International Journal on Advanced Science Engineering Information Technology

Vol.11 (2021) No. 5
ISSN: 2088-5334

The Analysis of Aerosol Distribution Using Modis AOD (Aerosol Optical Depth) With SARA (Simplified High Resolution Modis Retrieval Algorithm) for Air Quality Monitoring On 2017 (Study Case: Surabaya City, Indonesia)

Bangun Muljo Sukojo [a,*], Hepi Hapsari Handayani [a], Ardia Tiara Rahmi [a], Istiqomah [a], Rizki Hari Kurniawan [a]

[a] *Department of Geomatics Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia*
*Corresponding author: *bangunms@gmail.com*

***Abstract*— Aerosols are particles suspended in the atmosphere that can affect human's health, air quality, and climate. In monitoring the decrease in air quality due to aerosol distribution, it can be performed by calculating the thickness of the aerosol distribution. SARA (Simplified High-Resolution MODIS Aerosol Retrieval Algorithm) is the algorithm to calculate the distribution of AOD (Aerosol Optical Depth) values in Surabaya city using MODIS imagery. The distribution of AOD is calculated by considering the meteorological and land use aspects. The validation process is performed using ground-based measurements, i.e., the SPM and aerosol products at MODIS Level 2. The results of the AOD distribution vary in each month during 2017. The highest value of 1.794 µm occurred in May with a 7.0 mm/day rainfall in Dukuhpakis District. In comparison, the lowest AOD value of 0.494 µm occurred in January, with rainfall of 21.0 mm/day in Benowo District. The accuracy test result shows that the city of Surabaya is in the high category by reaching the value of 86%. While the accuracy-test with SPM data has a moderate level of correlation, giving the value of 42% with an RMSE value of 0.077 µm. The distribution of AOD is strongly influenced by the rainy season, proven by the correlation value between AOD and rainfall data reaching ~ 0.545. The correlation value between AOD and others meteorological and land use aspects is reaching ~ 0.391 for wind aspect and ~ 0.190 for land use.**

***Keywords*—Aerosol; AOD; MODIS; rainfall; Surabaya; SARA.**

Manuscript received 14 Sep. 2020; revised 12 Dec. 2020; accepted 22 Jan. 2021. Date of publication 31 Oct. 2021.

I. INTRODUCTION

Aerosol can be defined as a suspension from solid particles or solvent in the air between 10^{-9} – 10^{-4} µm, which affects human health, decreasing air quality and climate [6]. Mostly, aerosols are produced in a high and densely populated city. One of the densely populated cities in Indonesia is Surabaya. Surabaya is the Capital City of East Java Province. It was reviewed from crossing activity and populous factory amounting to 818 main industry, while total vehicle reached 4,521,629 in 2017 [3].

This research uses satellite imagery which can visualized aerosol featured in spatial with large coverage area [8]. The study area of this research is in Surabaya City and using MODIS Terra satellite data. The algorithm used in this research is SARA (Simplified high-resolution MODIS Aerosol Retrieval Algorithm) to get AOD (Aerosol Optical Depth) distribution value. AOD is one of the most important parameters in aerosol studies. AOD is the phenomenon of the blackout of optical light due to the presence of aerosols. Thus, AOD was used to determine the aerosol column concentration. For fine-mode aerosols, the AOD generally decreases with increasing wavelength.

The processing results of AOD distribution is tested to get the accuracy value using SPM data and MODIS L2 aerosol products as well as correlation test with meteorological aspects i.e., rainfall and wind patterns. Expected output from this research is providing information about air pollution as a consequence from aerosol distribution. The other benefit we can get is a method to monitor air quality, give recommendation for the government to monitor air quality by calculating aerosol emissions distributions and air quality monitoring as a reference in carrying out policy activities in improving for better air quality.

II. Materials and Method

A. Materials

Materials in this study are data and equipment as follows:

- MODIS MOD02HKM satellite imagery in 2017
- MODIS MOD03 satellite imagery in 2017
- MODIS MOD09GA satellite imagery in 2017
- MODIS MOD04 Level 2 satellite imagery in 2017
- Landsat 8 satellite imagery in 2017
- RBI vector map in scale 1:25.000
- Rainfall data in 2017
- Daily and Annual Wind pattern in 2017
- SPM (*Suspended Particulate Matter*) data in 2017

B. Method

This research was conducted in Surabaya City, East Java, Indonesia. Geographically, Surabaya is located at 07° 9"- 07° 21" S dan 112° 36" – 112° 54" E.

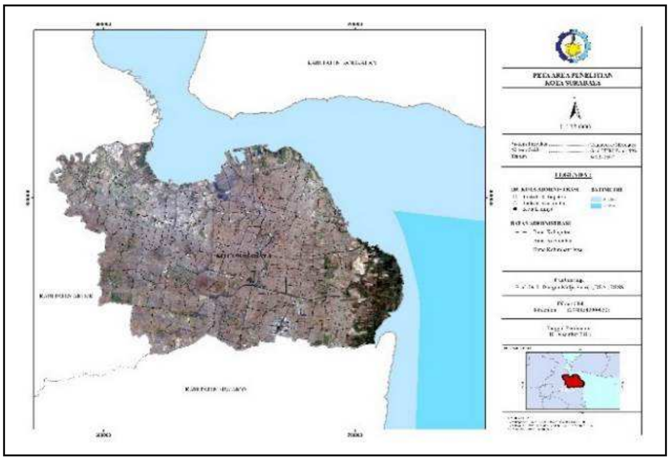

Fig. 1 Research Location Map

The first processing step is image registration. Image-to-image registration involves a georeferencing process when the reference image is already georeferenced. Georeferenced is the process of providing map coordinates to a planimetric image [7]. In the MODIS satellite image, a Bow-Tie correction process is carried out to improve the overlapping portion of the image data that occurs because of an instantaneous increase in Field of View (IFOV) from 1x1 km at the lowest point (nadir) to nearly 2x5 km at the maximum scan angle [7]. The MODIS and LandSat imagery are then georeferenced.

Furthermore, radiometric correction is carried out to perform radiometric calibration and make an atmospheric correction on MODIS MOD02HKM, MOD03 imagery. While in MOD09GA imagery, only radiometric corrections are carried out because MOD04 data is needed to find top of atmosphere reflectance value [6]. Image subsetting is performed by taking a certain area to be observed (area of interest), specifically Surabaya. After the image is cropped, then the image classification process is carried out using the Maximum Likelihood Classification method. The standard value of the Confusion Matrix is above 80% [4]. Landsat imagery is classified into two important parts, i.e., built-up land and non-built-up land. The next processing step is then carried out by calculating the SARA algorithm. This algorithm can display aerosol change's value in a spatial resolution of 500 m [1]. The AOD formula is as follows:

$$\tau_{a,\lambda} = \frac{\rho_{Aer(\lambda,\theta_s,\theta_v,\phi)} 4\mu_s\mu_v}{\omega_0 P_{a(\theta_s,\theta_v,\phi)}} \qquad (1)$$

The accuracy test is performed by comparing the AOD from SARA with the validation data, i.e., estimation data of MODIS Level 2 and SPM data. A correlation test is carried out to measure the relationship between two values. A correlation test is performed to test the correlation between aerosol distribution with meteorological and land use aspects, i.e., rainfall, wind patterns, and land use.

TABLE I
Correlation Level

Correlation (r)	Description
<0.20	Very low correlation: relationships are almost neglected
0.20 – 0.40	Low correlation; a certain but small relationship
0.40 – 0.70	Medium correlation; substantial relationship
0.70 – 0.90	High correlation; marked relationship
0.90 – 1.00	Very high correlation; very dependable relationship

AOD distribution in 2017 is calculated by giving weights or values to each parameter class using the formula [6]:

$$(0.5\times AOD) + (0.30\times rainfall) + (0.15\times land\ use) + (0.15\times wind\ patterns) \qquad (2)$$

Air quality classifications due to the distribution of AOD with aspects of rainfall, wind patterns, and land use are divided into several classes as follows:

TABLE II
AOD Classification

Classification	
0 – 50	Low
50 – 60	Moderate
60 – 70	High
>70	Very High

III. Results and Discussions

A. Aerosol Distribution Analysis Using SARA Algorithm

The aerosol distribution level that occurs in the dry season will be relatively higher compared to the rainy season. This is because aerosols are leached out during the rainy season, causing the number of aerosols to decrease [2].

TABLE III
AOD Distribution Value

Months (2017)	**Lowest (μm)**	**Highest (μm)**
January	0.082	0.141
February	0.345	0.778
March	0.235	1.356
April	0.111	1.566
May	0.317	1.794

Months (2017)	Lowest (μm)	Highest (μm)
June	0.738	1.513
July	0.120	0.996
August	0.187	0.873
September	0.143	0.906
October	0.047	0.651
November	0.141	0.681
December	0.172	0.494

In January, the highest AOD distribution value was 0.141 µm and the lowest was 0.082 µm. The area with the highest AOD distribution is in Gubeng District, while the area with the lowest AOD distribution is in Benowo District and the coastal areas.

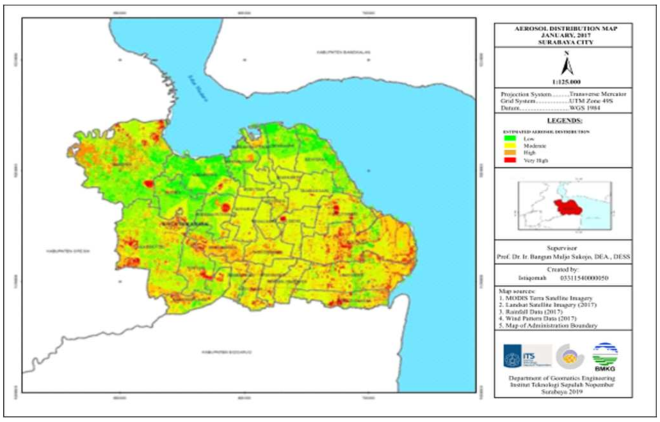

Fig. 2 Distribution of AOD in January 2017

January has a relatively low AOD distribution due to the rainfall of 25.0 mm/day, leading to aerosol leaching. The AOD distribution is evenly distributed in the city center and classed into the medium category with an RMSE of 0.011 µm. This value is small so that the results of the SARA algorithm can be considered correct.

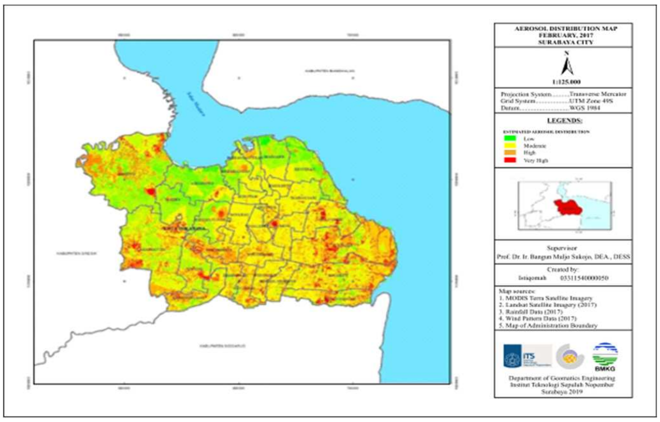

Fig. 3 Distribution of AOD in February 2017

In February 2017, the highest AOD value was 0.778 µm, and the lowest was 0.345 µm with a greater RMSE value of 0.043 µm compared to January 2017. There was an increase in AOD distribution value, causing the area of the AOD distribution in the moderate category to increase to 197.98 km^2 influenced by the decrease in rainfall intensity, which was only 16 mm/day and also caused by the smaller wind pressure value so that the wind intensity is small, making aerosols take a long time to dissolve and move. The highest AOD distribution is in Sukolilo, Dukuhpakis, Karangpilang and Rungkut Districts. Meanwhile, the lowest AOD distribution is in Asemworo, Semampir, Tandes, and coastal areas.

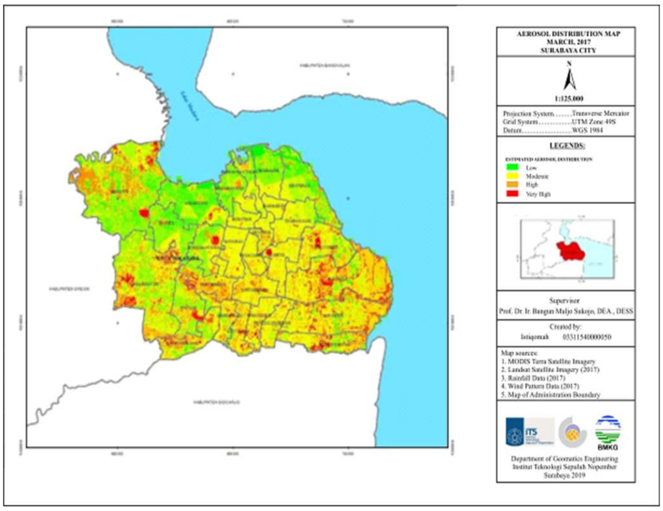

Fig. 4 Distribution of AOD in March 2017

In March, the highest AOD value was 1.356 µm, and the lowest was 0.250 µm, with the highest AOD distribution area is in the Mulyorejo. Meanwhile, the areas with the lowest AOD distribution are still in three sub-districts and coastal areas. Based on the AOD distribution results, it was found that the percentage of area with moderate aerosol distribution increased to 182 km^2 compared to February 2017. This is because of a decrease in wind patterns and rainfall intensity, which is classed into the high category ~ 19 mm/day. In comparison, the lowest aerosol distribution area has decreased to 82 km^2 due to a decrease in the wind pattern intensity so that aerosols in the city center take longer to dissolve and move.

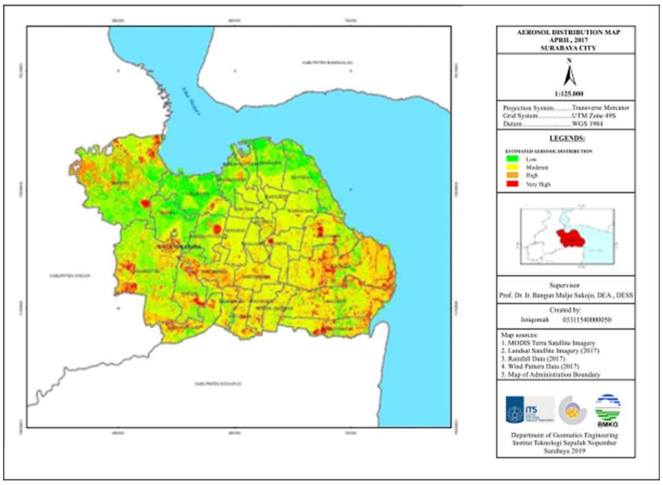

Fig. 5 Distribution of AOD in April 2017

In April, the highest AOD value was 1.566 µm, and the lowest was 0.111 µm, and the RMSE value was 0.159 µm. Meanwhile, the area with the highest AOD distribution was in Wonocolo District, with a maximum distribution value of

1.052 μm to 1.566 μm. The distribution of AOD has increased by a difference of 0.384 μm compared to March.

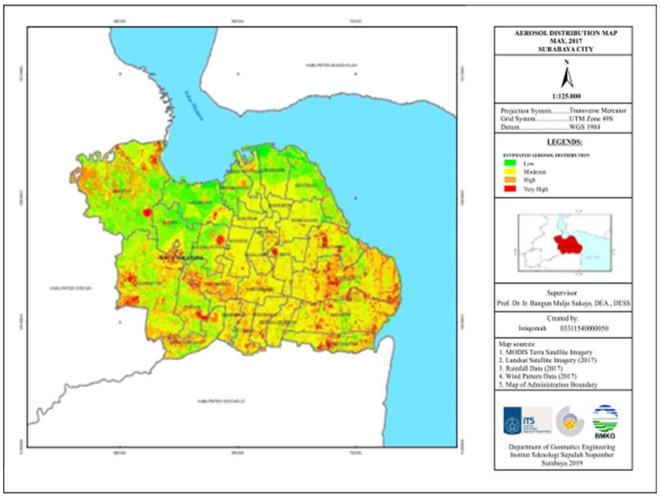

Fig. 6 Distribution of AOD in May 2017

In May, there was an increase in air quality due to the decreased distribution of aerosols. It was found that the distribution area of AOD in the very high category decreased to 56 km^2 with the highest aerosol distribution in Sukolilo, Gunung Anyar, and Rungkut Districts. The area of aerosol distribution in the low category is 99.3 km^2 with an even distribution of AOD, and especially the lowest distribution occurs in the Tandes and Asemworo Districts and the coastal areas.

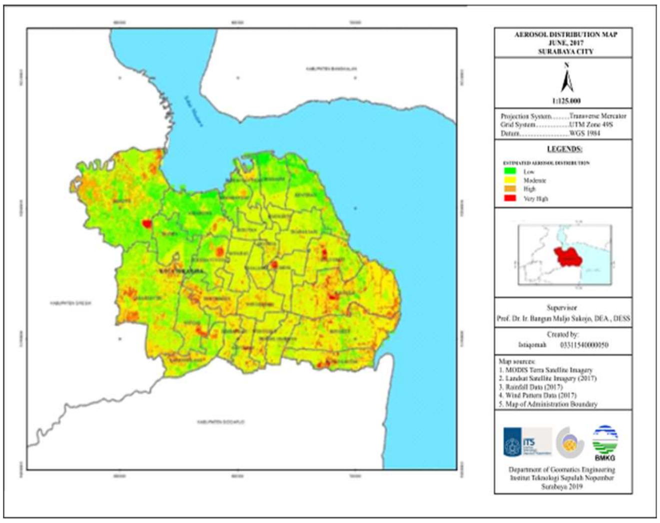

Fig. 7 Distribution of AOD in June 2017

In June, the rainfall intensity is 8.0 mm/day with the lowest AOD value of 0.738μm and the highest of 1.513 μm in Lakarsantri District. Meanwhile, the area that has low aerosol distribution is in the Kenjeran area due to the low number of vehicles and is classified as an area that has a low category of land use. The distribution of AOD in the medium category has the largest area of 184.9 km^2 with an even distribution of AOD. The distribution of AOD in the medium category is in the Rungkut and Gunung Anyar Districts.

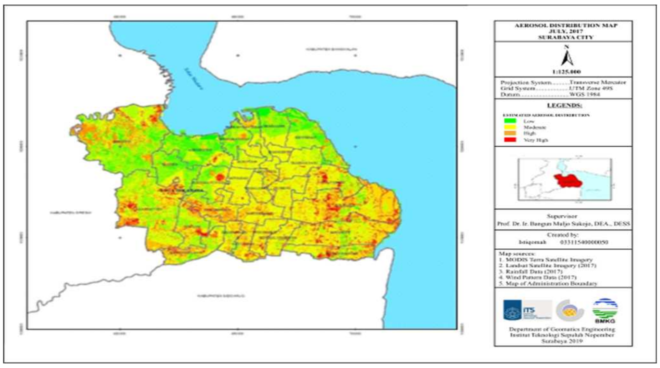

Fig. 8 Distribution of AOD in July 2017

In July 2017, the highest AOD distribution value was 0.996 μm, and the lowest value was 0.120 μm with an RMSE value of 0.039 μm. The effect of daily winds does not affect the AOD distribution, but the east monsoon wind patterns influence the AOD distribution. In July, there was a decrease in air quality in the southern region due to the high AOD distribution caused by low rainfall of 2.0 mm/day.

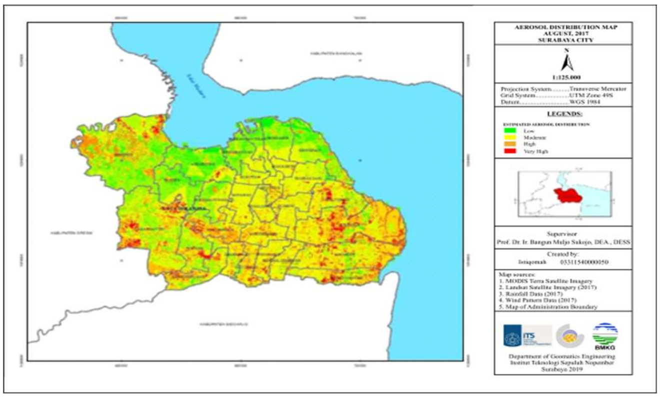

Fig. 9 Distribution of AOD in August 2017

In August 2017, the highest AOD distribution was 0.835 μm, and the lowest was 0.155 μm with an RMSE value of 0.037 μm. The area of the distribution of AOD in the moderate category occurs evenly in the city center with an area of 176 km^2, about 2.8 km^2 in high category. The area of the distribution of AOD in the very high category is in the south side of Surabaya with an area of 90 km^2.

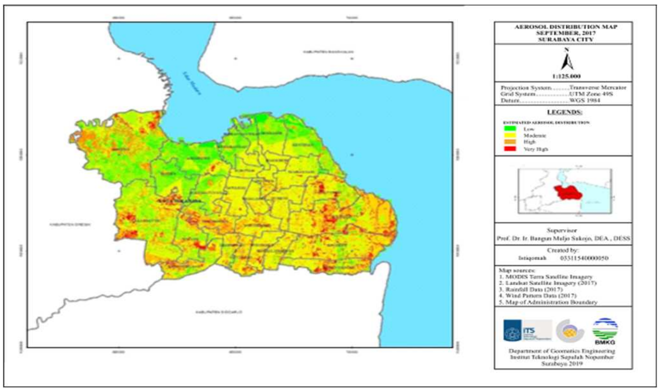

Fig. 10 Distribution of AOD in September 2017

In September, the highest AOD value was 0.835 µm, and the lowest AOD was 0.155 µm with an area that had a high aerosol distribution almost evenly in the central area of Surabaya City. In the level of accuracy, it had an RMSE value of 0.037 µm. In September 2017, the results of the distribution of aerosols with a low category were on the northern side of Surabaya City with a distribution area of 80 km^2. The distribution of aerosols in the medium category had an area of 182 km^2 and was distributed in the center of Surabaya City. The distribution of AOD with a very high category has an area of 56.89 km^2 and is inclined on the north side towards Surabaya. The high distribution of AOD is in the south side of Surabaya. This area is outskirt with Sidoarjo Regency where is a built-up area.

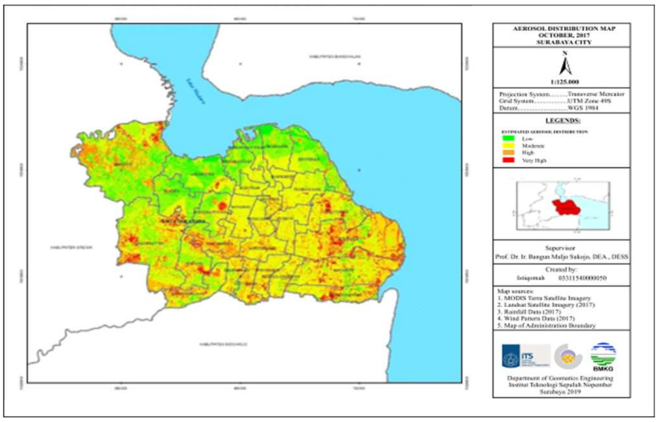

Fig. 11 Distribution of AOD in October 2017

In October, the highest AOD value was 0.651 µm, and the lowest was 0.041 µm with an RMSE value of 0.024 µm. The increase can see the increase in air quality of the total area of AOD distribution at the very high classification from 28.6 km^2 to 41.8 km^2.

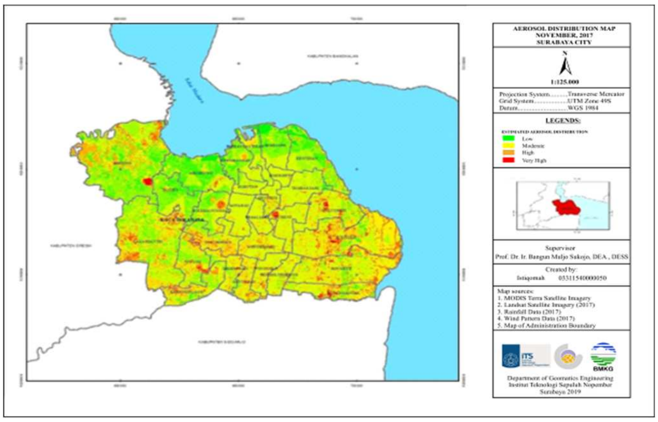

Fig. 12 Distribution of AOD in November 2017

In November, the highest AOD value was 0.681 µm, and the lowest value was 0.096 µm with an RMSE value of 0.055 µm. It was found that the distribution of AOD decreased and caused several Districts to experience an increase in air quality, such as in Sukolilo District, which previously had an AOD distribution area in a very high classification of 10 km^2 to 8 km^2. The increase in air quality was supported by the increased intensity of rainfall, which was 16 mm/day. The classification of the AOD distribution in the low category also increased from 79 km^2 to 98 km^2.

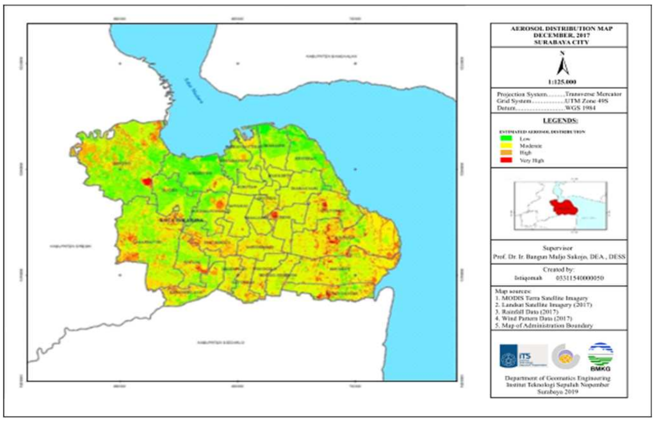

Fig. 13 Distribution of AOD in December 2017

In December, the highest AOD distribution was 0.494 µm, and the lowest value was 0.138 µm with a small processing error rate or RMSE value compared to the previous month, which was 0.038 µm. In December, there was a significant decrease in air quality despite an increase in rainfall intensity of 25 mm / day. The area in the low AOD distribution category increased from 98 km^2 to 127.9 km^2.

B. Correlation and Accuracy Test Analysis

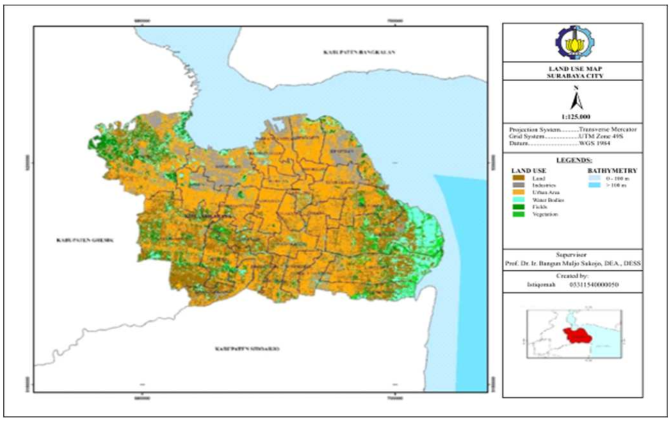

Fig. 14 Land Cover Classification

The land use classification result shows a strong level of accuracy with a value of 83.0558% and the Kappa Coefficient of 0.7487.

TABLE IV
LEVEL OF ACCURACY

Land Cover	Overall Accuracy (%)	Kappa
Urban	87.6993	0.8176
Industries	82.8939	0.7367
Land	84.6394	0.7800
Water Bodies	81.5192	0.7212
Fields	81.4933	0.7118
Vegetation	80.0897	0.7147
Average	**83.0558**	**0.7487**

The correlation test found that the effect of land use with the aerosol distribution in the medium category was around 0.4360 from the determinant result (R^2) of 0.191. Thus, the effect of high classified land use would cause the high distribution of AOD [9].

The distribution of aerosols is very easily carried away by the wind [6]. From the AOD correlation with wind speed, the coefficient of determination (R^2) is 0.015 with a correlation value of 0.124. Based on these results, it was found that the amount of wind in an area had a weak correlation or influence on the aerosol distribution.

The correlation between the AOD distribution and rainfall we get the coefficient of determination (R^2) is 0.2036 (R = 45.12%) which is at a moderate level.

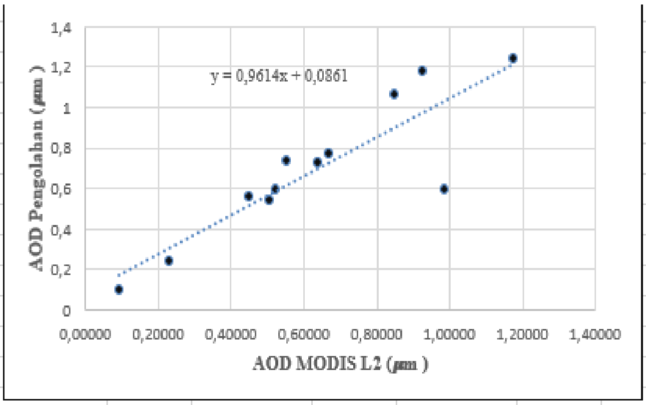

Fig. 15 Accuracy Test of AOD from SARA and MODIS L2

Based on this model, it can be seen that each increase in the AOD value of the MODIS Level 2 image will be followed by the added value of 0.1674 µm from the AOD MODIS value calculated by the SARA algorithm.

TABLE V
REGRESSION STATISTICS OF ACCURACY TEST

Regression Statistics	
Multiple R	0.978203156
R Square	0.956881415
Adjusted R Square	0.865972324
Standard Error	0.15198615
Observations	12

In the accuracy-test result, we get the highest accuracy value of Adjusted R Square ~ 0.865 (86%).

TABLE VI
VALUE COMPARISON BETWEEN SPM AND AOD

Months	**SPM PM 10**	**AOD (µm)**
January	92.14	0.094
February	91.94	0.755
March	85.94	0.712
April	140.05	1.097
May	128.55	1.510
June	104.15	1.348
July	111.85	0.875
August	73.94	0.647
September	82.34	0.741
October	81.94	0.585
November	81.94	0.662
December	79.24	0.282

Suspended Particulate Matter (SPM) is a mixture of dust, while PM 10 (Particulate Matter 10) is particulates with a radius of less than 10 µm [10]. From Table 6, the SPM data does not significantly differ in the increase and decrease of the AOD value from the SARA algorithm. Thus, the SPM data can be used as validation data [14].

TABLE VII
REGRESSION STATISTICS OF CORRELATION TEST

Regression Statistics	
Multiple R	0.691179
R Square	0.477728
Adjusted R Square	0.425501
Standard Error	15.83205
Observations	12

The suitability supports the use of the AOD and SPM validation tests that when the AOD increases, the SPM PM10 measurement results have the same increasing value, so it causes the decrease in air quality and vice versa. The level of accuracy is classed into the medium category with the determinant coefficient (R^2) of 0.477 µm.

IV. CONCLUSIONS

The validation test shows the accuracy level results between AOD and MODIS Level 2 are 86% with an RMSE value of 0.091µm. Thus, aerosol distribution processing using the SARA algorithm has a high accuracy value for level 2 products. Based on the results of the correlation test with SPM has an RMSE value of 0.076 µm. Thus, it can be used as the validation data over AOD from MODIS data using the SARA algorithm for monitoring air quality by taking into account the meteorological and land use aspects.

Aerosol distribution mapping on meteorological aspects (rainfall and wind) and land use have a significant role. The aerosol and rainfall have a correlation value of 0.545, while the effect of wind patterns has a correlation of 0.1236 and the impact of land use has a correlation of 0.4360. Thus, the most related aspect that plays an important role in the AOD distribution is rainfall and land use.

ACKNOWLEDGMENT

The authors are grateful to Mr. Muhammad Billal as the SARA algorithm's inventor and Mr. Alvaro Caceres as the SARA algorithm researcher for their huge contribution to this research. The authors are also obliged to BMKG Juanda Surabaya and BMKG Karangploso for providing the required data in this research.

REFERENCES

[1] Anderson. L.O. "Sensor MODIS: Uma Abordagem Geral Sensor MODIS," Incluye Informastion de la SE Funcion Publica, vol. 2, no. MODIS, p. 58, 2017.

[2] Alvaro Cáceres dan Michael Hahn, "Implementation of a MODIS Aerosol Algorithm for Air Pollution Detection," Journal International Remote Sensing of Enviroment, vol. 453, no. Pollution, pp. 146 - 150, 2017.

[3] B. C. Seinfeld J.H., "Improving our fundamental understanding of the role of aerosol−cloud interactions in the climate system," in Procedings of the International Academy of Sciences, Chicago, 113.

[4] Chu D.A., "Validation of MODIS Aerosol Optical Depth Retrieval Over Land," Geophysical Research Letter, vol. 29, pp. 4 - 7, 2002.

[5] Engel-Cox, J.A., Christopher, H.H., Coutant, B.W., Hoff, R.M., "Qualitative and quantitative evaluation of MODIS satellite sensor data for regional and urban scale air quality. Atmospheric Environment 38, 2495–2509. 2004.

[6] Gupta P. Khan, "MODIS Aerosol Optical Depth Observations Over Urban Areas in Pakistan: Quantity and Quality of the Data for Air Quality Monitoring," Atmospheric Pollution Research, vol. 4, no. Atmospheric Pollution, pp. 43-52, 2013.

[7] H. Kernel, "The Retrieval of Cloud Base Heights from MODIS and Three-Dimensional Cloud Fields from NASA's EOS Aqua Mission," Journal of Remotes Sensing, vol. 23, pp. 5249-5265, 2002.

[8] H. Zhang et al., "A multi-angle aerosol optical depth retrieval algorithm for geostationary satellite data over the United States," Atmos. Chem. Phys., vol. 11, no. 23, pp. 11977–11991, 2011.

[9] Kaufman, Y.J., Tanre, D., Boucher, O., 'A satellite view of aerosols in climate systems.' Nature 419, 215–223. 2002.

[10] L. Q. Wang C., "Air Quality Evaluation on an Urban Scale Based on MODIS Satellite Images," Atmospheric Pollution Research, pp. 132-133, 2013.

[11] Levy R.C., "The Collection 6 MODIS Aerosol Products Over Land and Ocean," Atmospheric Measurement Techniques, vol. 6, pp. 2989-3034, 2013.

[12] Muhammad Billal, "A Simplified high resolution MODIS Aerosol Retrieval Algorithm (SARA) for Use Over Mixed Surfaces," Journal International Remote Sensing of Enviroment, pp. 135 - 145, 2017.

[13] O. Hagolle, G. Dedieu, B. Mougenot, V. Debaecker, B. Duchemin, and A. Meygret, "Correction of aerosol effects on multi-temporal images acquired with constant viewing angles: Application to Formosat2images,"Remote Sens. Environ., vol. 112, no. 4, pp. 1689–1701, Apr. 2008.

[14] O. H. M. Y. Takemura Tagashi, "Global Three-Dimensional Simulation of Aerosol Optical Thickness Distribution of Various Origins," Journal of Geophysical Research Atmospheres, vol. 10, no. Atmosphere Research, pp. 12-17, 2000.

[15] Péré J. C., "Influence of the Aerosol Solar Extinction on Photochemistry during the 2010 Russian Wildfires Episode," Atmospheric Chemistry and Physics, vol. 15, pp. 1098-1098, 2015.

[16] R. U. I Gusti Hasan, 2017, " Correlation Test for Improvement of Settlements on Landsat 8 Images (Case Study: Surabaya), Semarang, Universitas Diponegoro, 2017, pp. 1 - 15.

[17] Remer L.A., "Global Aerosol Climatology from the MODIS Satellite Sensors". Atmospheric Pollution Research, vol. 9, pp. 23-26, 2008.

[18] Sapkota, A., Symons, J. M., Kleissl, J. A. N., Wang, L. U., Parlange, M. B., Ondov, J., dan Diette, G. B., "Impact of the 2002 Canadian Forest Fires on Particulate Matter Air Quality in Baltimore City", Journal of Geophysical Research Atmospheres 39(1), 24–32, 2005

[19] X.Ma,J.Wang,F.Yu,H.Jia,andY.Hu,"Can MODIS AOD be employed to derive PM2.5 in Beijing-Tianjin-Hebei over China?" Atmos. Res., vol. 181, pp. 250–256, Nov. 2016.

[20] Zhang, M.; Huang, B.; He, Q. An evaluation of four MODIS collection 6 aerosol products in a humid subtropical region. Remote Sens., 9, 1173. 2017.