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Dispersion model and impact assessment of Landing and Take Off (LTO) activity at New Yogyakarta International Airport using Aermod

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ABSTRACT

Pollutant dispersion modeling around Yogyakarta International Airport was conducted using AERMOD software. There is a strong positive correlation between the number of aircraft and land transportation and the number of pollutants considered. The ambient air quality at the study site for all pollutants originating from the landing and take-off (LTO) cycle is still below quality standards, but those sourced from the combination of the LTO cycle and land transport traffic for NO_2 pollutants exceed the quality standard, while for CO and hydrocarbon pollutants it is still below quality standards.

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1. INTRODUCTION

An airport is a place where activities related to airplanes to landing and take-off (LTO) including ground support activities such as passenger transportation. As a result, airports have become one of the most complex sources of air pollution. One of the major activities at the airport he t is the aircraft LTO cycle. The LTO cycle includes all aircraft activities that occur below 3000 feet (915 m). The LTO cycle comprises 4 operating modes: approach, taxi (taxi-in and taxi-out), take-off, and climb-out, as shown in Figure 1. Thrust settings and time in mode (TIM)shown in Table 1, affect aircraft fuel consumption and emission factors for each LTO cycle mode [1]-[3].

Besides the LTO cycle, there are other activities at the airport, like transportation traffic around the airport. These activities emit various types of pollutants, such as NO_2, CO, and hydrocarbons [3]. The LTO cycle and ground transportation traffic cause an accumulative impact on air quality. Along with the increase in those activities, emitted more pollutants and decrease ambient air quality.

Pollutant dispersion modeling is one of the most substantial aspects of air quality analysis and is used to predict pollutant distribution as part of risk mitigation [4]. According to the mathematical equations used, there are many variations in the pollutant dispersion model. One of them is the Gaussian Plume model, which is most often used for various types of emission sources [5]. One of the software's applying the Gaussian plume model is AERMOD.

The American Meteorology Society (AMS) and US Environmental Protection Agency (US EPA) developed the AERMOD modeling system [6]. AERMOD is one of the widely used Gaussian steady-state modeling systems recommended by the US EPA for modeling air and pollutant dispersion with distances < 50 km [4, 7, 8, 9]. The AERMOD modeling system implements the PBL (planetary boundary layer) concept in air pollutants dispersion [10]. By implementing PBL, the AERMOD modeling system has the advantage of predicting the ground-level concentration (GLC) [4]. In addition, AERMOD has another advantage such as being able to be used for various types of sources, does not limit the source area to rectangular shapes, and can model the downwash effect of buildings or terrain [6, 9, 10, 11]. The AERMOD modeling system is sensitive to surface characteristics, topography, and meteorological conditions because these variables affect the height of PBL [12]. Therefore, the AERMOD modeling system requires topographic data and climate data in the modeled area.

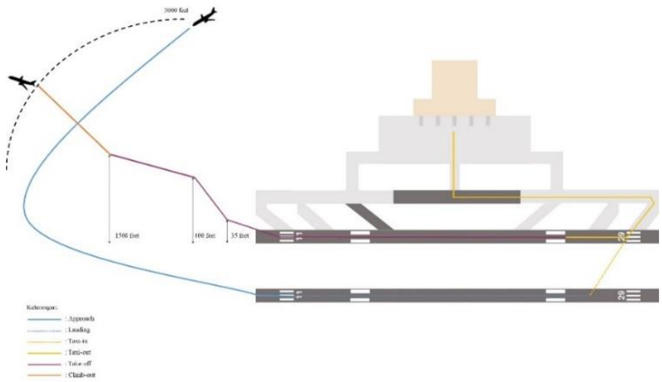


Figure 1. Illustration of the LTO cycle of aircraft at New Yogyakarta International Airport

Table 1. TIM and thrust setting for each LTO cycle mode

LTO cycle mode	Simulation TIM (minute)	Thrust setting (%)
Approach	4[a]	30
Taxi-in	4,8[b]	7
Taxi-out	10,23[b]	7
Take-off	0,7[a]	100
Climb-out	2,2[a]	85

a: TIM default ICAO; b: TIM airport

The Special Region of Yogyakarta Province is a tourist destination in central Java. The airport is one of the ways tourist visits it. To welcome the tourists, Yogyakarta International Airport was built in the Special Region of Yogyakarta Province to replace Adisutjipto Airport in terms of commercial flight services. Due to the increase in tourists, the Yogyakarta International Airport will develop to increase its capacity. According to the airport master plan of Yogyakarta International Airport (Rencana Induk Bandara/RIB), the capacity of the airport to provide an LTO cycle of aircraft will be increased step by step as shown in Table 2. The increase in aircraft passengers causes transportation traffic around Yogyakarta International Airport to increase. According to the traffic impact assessment, the increase in transportation is predicted as shown in Table 3.

Ambient air quality at airports has been a concern since the 1970s [13]. Research related to pollutant dispersion modeling at airports using the AERMOD modeling system has been carried out at several airports, such as Ferihegy Airport, Hungary; Athens International Airport, Greece; Amerigo Vespucci Airport, Italy; Los Angeles International Airport, USA; and Istanbul Ataturk Airport, Turkey [14, 15, 16, 17, 18]. The study of air dispersion at Yogyakarta airport using AERMOD has not been conducted before. The aim of this study is to predict the dispersion and determine the ambient air quality for the pollutant parameters NO_2, CO, and hydrocarbons at each stage of the development of New Yogyakarta International Airport using AERMOD software.

Table 2. Estimated number of aircraft at New Yogyakarta International Airport (source: RIB New Yogyakarta International Airport, 2018)

	Existing	Stage 1	Stage 2	Stage 3
Domestic	71,589	90,500	125,600	144,200
International	3,440	6,800	12,300	16,700
Total	75,029	97,300	137,900	160,900

Table 3. Estimated number of land transportation at intersections near airports (source: Traffic impact assessment, 2018)

Intersection	Existing	Stage 1	Stage 2	Stage 3
Simpang Congot	3,180	3,820	5,622	8,113
Simpang Glagah 1	2,287	2,935	4,259	5,654
Simpang Sindutan	5,568	6,588	9,656	9,724
Simpang Glagah 2	5,158	10,402	14,263	14,263
Gate Bandara	1,469	1,720	2,163	2,527

2. RESEARCH METHOD

The study area is at New Yogyakarta International Airport in Temon, Kulon Progo, with a radius of 5 km from the reference point on the airport apron. The sampling location was 4 location points and was taken on June 2020, as shown in Figure 2 and Table 4.

Figure 2. Sampling locations and reference points

Table 4. Locations and coordinates of sampling points and reference points

Location	Code	Coordinate	
		S	E
Reference point	TR	S: 07° 54.065'	E: 110° 3.502'
Settlements near east runway	UA-1	S: 07º 54.468'	E: 110º 4.750'
Settlements near incinerator	UA-2	S: 07º 53.597'	E: 110º 2.850'
Airport apron area	UA-3	S: 07º 54.096'	E: 110º 3.624'
Airport parking building area	UA-4	S: 07º 53.820'	E: 110º 3.572'

This research begins with collecting data from various related institutions or parties. Weather data from the 2016-2020 period were obtained from Sleman Meteorological Station. There are 9 important meteorology parameters that must be provided that are cloud cover, temperature, relative humidity, air pressure, wind direction and wind speed, ceiling height, precipitation, and global radiation. All data were provided in one-hour measurement. The meteorology data was processed using AERMET to produce profile data files (.pfl) and surface data files (.sfc) that are important for AERMOD software. There are several data variables from the profile data file (.pfl) and surface data file (.sfc) that are not available at the Sleman Meteorology Station, so these data variables can be filled with the default values [4]. Windrose, as the first step in modeling, was made with WRPLOT View software released by Lakes Environmental. Pollutant dispersion modeling was carried out using the AERMOD software provided by US EPA. The modeling results were further visualized with the SURFER13 software [4].

Terrain data was obtained from SRTM3 and processed by AERMAP[4]. The aircraft data traffic was supplied by PT Angkasa Pura I and the engine type of various aircraft was obtained from an article related to atmospheric modeling of LTO cycles around Soekarno Hatta Airport [3]. The ICAO Engine Emissions Databank (EEDB) is used as a reference for aircraft emission factors [2], while the emission factors for land transportation refer to the Ministry of Environment Regulation Number 12 of 2010 About the

Implementation of Air Pollution Control in the Regions [4]. The pollutant concertation of several parameters, such as NO_2, CO, and hydrocarbon in the area study was obtained on June 2020 for validation method.

Furthermore, the modeling of NO_2, CO, and hydrocarbon dispersion was performed with AERMOD software released by the US EPA. The modeling results of the AERMOD modeling system were further visualized with the SURFER13 software [4]. The AERMOD modeling system workflow showed in Figure 3.

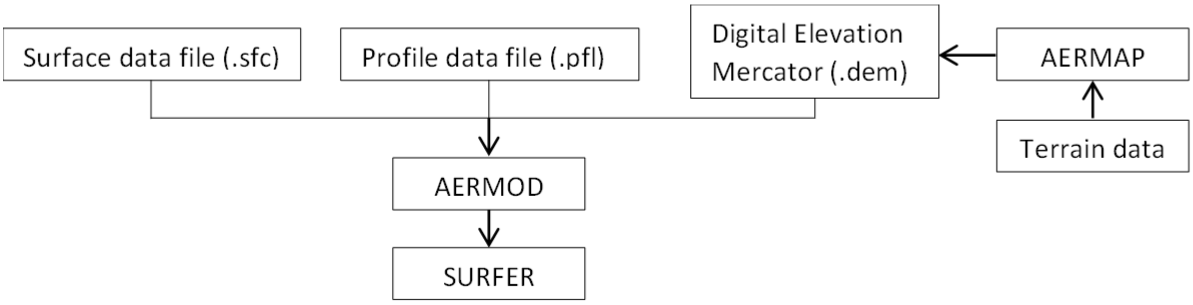


Figure 3. Simulation flow of pollutant dispersion modeling with AERMOD modeling system

Then, the dispersion pollutant of NO_2, CO, and hydrocarbon in the area study was assessed and characterized using the CML method as shown in Table 5. The predicted concentration from the dispersion model was compared with the observed concentration quantitatively by using statistical measurement as summarized in Table 6 [19].

Table 5. Environmental impact characterization factors

Environmental impact characterization	Unit	Pollutant		
		NO_2	CO	Hydrocarbon
Global Warming Potential (GWP)	kg CO_2	5	3	0.0452
Ozone Depletion Potential (ODP)	kg CFC-11			0.000023
Human Toxicity Potential (HTP)		1.2		11.4
Freshwater Aquatic Ecotoxicity Potential (FAETP)	kg 1,4 dichlorobenzene			0.0228
Marine Aquatic Ecotoxicity Potential (MAETP)				0.0052
Terrestrial Ecotoxicity Potential (TETP)				0.00261
Acidification Potential (AP)	kg SO_2	0.5		
Eutrophication Potential (EP)	kg NO_2	1.2		
Damage to Ecosystem Quality caused by the Combined Effect of Acidification an Eutrophication (EQ by EP&AP)	PDF m^2 yr	5.713		
Respiratory Effects on Human-caused by Inorganic Substances (REI)	DALY	0.000087	0.000000731	
Respiratory Effects on Human-caused by Organic Substances (REO)				0.00000128
Environmental Priorities Strategies (EPS)	elu	2.13	0.331	

Table 6. Statistical measures used in comparing simulation results with observation

Statistic	Formula	Note
Normalized mean square error (NMSE)	$\overline{(m-o)^2} / \overline{(m \times o)}$	A perfect model would have NMSE and FB = 0.0
Fractional bias (FB)	$FB = 2\frac{(\bar{o}-\bar{m})}{(\bar{o}+\bar{m})}$	
Correlation coefficient (R)	$R = \frac{1}{n-1}\sum_{i=1}^{n}\frac{(m_i-\bar{m})}{\sigma_m}\left(\frac{o_i-\bar{o}}{\sigma_o}\right)$	A perfect model would have R and FAC2 = 1.0

3. RESULT AND DISCUSSION

The research was carried out around New Yogyakarta International Airport includes four intersections near the airport, Glagah 1 Intersection, Glagah 2 Intersection, Congot Intersection, and Sindutan Intersection. The airport is bordered by agricultural land and residential areas on the north, east, and west sides, while on the south side, it is bordered by the coastline of the south sea. The selection of the study area is based on the presence of airports in rural areas, where airports can be the single largest source of emissions in rural areas [13].

The study area has a height that varies from 0 to 327 meters, as shown in Figure 4, so the study area is a lowland. In the lowlands, the pattern of pollutant dispersion is more influenced by local wind conditions [20]. As seen in figure 5, the dominant wind direction in the 2016-2020 period is north-northeast (NNE), followed by north with an average speed of 3.6 to 5.7 m/s, and the percentage of calm winds is 0 %. This is influenced by the geographical conditions of the Special Region of Yogyakarta Province, which is a lowland flanked by the Indian Ocean on the south side and Mount Merapi on the north side, so that the wind can move freely with little resistance and move dominantly towards the north and northeast [4].

Figure 4. Contour map of the study area

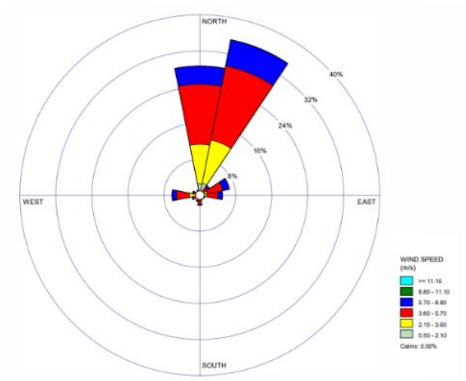


Figure 5. Windrose in the study area in 2016-2020

3.1. Emission Source

The emission sources used in this study are the LTO cycle and land transportation traffic around the airport, the two dominant sources of emissions resulting from airport activities [8]. The number of LTO cycles at the airport is equal to the number of flight activities, as shown in Table 2. The increasing number of flight activities in each stage of development is accompanied by increased pollutants emitted. The amount of pollutants emitted is also affected by the type of aircraft. This is because the emission factors and fuel flow rates for each aircraft are different. The type of aircraft reviewed in this study is a commercial aircraft with a percentage greater than 1%, as shown in Table 7.

Table 7. Percentage of aircraft types

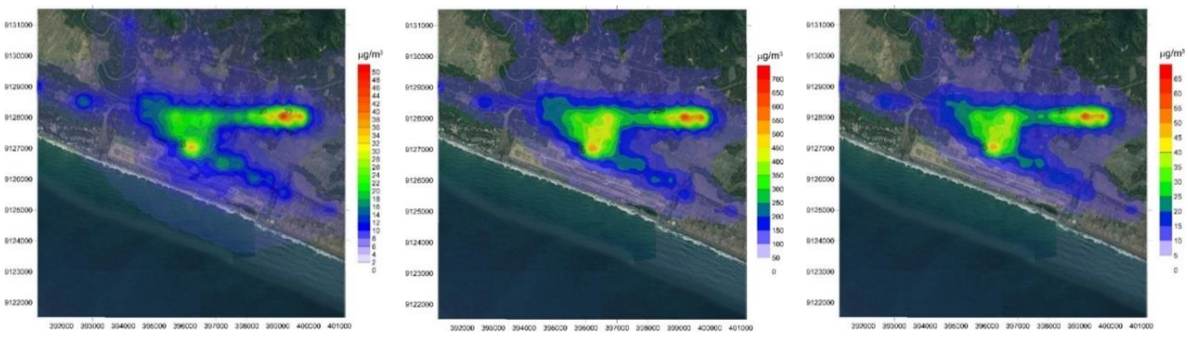
Aircraft type	Actual percentage (%)	Simulation percentage (%)
A320	32.80	36.18
B738	22.87	25.22
B739	15.08	16.64
B733	7.32	8.07
B735	4.23	4.67
ATR72	3.03	3.34
AT72	2.71	2.99
ATR72-500	2.62	2.89

Emission sources from transportation traffic along four intersections near the airport and parking buildings in the airport. Table 3 shows the prediction of traffic volume in the study area under each airport development condition. Like airplanes, the amount and type of land transportation affect the number of emissions produced. The percentages for each type of land transportation are 3% motorcycles, 62% cars, 25% buses, and 10% trucks. This percentage is based on the choice of passenger transportation mode and traffic conditions on the road.

3.2. Pollutant Dispersion Model

Pollutant dispersion modeling were performed using the AERMOD, with a measurement time of 24 hours for NO_2, 1 hour for CO, and 3 hours for hydrocarbons. This time selection adjusted to the measurement time used when sampling to simplify validation of the simulation results. The simulation results are further visualized into a concentration isopleth map using the SURFER13 software.

Figure 6 show the simulation results of pollutant dispersion modeling under existing conditions. The validation result of simulation is shown in Table 8. If all location was simulated, the NMSE was 1.23 and FB was -0.34 indicating the deviation between model and observation is high due to over predicted value at UA-4 (entry 1). When we omitted data from UA-4, we get the better score of statistics (entry 2) indicating the AERMOD simulation results are close to the monitoring data. The simulation result at UA-4 is quite different from the monitoring data because there is an underpass near the airport parking building area, which is modeled like any other open road. The dispersion of pollutants in the underpass differs from on the open road. In the underpass, pollutants tend to accumulate in it because of its more closed area [21]. The validation results show that the AERMOD can be used to predict the dispersion of pollutants at stage 1 to stage 3 of airport development.



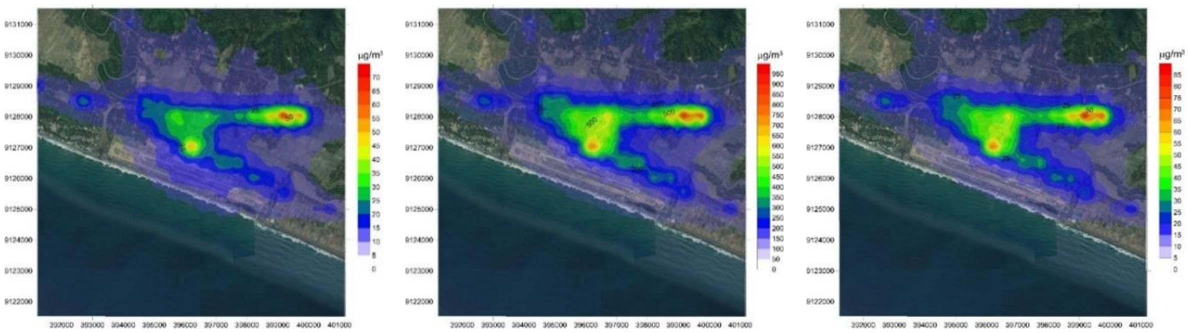
(a) (b) (c)

Figure 6. Simulation results of pollutant dispersion (a) NO_2, (b) CO, and (c) hydrocarbons in existing conditions

Table 8. Validation of simulation results

Entry	NMSE	R	FB	FAC2	Note
1	1.23	0.838	-0.34	1.41	All location
2	0.00	0.995	+0.03	0.96	Without UA-4

The simulation results of pollutant dispersion modeling in stage 1 until stage 3 of the development of the New Yogyakarta International Airport can be seen in Figure 7 for stage 1, Figure 8 for stage 2, and Figure 9 for stage 3 of the development of New Yogyakarta International Airport. As seen in Table 9, the NO_2 pollutant concentration at stages 2 and 3 of airport development at the UA-4 sampling point exceeded the quality standard.



(a) (b) (c)

Figure 7. Simulation results of pollutant dispersion (a) NO_2, (b) CO, and (c) hydrocarbons at stage 1 of airport development

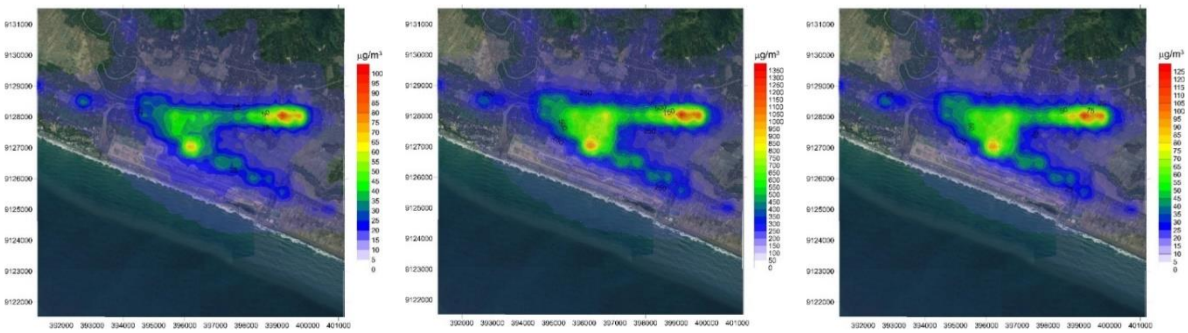


Figure 8. Simulation results of pollutant dispersion (a) NO_2, (b) CO, and (c) hydrocarbons in stage 2 of airport development

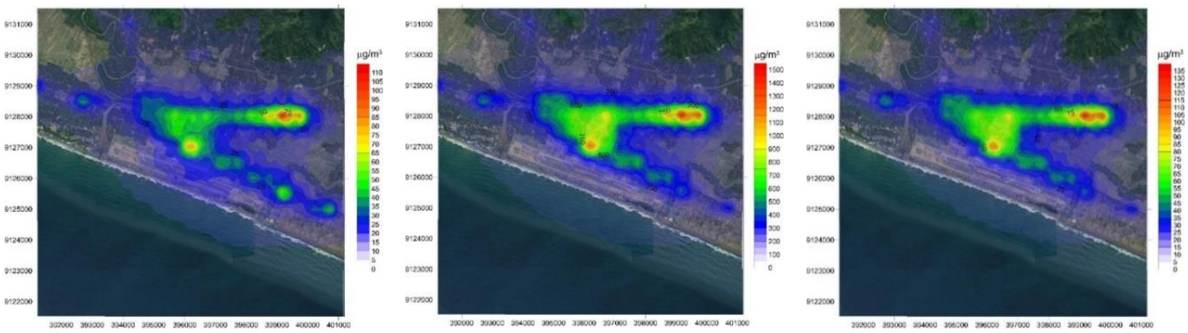


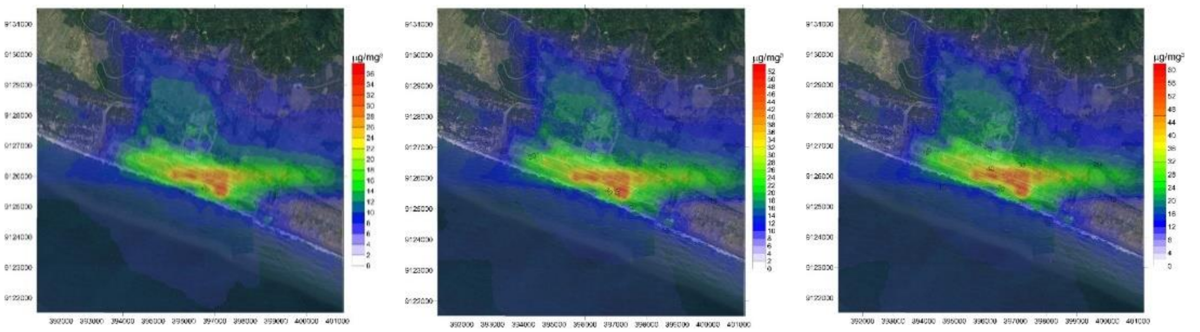
Figure 9. Simulation results of pollutant dispersion (a) NO_2, (b) CO, and (c) hydrocarbons at stage 3 of airport development

Table 9. Air quality at sampling locations

Sampling location	Parameter	Quality standards[1] (µg m^{-3})	Observed data (µg m^{-3})	Simulation result (µg m^{-3})				Remark
				Existing	Stage 1	Stage 2	Stage 3	
UA-1	NO_2	65	11.1	10.26	26.01	32.34	37.08	Not exceed
	CO	10000	148.9	149.33	364.40	457.34	496.19	Not exceed
	HC	160	< 13.6	13.31	32.90	41.24	44.78	Not exceed
UA-2	NO_2	65	9.4	10.17	23.87	29.99	32.45	Not exceed
	CO	10000	143.1	144.68	347.18	432.96	468.29	Not exceed
	HC	160	< 13.6	12.88	31.82	39.49	42.71	Not exceed
UA-3	NO_2	65	11.2	11.59	27.18	33.77	36.69	Not exceed
	CO	10000	171.8	149.98	376.87	458.68	496.04	Not exceed
	HC	160	< 13.6	13.29	31.84	39.24	42.56	Not exceed
UA-4	NO_2	65	11.1	30.16	54.23	71.82	78.89	Exceed for stage 2-3
	CO	10000	186.1	467.46	829.17	1085.64	1202.88	Not exceed
	HC	160	< 13.6	41.80	71.08	94.46	104.82	Not exceed

[1]Goverment regulation No 21/2022

The concentration of NO_2 pollutants that exceeds the quality standard is estimated from land transportation traffic sources around the airport because the maximum concentration for all pollutants occurred at Glagah 2 intersection, which is outside the airport area. This prediction is also based on the wind speed, which decreases with lower altitude due to frictional forces on the surface that dampen the movement of the wind. Pollutants emitted from land transportation are at lower altitudes with slower speeds than aircraft, making the emissions they produce more difficult to disperse [22, 23]. Therefore, the dispersion of pollutants from the LTO cycle was simulated to determine whether the LTO cycle was the solely cause of NO_2 pollutants that exceeded the quality standard or not as shown in Figure 10.



(a) (b) (c)

Figure 10. Simulation results of NO_2 pollutant dispersion sourced from the LTO cycle under (a) stage 1, (c) stage 2, and (d) stage 3 airport development

Table 10. Maximum concentrations of pollutants sourced from the LTO cycle

Pollutant	Quality standards[1] (µg m^{-3})	Simulation result (µg m^{-3})				Remark
		Existing	Stage 1	Stage 2	Stage 3	
NO_2	65	28.60	34.96	50.84	58.06	Not exceed
CO	10000	11.59	14.17	20.61	23.18	Not exceed
HC	160	0.87	1.06	1.54	1.74	Not exceed

[1]Goverment regulation No 21/2022

3.3 Environmental Impact

From the simulation results above, it is known that there is an increase in the number of emissions produced at each stage of airport development, which causes a decrease in air quality and increases the negative impact on the environment, as shown in Table 11. Each pollutant has different environmental impacts, as shown in Table 5. As shown in Figure 11, the LTO cycle has a significant environmental impact on global warming, acidification, eutrophication, and respiratory effects in humans caused by inorganic substances. While the land transportation traffic has a significant impact on ozone layer depletion, ecotoxicity of seawater, freshwater, and terrestrial, and respiratory effects on humans caused by organic substances. This is affected by the emission of each pollutant produced and a characterization factor.

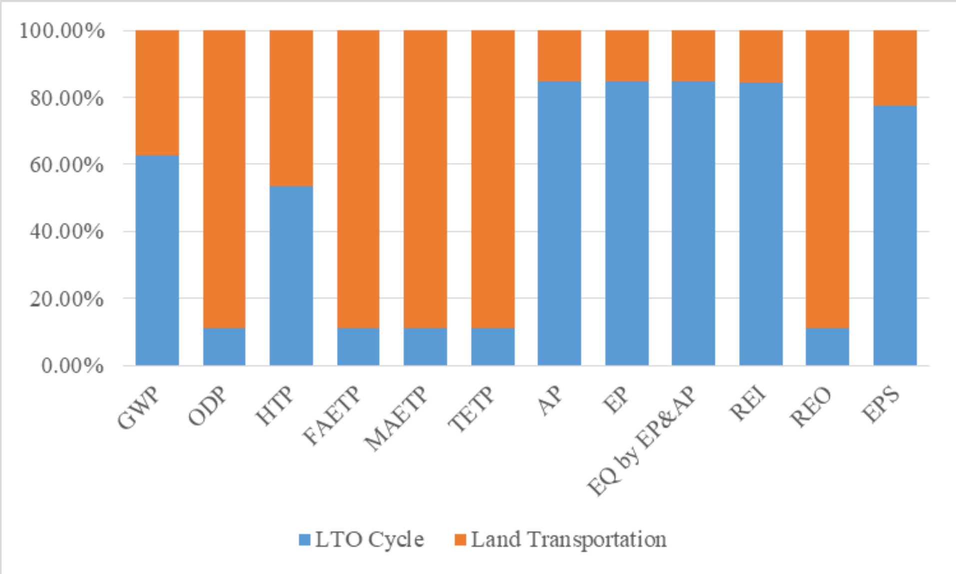


Figure 11. Environmental impacts of the operational activities of New Yogyakarta International Airport

Table 11. Environmental impact of New Yogyakarta International Airport operational activities in every development stage

Environmental impact indicators	Airport development stage			
	Existing	Stage 1	Stage 2	Stage 3
Global Warming Potential (kg CO_2 eq)	4.35×10^6	5.77×10^6	8.17×10^6	9.47×10^6
Ozone Depletion Potential (kg CFC-11 eq)	1.09	1.49	2.11	2.39
Human Toxicity Potential (kg 1,4-DB eq)	1.27×10^6	1.70×10^6	2.41×10^6	2.78×10^6
Freshwater Aquatic Ecotoxicity Potential (kg 1,4-DB eq)	1.08×10^3	1.47×10^3	2.09×10^3	2.36×10^3
Marine Aquatic Ecotoxicity Potential (kg 1,4-DB eq)	2.46×10^2	3.36×10^2	4.76×10^2	5.39×10^2
Terrestrial Ecotoxicity Potential (kg 1,4-DB eq)	1.23×10^2	1.69×10^2	2.39×10^2	2.70×10^2
Acidification Potential (kg SO_2 eq)	3.07×10^5	4.02×10^5	5.70×10^5	6.68×10^5
Eutrophication Potential (kg NO_2 eq)	7.36×10^5	9.65×10^5	1.37E $\times10^6$	1.60×10^6
Damage to Ecosystem Quality caused by the Combined Effect of Acidification and Eutrophication (PDF m^2 yr)	3.51×10^6	4.60×10^6	6.51×10^6	7.63×10^6
Respiratory Effects on Human-caused by Inorganic Substances (DALY)	5.47×10^1	7.18×10^1	1.02×10^2	1.19×10^2
Respiratory Effects on Human-caused by Organic Substances (DALY)	6.05×10^{-2}	8.28×10^{-2}	1.17×10^{-1}	1.33×10^{-1}
Environmental Priorities Strategies (elu)	1.45×10^6	1.91×10^6	2.70×10^6	3.15×10^6

4. CONCLUSION

From the results, we can conclude that AERMOD can predict air pollution from operational activities at New Yogyakarta International Airport. The concentration of pollutants increases with the airport development stage due to the increasing number of operational activities. Concentrations of NO_2, CO, and hydrocarbon pollutants at New Yogyakarta International Airport at every stage of airport development from the LTO cycle are still below the prevailing ambient air quality standards.

5. AKCKNOWLEDMENT
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