + Ib$$

Where: I – AQI value for pollutant concentration, Ia - Upper limit ISPU, Ib - Lower limit ISPU, Xa - Upper limit ambient concentration, Xb - Lower limit ambient concentration, Xx - Actual ambient concentration measured.

The results of the satellite image processing were then used to obtain the spatial distribution of pollutants through visualization and interpolation, and processed into thematic maps depicting air quality conditions in the study area. Then, the average concentration and RMSE values were generated to provide an overview of how far the predicted values deviated from the actual values. The concentration results were analyzed in the Air Pollution Standard Index category.

4. RESULTS AND DISCUSSION

4.1.1 Estimation of Air Pollutant Concentrations Based on Satellite Imagery

The analysis process was carried out by importing satellite data, filtering the measurement dates, and then compiling daily composite images for each parameter. The data was clipped according to the AOI shapefile in nine subdistricts in Pangkep Regency, then exported and analyzed in ArcGIS after undergoing lighting and spectral correction to improve image quality. This analysis produced visual information on the distribution of pollutant concentrations at the study site. The observation period covered October 9–30, 2023, coinciding with air quality measurements at X Cement Industry.

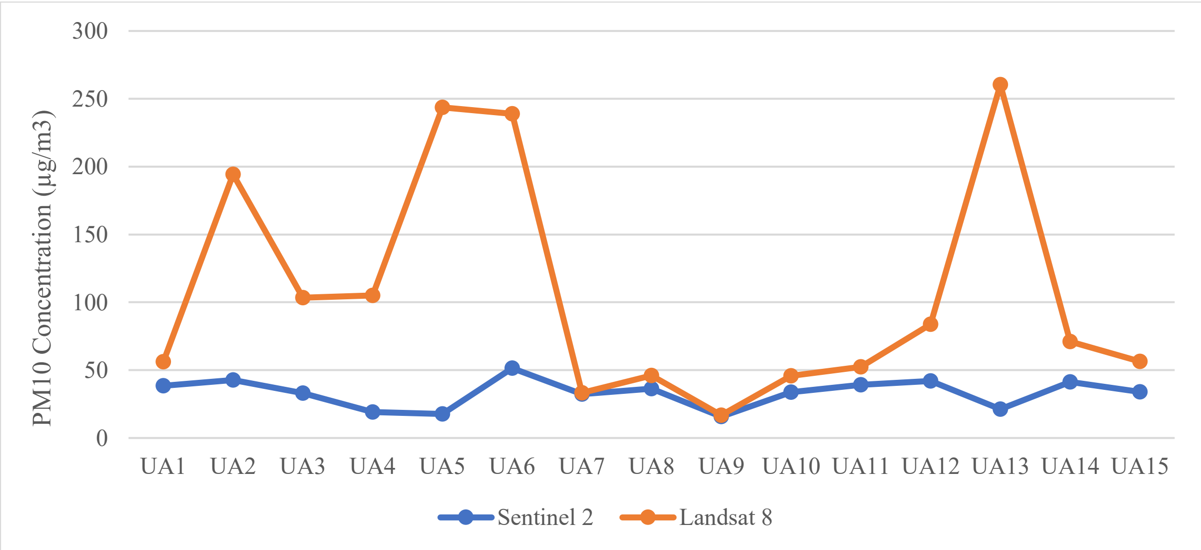


Figure 2 : Comparison of PM_{10} concentrations

The mobilization of materials using heavy equipment generates dust from limestone, clay, and silica sand, thereby increasing PM_{10} concentrations around the work area. Domestic activities such as open burning also contribute to emissions, while wind and humidity affect the dispersion and deposition of particles (Ramdhana, 2022). Dust particles at high temperatures tend to settle more slowly than at low temperatures. This occurs because the air becomes less dense at high temperatures, causing the concentration of air pollution to decrease. In addition, dust particles become lighter at high temperatures, causing them to remain in the air longer in turbulent conditions.

One of the main reasons PM_{10} values appear high on satellite images is due to high concentrations of dust in the atmosphere, both from industrial activity and road dust stirred up by vehicles or wind. PM_{10} particles in the air can cause increased reflectance or light scattering, which makes the area appear brighter or hazy in the image. Satellites capture this phenomenon as an increase in Digital Number (DN) or indices such as Aerosol Optical Depth (AOD) which are directly related to the concentration of particles in the air.

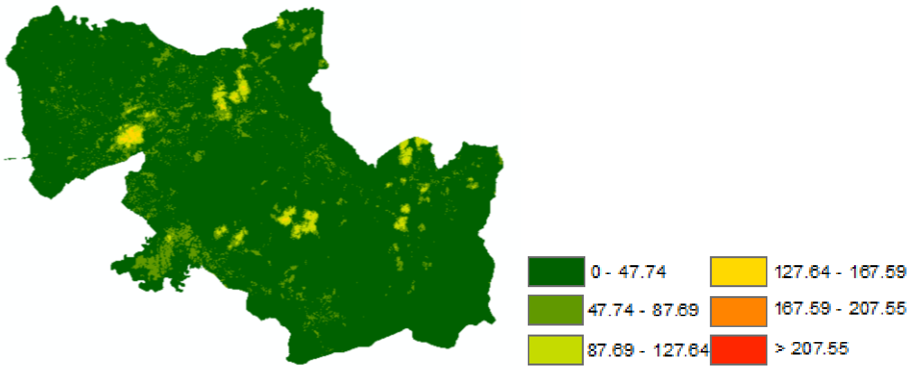
Table 3 : Estimation of air pollutant concentrations based on satellite imagery

No	Area	Location	Code	Sentinel 2	Landsat 8
1	Operational	Bontoa Clay Mine (Kehati Park)	UA1	38.4	56.17
2		Limestone Mine	UA2	42.68	194.39
3		Packer Unit 5	UA3	33.04	103.35
4		Cement Mill Unit 5	UA4	19.02	105.11
5		Kiln Unit 2/3	UA5	17.81	243.6
6		Coal Stock Pile Unit 2/3/4	UA6	51.46	239.06
7		Biringkassi Cement Silo	UA7	32.26	33.31
8		Biringkassi 1 Steam Power Plant	UA8	36.47	46.12
9	Residential Area	Residential Area Near the Tabo-Tabo Mine	UA9	15.74	16.79
10		Residential Area Near Bulutellue Mine	UA10	33.67	45.78
11		Residential Area Near Tonasa Clay Mine 1	UA11	39.26	52.43
12		Taraweang Village	UA12	42.1	83.75
13		In front of Sela Village Mosque	UA13	21.27	260.36
14		Biringere Village Office	UA14	41.31	71.05
15		Bungoro Intersection	UA15	33.89	56.53

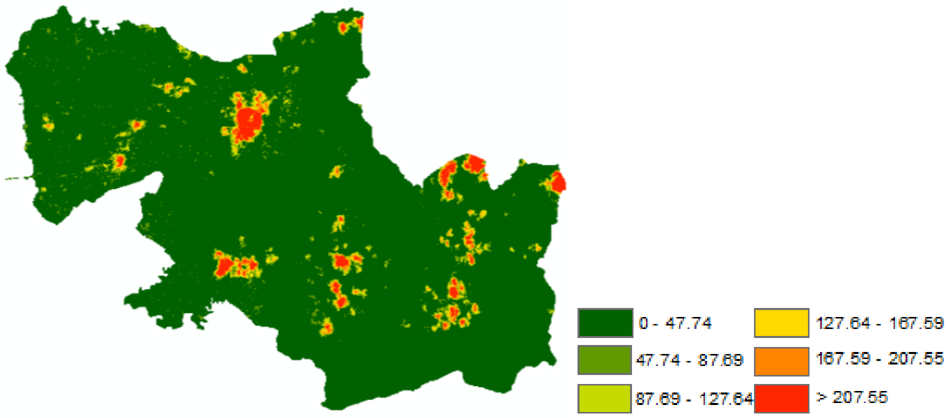
Source: Data Processing, 2025

Concentration estimates were made at 15 observation points representing industrial and residential areas around the cement production complex. The results show a spatial pattern, where pollutant concentrations tend to be higher in areas close to major industrial activities, such as raw material mines, cement factories, and coal-fired power plants. These estimated values serve as a starting point for further analysis, including comparison with field measurement results and spatial distribution mapping in the form of graphs and thematic maps. In addition, this information is also important as a basis for evaluating the risk of air pollution to the surrounding environment, while also providing input for the formulation of emission control strategies and air quality management in cement industrial areas.

Landsat 8 and Sentinel-2 can be used to monitor air quality even though they are not satellites specifically designed for pollution monitoring. Analysis is carried out using environmental parameters such as vegetation cover, human activity, and atmospheric conditions (smoke or dust). Sentinel-2, with its higher resolution, is effective at monitoring rapid changes, such as the impact of forest fires, while Landsat 8 is more suitable for observing long-term trends. With image processing, both are capable of indirectly mapping pollution sources and supporting environmental monitoring.



(a)



(b)

Figure 3. PM_{10} distribution map based on satellite (a) Sentinel 2 (b) Landsat 8, 2023

PM_{10} concentrations resulting from processing Sentinel 2 satellite imagery ranged from 15 to 51 µg/m³. The highest concentration was at point UA13 with a value of 51.46 µg/m³, and the lowest was at point UA26 with a value of 15.74 µg/m³. On Landsat 8, it ranged from 16 to 260 µg/m³. The highest concentration was at point UA34 with a value of 260.36 µg/m³ and the lowest was at point UA26 with a value of 16.79 µg/m³.

High-resolution satellites such as Sentinel-2 can capture small changes on the surface and in the atmosphere, including dust clouds from chimneys or dust spreading over open land. In addition, the time of image capture (hour and day) also has an effect; in the morning when industrial activity is just starting or in the afternoon when atmospheric conditions change, different particle concentrations can be observed. Therefore, high PM_{10} values in satellite imagery are influenced by numerous factors such as dust emission levels, atmospheric reflectivity due to particles, weather conditions, wind speed, and the satellite sensor's own capabilities. All these factors contribute to how surface air quality is displayed and interpreted from remote sensing imagery.

RMSE (Root Mean Square Error)

RMSE is a statistical indicator for assessing model accuracy by calculating the square root of the average of the differences between predicted and actual values. A small RMSE value indicates more accurate predictions, with the advantage of giving greater weight to large errors. RMSE is often used in regression, forecasting, and environmental modeling to compare model performance. RMSE is a statistical measure of model accuracy, where smaller values indicate better predictions. In 2023, Sentinel-2 estimates of PM_{10} using the Othman model showed relatively low RMSE values (123,47 in the Operational Area and 93,06 in Residential Area).

4.1.2 The PM_{10} Phenomenon Based on Previous Research

Based on Table 3, according to Othman (2010), the distribution of PM_{10} concentrations can be analyzed using atmospheric reflectance in the red (B3), green (B2), and blue (B1) bands of Landsat 7 ETM+ imagery. The analysis was performed using a linear regression approach to obtain an algorithm with the highest correlation (R) value. The red, green, and blue bands were chosen because they are within the visible light spectrum, which is sensitive to fine particles in the atmosphere. The presence of PM_{10} affects the reflectance or path radiance recorded by the sensor, so that changes in pollutant concentration can be detected visually and quantitatively. In addition to their consistent availability in satellite data, these three bands have also been proven to have a strong correlation with pollutant concentrations in various previous studies, making them effective for use in spatial modeling of air quality.

In addition to analyzing the central tendency of air quality data, efforts to determine the significance of changes were also carried out through RMSE data testing. This analysis shows that all air quality parameters experienced significant differences with RMSE values. PM_{10} concentrations in areas with high air temperature and humidity will form absorption with water vapor, causing it to easily fall to the surface, whether to the ground, buildings, or plants (Kayes et al., 2019).

4.1.3 Air Pollution Standard Index (ISPU)

Ministry of Environment and Forestry Regulation No. 14 of 2020, the Air Pollution Index (API) is a dimensionless number that describes the quality of ambient air at a specific time and location, based on its impact on health, aesthetics, and living things. The ISPU makes it easier for the public to understand the air conditions at 15 measurement points, whether they are clean or polluted, as well as the risks to health, animals, plants, buildings, and the environment. The air quality categories for the 15 measurement points based on ISPU calculations are presented in Table 4.

Table 4 : Air Pollution Standard Index (ISPU) based on satellite imagery estimation

No	Area	Location	Code	ISPU Value Sentinel 2	Category	ISPU Value Landsat 8	Category
1	Operational	Bontoa Clay Mine (Kehati Park)	UA1	44.2	Good	53.1	Moderate
2		Limestone Mine	UA2	46.3	Good	122.2	Unhealthy
3		Packer Unit 5	UA3	41.5	Good	76.7	Moderate
4		Cement Mill Unit 5	UA4	34.5	Good	77.6	Moderate
5		Kiln Unit 2/3	UA5	33.9	Good	146.8	Unhealthy
6		Coal Stock Pile Unit 2/3/4	UA6	50.7	Moderate	144.5	Unhealthy
7		Biringkassi Cement Silo	UA7	41.1	Good	41.7	Good
8		Biringkassi 1 Steam Power Plant	UA8	43.2	Good	48.1	Good
9	Residential Area	Residential Area Near the Tabo-Tabo Mine	UA9	32.9	Good	33.4	Good
10		Residential Area Near Bulutellue Mine	UA10	41.8	Good	47.9	Good
11		Residential Area Near Tonasa Clay Mine 1	UA11	44.6	Good	51.2	Moderate
12		Taraweang Village	UA12	46.1	Good	66.9	Moderate
13		In front of Sela Village Mosque	UA13	35.6	Good	155.2	Unhealthy
14		Biringere Village Office	UA14	45.7	Good	60.5	Moderate
15		Bungoro Intersection	UA15	41.9	Good	53.3	Moderate

Source: Data Processing, 2025

The Air Pollutant Index (ISPU) plays an important role in environmental management in industrial areas by measuring air quality based on pollutant levels such as PM_{10}. ISPU helps the government and industry monitor the impact of emissions, identify times or areas with high pollution, and take mitigation measures to protect the health of the community and workers. Regular AQI monitoring also supports environmental policy-making, spatial planning, and raises public awareness of air pollution. Residential areas far from sources of pollution generally have better and more stable air quality. Most ISPU measurements show “Good” quality, but the existence of areas with a “Moderate” category emphasizes the importance of continuous monitoring and the implementation of mitigation measures to reduce the risk of pollution, especially in areas with high industrial activity, in order to protect public health and the environment.

The "Unhealthy" category appearing in several locations is influenced by the algorithms used in satellite image processing (Sentinel-2 and Landsat 8) to estimate PM_{10} concentrations. Changes in spatial resolution, atmospheric corrections, and radiometric adjustments can cause variations in ISPU values, so that certain points with dense industrial emissions tend to be classified as "Unhealthy." This demonstrates that algorithm-based analysis of satellite imagery is capable of capturing pollution peaks that may not be fully detected by field monitoring, but still provide important information for pollution control and management.

5. CONCLUSIONS

The results of the study indicate that air quality monitoring based on Sentinel-2 and Landsat 8 satellite imagery can be used to estimate PM_{10} concentrations in cement industrial areas. The average PM_{10} concentration in 2023 was recorded at 70.20 $\mu g/m^3$ with an ISPU category of "Moderate" (60.10). The highest concentration in Sentinel-2 imagery was detected in the operational area (Coal Stock Pile Unit 2/3/4), while in Landsat 8 imagery it was identified in the residential area (in front of the Kampung Sela Mosque). The RMSE value was 123.47 in the operational area and 93.06 in the residential area. In general, most monitoring points had air quality categories of Good to Moderate, but there were several points with an Unhealthy category, especially around intensive industrial activities. This emphasizes the importance of continuous monitoring using remote sensing technology to support emission control, spatial planning, and public health protection in cement industrial areas.

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