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Maximum Hourly and Daily Concentration Patterns of Urban Jakarta Tropospheric Ozone

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Abstract
Tropospheric ozone is formed through UV radiation from sunlight with NOx and VOC precursors. Continuous O_3 measurement data were obtained from US Embassy in Central Jakarta from November 4 2022 to September 30, 2023. The data were analyzed and compared with Indonesian NAAQS for 1-hour and 8-hour. Based on NAAQS, 1-hour O_3 concentration is measured between 11:00-14:00; The 8-hour concentration is the average of the 8 hours measurements between 06:00-18:00. Based on the analysis, maximum concentration tends to occur between 11:00-16:00. The 1-hour concentration increased in July-September 2023, while maximum of 103 μg /m^3 was recorded on November 4, 2022 at 14:00-15:00. Based on the recorded data, the 8-hour concentration can be calculated as the average of 8 hours concentration between 06:00 to 21:00. The measurement between 10:00-18:00 shows higher average 8-hour ozone concentration compared to other ranges. Lowest value was obtained in between 06:00-14:00. With additional O_3 concentration data is expected Jakarta air quality can be more understood. With fast application of Low-Cost Sensor (LCS) for $PM_{2.5}$, LCS for O_3 can be considered to support limited number of AQMS in Jakarta. More O_3 measurement is needed since this parameter is strongly influenced by local meteorological conditions, contributing NOx and VOC pollutants activities, as well wind movement pattern.
Keywords: *Indonesia NAAQS , Jakarta, ozone concentration, urban air pollution*

Abstrak
Ozon troposfer terbentuk melalui radiasi UV sinar matahari dengan prekursor NOx dan VOC. Data pengukuran kontinu O_3 diperoleh dari Kedutaan Besar Amerika Serikat di Jakarta Pusat dari tanggal 4 November 2022 hingga 30 September 2023. Data tersebut dianalisis dan dibandingkan dengan Baku Mutu Udara Ambien Indonesia untuk Ozon 1-jam dan 8-jam. Berdasarkan Baku Mutu Udara Ambien, konsentrasi O_3 1-jam diukur antara pukul 11.00-14.00; Konsentrasi O_3 8-jam merupakan rata-rata pengukuran 8 jam antara pukul 06:00-18:00. Berdasarkan analisis, konsentrasi maksimum cenderung terjadi antara pukul 11.00-16.00. Konsentrasi 1 jam meningkat pada Juli-September 2023, konsentrasi maksimum 103 μg/m^3 tercatat pada 4 November 2022 pukul 14.00-15.00. Berdasarkan data yang tercatat, konsentrasi O_3 8-jam dapat dihitung sebagai rata-rata konsentrasi 8 jam antara pukul 06:00 hingga 21:00. Pengukuran antara pukul 10:00-18:00 menunjukkan rata-rata konsentrasi ozon 8-jam lebih tinggi dibandingkan rentang lainnya. Nilai terendah diperoleh pada pukul 06.00-14.00. Dengan tambahan data konsentrasi O_3 diharapkan kualitas udara Jakarta dapat lebih dipahami. Dengan pesatnya penerapan Sensor Berbiaya Rendah (LCS) untuk $PM_{2.5}$, maka LCS untuk O_3 dapat dianggap mendukung jumlah stasiun pengukuran udara yang terbatas di Jakarta. Pengukuran O_3 lebih banyak diperlukan karena parameter ini sangat dipengaruhi oleh kondisi meteorologi setempat, berkontribusi aktivitas polutan NOx dan VOC, serta pola pergerakan angin.
Kata Kunci: *baku mutu udara ambien indonesia, jakarta, konsentrasi ozon, polusi udara perkotaan*

1. Introduction

Ozone (O_3) in the layer troposphere is a secondary pollutant and formed from complex and non-linear photochemical reaction [1,2]. This photochemical reaction mainly occurs due to the presence of nitrogen oxide (NOx) and volatile organic compounds (VOC) precursors [3,4]. NOx pollutants tend to be emitted from fuel combustion, while VOCs tend to be emitted from vehicle activities and the release of organic solvents [5]. These precursors in the troposphere are exposed to the sun's ultraviolet rays ($h\upsilon$) and become radical compounds, such as NO* and OH*. These radical compounds can then react with O_2 in the air and form O_3. In general, the ozone formation reaction in the troposphere can be explained as follows [6,7]:

$$NO_2 + O_2 + h\upsilon \Leftrightarrow NO + O_3 \quad (1)$$
$$CO + 2O_2 + h\upsilon \rightarrow CO_2 + O_3 \quad (2)$$
$$CH_4 + 4O_2 + 2h\upsilon \rightarrow HCHO + H_2O + 2O_3 \quad (3)$$
$$RH + 4O2 + 2h\upsilon \rightarrow R'CHO + H_2O + 2O_3 \quad (4)$$

Photochemical reactions tend to occur in the morning and noon time when the sun is shining brightly, and ozone formation tends to occur in the afternoon to evening. After sunset, the reaction will stop and ozone will change back to O_2. Therefore, ambient air quality standards for ozone parameters tend to be carried out during the day to obtain maximum concentration measurement results.

Ozone (O_3) along with Particulate Matter (PM) and Nitrogen dioxide (NO_2) are known as the primary air pollutants of premature mortality, respiratory and cardiovascular diseases [8]. All of these pollutants present in urban area as the results of transportation activities and combustion using fossil fuels [9]. Study of urban photochemical smog pollution in Jakarta, Indonesia has been conducted using air monitoring data from local authority [10], and JEPA manual and automatic monitoring stations [11].

Measurement of Ozone can be done using air monitoring station and recently by utilizing LCS technology. The LCS gains popularity due to its simplicity and affordability, however the accuracy of measurement still needs to be improved [12]. Study on low level ozone utilizes LCS has been conducted in many places, including in Lisbon, Portugal [13], Berlin, Germany [14], North China Plain [15].

Republic of Indonesia Government Regulation no. 22 of 2021, Appendix VII concerning Ambient Air Quality Standards [16], states that the quality standard for photochemical oxidant parameters as Ozone (O_3) for a 1-hour measurement time is 150 $\mu g/m^3$, while an 8-hour measurement is 100 $\mu g /m^3$. The 1-hour ozone concentration is the result of measurements carried out every 30 minutes (2 measurements are taken in 1 hour) and measurements are conducted between 11:00-14:00. In contrast, the Indonesian National Standard [17], it is said that sampling should be carried out between 11:00-15:00. Meanwhile, the 8-hour ozone concentration reported according to PPRI no 22/2021, Appendix VII is the concentration resulting from measurements taken between 06:00-18:00 for a duration of 8 hours.

This article aims to examine ambient air quality monitoring data, especially photochemical oxidants (ozone). The study was carried out to determine the pattern of changes in daily concentrations considering that the formation of ozone in the lower atmospheric layers is strongly influenced by the presence of ultraviolet rays from the sun. The 1-hour ozone concentration was also analyzed to find out when the maximum concentration occurred and compared with the time range recommended in the Ambient Air Quality Standards and Indonesian National Standards. The analysis was also carried out to determine the time span for maximum 8-hour ozone concentrations to occur and compared with measurement patterns in Indonesia, WHO Guidelines [18] and US-EPA [19]. It is hoped that this article can provide readers with an idea of the pattern of ozone parameter measurements that occur.

2. Methodology

Source of Ozone Air Quality Measurement Data

Ambient air quality measurement data was obtained from the AirNow website which can be searched via the link https://www.airnow.gov/international/us-embassies-and-consulates/#Indonesia$Jakarta_Central. Starting November 2022, in addition to $PM_{2.5}$, the US Embassy also measures O_3 concentrations every hour with the Teledyne T400 instrument.

The data collected is hourly data, originating from monitoring stations in Central Jakarta in the time period 4 November 2022, at 00:00 to 30 September 2023, 24:00. The data is published every hour and measurements are after noon until just before 13:00 will be reported as data at 13:00.

This ambient air quality measurement station is a facility provided by the United States government through the Department of States at their Embassies and Consulates for their personnel and citizens abroad. The data released by AirNow has undergone initial testing for data quality but has not undergone full validation to meet the requirements as official data according to US-EPA regulations. Data from AirNow is intended to report the Air Quality Index to the public.

Data Processing

In the period from 4 November 2022 to 30 September 2023, there were incomplete data and therefore were excluded from the analysis, namely on 6-8 November 2022 and 13-14 November 2022. There was also some missing data, but this occurred before 6 am, consequently the data on the day in question is still used in the analysis. This is done considering that ozone formation tends to occur between 06:00 and 18:00. Data excluded in the analysis are presented in the following **Table 1**.

Table 1. Data excluded from analysis.

Date	Time	Description
6 – 8 November 2022	Whole day	Data were discarded because they were incomplete
9 November 2022	00:00-03:00	Data were lost in monitoring
13 – 14 November 2022	Whole day	Data were discarded because they were incomplete
9 November 2022	00:00-01:00	Data were lost in monitoring
20 Desember 2022	04:00	Data were lost in monitoring
16 April 2023	04:00	Data were lost in monitoring
14, 18, 25, 28 Mei 2023	04:00	Data were lost in monitoring
20, 23 Juni 2023	04:00	Data were lost in monitoring

The data are sorted based on measurement time in order to analyze and determine the 1-hour ozone concentration pattern. Apart from that, the data are also grouped into 8-hour time frames which are divided into time groups 06:00-14:00, 07:00-15:00, 08:00-16:00, 09:00-17:00, 10: 00-18:00, 11:00-19:00, 12:00-20:00, and 13:00-21:00. Grouping within an 8-hour time span is intended to determine the 8-hour ozone concentration pattern. The measurement time is also adjusted to the data reporting pattern from AirNow, namely by adjusting the data at 1 to measurements in the range of 00:00-01:00, and so on.

3. Analysis

Concentration of 1-hour Ozone

The 1-hour ozone concentration pattern over a 24-hour period is presented in **Figure 1** and **Table 2**. The Box Whisker diagram in **Figure 1** shows the values sequentially from the bottom: minimum, 1st quartile, median, 3rd quartile, and maximum; as well as monitoring results values that are outside the minimum or maximum values. It appears that ozone may not have been detected or was not present in measurements from 18:00 to 07:00. This can be seen in the minimum concentration value in this time period of 0 μg/m^3. Maximum concentrations tend to occur between measurements at 11:00-16:00. The data for measurements at 13:00-14:00, the average, median and 3rd quartile figures are the highest compared to data in other 1-hour measurement ranges.

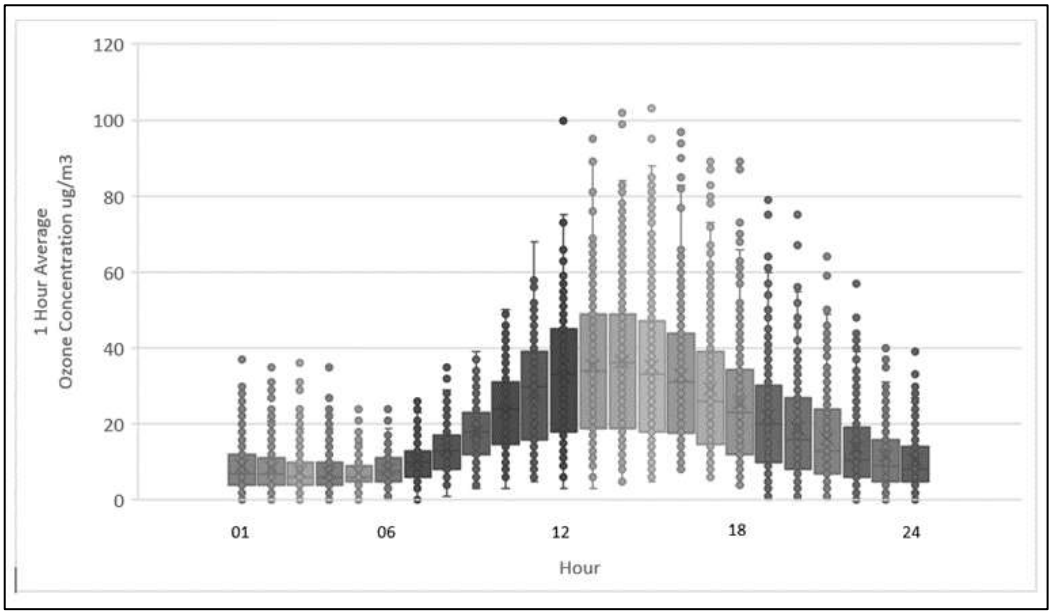

Figure. 1. Pattern of 1-hour ozone concentration.

Table 2. Statistics of 1-hour ozone concentration.

Time	1-hour Ozone Concentration (μg/m^3)						
	Minimum	Maximum	Average	Std. Dev	Q1	Q2	Q3
00:00-01:00	0	37	9.2	6.7	4	7	12
01:00-02:00	0	35	8.3	6.1	4	7	11
02:00-03:00	0	36	7.5	5.5	4	6	10
03:00-04:00	0	35	7.3	5.4	4	6	10
04:00-05:00	0	24	7.2	4.1	5	6	9
05:00-06:00	0	24	8.2	3.9	5	7.5	11

Time	1-hour Ozone Concentration (μg/m^3)						
	Minimum	Maximum	Average	Std. Dev	Q1	Q2	Q3
06:00-07:00	0	26	10.3	4.7	6	10	13
07:00-08:00	1	35	13.3	6.1	8	13	17
08:00-09:00	3	39	17.9	7.8	12	18	23
09:00-10:00	3	50	23.4	10.2	14.75	24	31
10:00-11:00	5	68	28.4	12.9	16	30	39
11:00-12:00*#	3	100	32.6	15.6	18	33	45
12:00-13:00*#	3	95	35.3	18.0	19	34	49
13:00-14:00*#	5	102	36.3	18.9	19	36	49
14:00-15:00#	5	103	35.3	19.1	18	33	47
15:00-16:00	8	97	32.9	18.1	17.75	31	44
16:00-17:00	6	89	29.3	17.0	14.75	26	39
17:00-18:00	4	89	25.6	15.6	12	23	34.25
18:00-19:00	0	79	22.0	14.0	10	20	30.25
19:00-20:00	0	75	18.8	12.7	8	16	27
20:00-21:00	0	64	16.3	11.3	7	13	24
21:00-22:00	0	57	13.7	9.8	6	10.5	19.25
22:00-23:00	0	41	11.6	8.2	5	9	16
23:00-24:00	0	40	10.4	7.6	5	8	14

Note:
* Measurement time range based on PPRI 22/2021, Appendix VII for 1-hour Ozone
# measurement time range based on SNI 19-7119.8-2005 for 1-hour Ozone

When compared with PPRI no. 22 of 2021, Appendix VII concerning Ambient Air Quality Standards, it is stated that the 1-hour ozone concentration is the concentration resulting from measurements carried out every 30 minutes (2 measurements are made in 1 hour) and measurements are carried out between 11:00-14:00. In **Table 2**, the measurement time range referred to is the measurement from 11:00 to 14:00.

Meanwhile, the Indonesian National Standard (SNI 19-7119.8-2005) regarding ambient air - Part 8: How to test oxidant levels using the neutral buffer potassium iodide (NBKI) method using a spectrophotometer, it is said that sampling is carried out in the time range 11:00- 15:00. In **Table 2**, the measurement time range referred to is the measurement from 11:00 to 14:59.

Table 2 indicates that the time range with the highest ozone concentration occurred during measurements from 11:00 to 16:00. The 1-hour ozone concentration measurement time range based on PPRI no. 22 of 2021, Appendix VII is included in the time range for peak concentrations. However, there is a possibility that the maximum concentration occurs between 14:00-16:00 which is outside the designated time range.

Concentration of 8-hour Ozone

The 8-hour ozone concentration is the average of ozone measurements over an 8-hour time span. This means that the 8-hour ozone concentration value could come from the average of 8 of 1-hour measurements, or the average of 16 of 30-minute measurements. In measurements using automatic monitoring tools, the sampling period can occur in the range of less than 1 minute. Thus, for example, in 1 minute there are 5 data, then over a period of 8 hours there are 2400 data, which will be averaged to become an 8-hour ozone concentration.

PPRI no 22/2021, Appendix VII, it is stated that the 8-hour ozone concentration is the concentration resulting from measurements carried out between 06:00-18:00. Based on **Figure 2** and **Table 3**, it appears that the measurement range from 10:00 to 18:00 shows a higher 8-hour average ozone concentration than the average for other ranges. The lowest value was obtained in the measurement range from 06:00 to 14:00, hence, there is a possibility that the minimum concentration can be reported.

The maximum 8-hour ozone concentration was recorded in the measurement data at 11:00-19:00. Therefore, there is a possibility that the maximum concentration could occur outside of the designated time range.

The WHO and US-EPA has no longer use 1-hour ozone concentration values, and only use 8-hour maximum ozone concentrations as short-term exposure measurements. The 8-hour daily ozone concentration reporting pattern based on the 2021 WHO Air Quality Guidelines (AQG) and 2020 US-EPA is carried out by looking for the average maximum value for 8 hours in a day. The maximum 8-hour ozone concentration based on WHO AQG is 100 μg/m^3. For US-EPA, an 8-hour ozone concentration can be imputed if in a day there are at least 18 of the 24 possible 8-hour average values, or there are less than 6 hours of missing data. The primary ambient air quality standard for ozone is 0.070 ppm or the equivalent to 137 μg/m^3. From the analysis results, it was found that the maximum 8-hour ozone concentration in the range 4 November 2022-30 September 2023

was 84.4 μg/m^3, with an average of 32.7 μg/m^{3}and a standard deviation of 16.1 μg/m^3. This shows that the 8-hour ozone concentration still meets the Indonesian Ambient Air Quality Standards, as well as meeting WHO AQG.

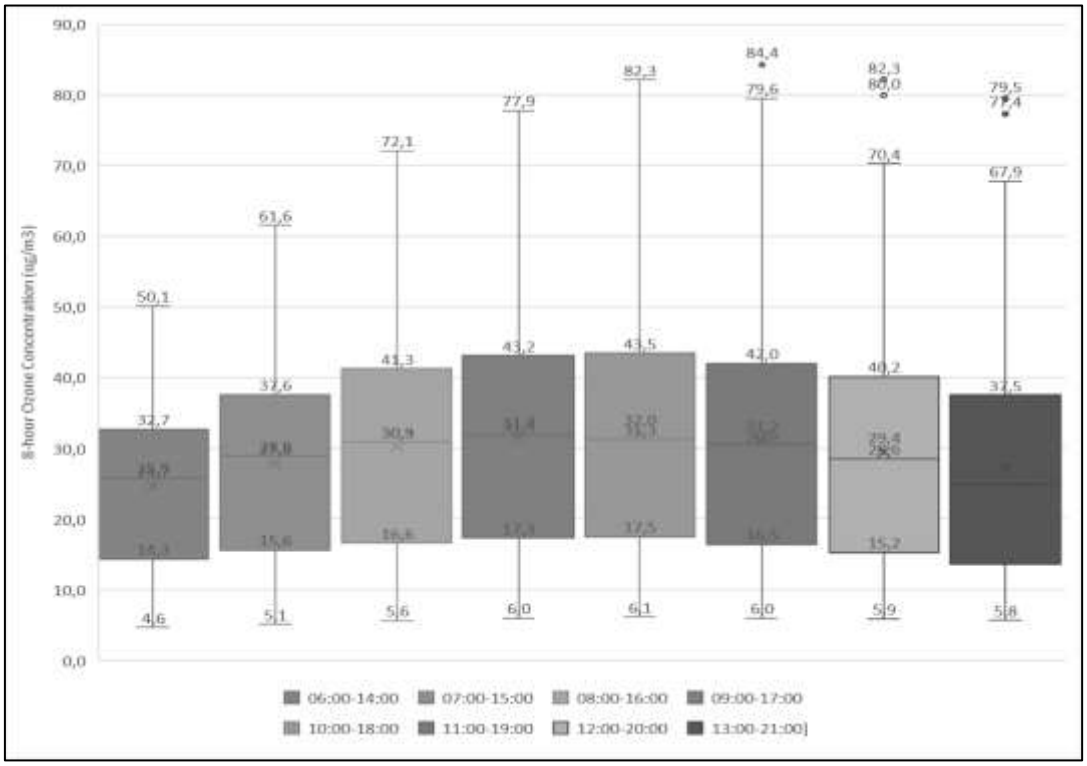

Figure 2. Pattern of 8-hour ozone concentration

Table 3. Statistics of 8-hour ozone concentration

Time	8-hour Ozone Concentration (μg/m^3)						
	Minimum	Maximum	Average	Std. Dev	Q1	Q2	Q3
06:00-14:00	4.6	50.1	24.7	10.6	14.3	25.9	32.7
07:00-15:00	5.1	61.6	27.8	12.5	15.6	28.9	37.6
08:00-16:00	5.6	72.1	30.3	14.0	16.6	30.9	41.3
09:00-17:00	6.0	77.9	31.7	15.2	17.3	31.9	43.2
10:00-18:00	6.1	82.3	32.0	15.9	17.5	31.3	43.5
11:00-19:00	6.0	84.4	31.2	16.2	16.5	30.6	42.0
12:00-20:00	5.9	82.3	29.4	15.9	15.2	28.6	40.2
13:00-21:00	5.8	79.5	27.1	15.1	13.6	24.9	37.5

4. Conclusion

The 1-hour ozone concentration measurements are still implemented in Indonesia considering that measurements can still be done manually. However, WHO AQG 2021 has recommended that measurements be carried out continuously for 24 hours, and that the maximum value reported occurs within an 8-hour time span. In Indonesia, this cannot yet be done considering that equipment for continuous measurements is still limited.

In Indonesia, measurements for 8-hour concentrations are required to be carried out between 06:00-18:00. This can result in the 8-hour ozone concentration value not being the maximum if measurements start before 08:00. The 8-hour ozone concentration will increase in measurements starting at 08:00 until 20:00. Restrictions until 18:00 can allow the maximum 8-hour average ozone concentration that occur between 11:00-19:00 to be unreported.

Based on the results of measurements on 4 November 2022-30 September 2023, the 1-hour ozone concentration is still below the Ambient Air Quality Standards, likewise the 8-hour ozone concentration still meets the Ambient Air Quality Standards and WHO AQG. The use of Low-Cost Sensor can be implemented to support air monitoring stations and to give better information to the public on the importance of maintaining clean air in urban area.

5. References

[1]. Chameides, W. and Walker, J. C. G.: A photochemical theory of tropospheric ozone, *J. Geophys. Res*., 78, 8751–8760, https://doi.org/10.1029/JC078i036p08751 (1973).

[2]. Soedomo, M., and Brunner, IM. Model kinetika pembentukan ozon di troposfer dengan perkursor hidrokarbon dan NOx. *Jurnal Teknik Lingkungan*, 1 (2), 37-45 (1996)

[3]. Okamoto, S., Cuesta, J., Beekmann, M., Dufour, G., Eremenko, M., Miyazaki, K., Boonne, C., Tanimoto, H., and Akimoto, H. Impact of different sources of precursors on an ozone pollution outbreak over Europe analysed with IASI+GOME2 multispectral satellite observations and model simulations, Atmos. Chem. Phys., 23, 7399–7423, https://doi.org/10.5194/acp-23-7399-2023 (2023).

[4]. Wang, P., Chen, Y., Hu, J., Zhang, H., and Ying, Q. Attribution of Tropospheric Ozone to NOx and VOC Emissions: Considering Ozone Formation in the Transition Regime. *Environmental Science & Technology*, *53* (3), 1404-1412 (2019). DOI: 10.1021/acs.est.8b05981

[5]. Beck, J.P., Krzyzanowski, M. and Koffi, B: Troposheric Ozone in the European Union. Report to the European Commission by the European Environment Agency European Topic Centre on Air Quality in the Framework of Council Directive 92/72/EEC on Air Pollution by Ozone (1999) https://www.eea.europa.eu/publications/TOP08-98

[6]. Rao, M.V., Koch, J.R., and Davis, K.R.: Ozone: a tool for probing programmed cell death in plants, Plant Molecular Biology 44: 345–358 (2000)

[7]. Hester, R.E.; Harrison, R.M. *Air Quality in Urban Environments*. Royal Society of Chemistry: London, UK (2009).

[8]. Huangfu, P. , and Atkinson, R. Long-term exposure to NO_2 and O_3 and all-cause and respiratory mortality: A systematic review and meta-analysis. *Environment International*, 144, 105998 (2020) https://doi.org/10.1016/j.envint.2020.105998

[9]. Sicard, P., Agathokleous, E., Anenberg, S.C., De Marco, A., Paoletti, E., and Calatayud, V. Trends in urban air pollution over the last two decades: A global perspective. *Science of The Total Environment*, 858 (2), 160064 (2023). https://doi.org/10.1016/j.scitotenv.2022.160064

[10]. Suhadi, D.R., Awang, M., Hassan, M.N., Abdullah, R. and Hj. Muda, A. Review of Photochemical Smog Pollution in Jakarta Metropolitan, Indonesia. *American Journal of Environmental Sciences*, 1(2), 110-118 (2005)

[11]. Permadi, D.A., Oanh, N.T.K. Episodic ozone air quality in Jakarta in relation to meteorological conditions, Atmospheric Environment, 42, 6806–6815 (2008)

[12]. Cross, E. S., Williams, L. R., Lewis, D. K., Magoon, G. R., Onasch, T. B., Kaminsky, M. L., Worsnop, D. R., and Jayne, J. T. Use of electrochemical sensors for measurement of air pollution: correcting interference response and validating measurements. *Atmos. Meas. Tech*., 10, 3575–3588. (2017) https://doi.org/10.5194/amt-10-3575-2017

[13]. Soares, A.R., Neto, D., Avelino, T., and Silva, C. Ground Level Ozone Formation Near a Traffic Intersection: Lisbon "Rotunda De Entrecampos" Case Study. *Energies*, 13(7), 1562 (2020). https://doi.org/10.3390/en13071562

[14]. Schmitz, S., Villena, G., Caseiro, A., Meier, F., Kerschbaumer, A., and von Schneidemesser, E. Calibrating low-cost sensors to measure vertical and horizontal gradients of NO_2 and O_3 pollution in three street canyons in Berlin. *Atmospheric Environment*, 307, 119830 (2023). https://doi.org/10.1016/j.atmosenv.2023.119830.

[15]. Wang, R., Zhang, S., Xue, J., Guo, L., and Li, L. Speciated VOCs emissions and ozone formation potential from on-road vehicles in North China Plain based on detailed and localized source profiles. *Environmental Technology & Innovation*, 32, 103422 (2023). https://doi.org/10.1016/j.eti.2023.103422

[16]. Republic of Indonesia Government Regulation no 22/2021, Appendix VII concerning Ambient Air Quality Standards

[17]. SNI 19-7119.8-2005 regarding ambient air - Part 8: How to test oxidant levels using the neutral buffer potassium iodide (NBKI) method using a spectrophotometer

[18]. WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide (2021) https://www.who.int/publications/i/item/9789240034228

[19]. Ozone National Ambient Air Quality Standards (NAAQS). https://www.epa.gov/ground-level-ozone-pollution/ozone-national-ambient-air-quality-standards-naaqs