

Air Quality Based on Particulate Matter Concentrations (TSP, PM₁₀, and PM_{2.5}) in Paal Dua, Manado City

Zefanya Sheren Pontoh*, As'ari, Megastin Massang Lumembang

Physics Study Program, Faculty of Mathematics and Natural Sciences, Sam Ratulangi University, Manado City

*e-mail: zefanyaashrnn12@gmail.com

Received: 24 07 2026. Accepted: 31 07 2026. Published: 07 2026

Abstract

The Paal Dua area of Manado City is an urban area characterized by intensive traffic and commercial activities that may contribute to elevated particulate matter concentrations in ambient air. This study aimed to determine and analyze Total Suspended Particulate (TSP), PM₁₀, and PM_{2.5} concentrations at three sampling sites with different environmental characteristics and to evaluate their compliance with ambient air quality standards specified in Government Regulation No. 22 of 2021, Annex VII. Measurements were conducted for 24 hours at each site using a High Volume Air Sampler (HVAS) and the gravimetric method, following SNI 7119.3:2017 for TSP, SNI 7119.15:2016 for PM₁₀, and SNI 7119.14:2016 for PM_{2.5}. Although all methods employ the same gravimetric principle, they differ in particle-size-selective inlet specifications. TSP concentrations ranged from 6.19 to 24.46 $\mu\text{g}/\text{m}^3$, PM₁₀ from 1.38 to 10.89 $\mu\text{g}/\text{m}^3$, and PM_{2.5} from 0.24 to 3.83 $\mu\text{g}/\text{m}^3$. The highest TSP and PM₁₀ concentrations were observed at Site 1, near a road and market area, while PM_{2.5} concentration at Site 3 exceeded that at Site 2. This spatial difference was presumably associated with prevailing wind direction and surrounding building configuration, although meteorological and statistical analyses are required for confirmation. All measured particulate concentrations were below ambient air quality standards during August 2025. These results represent conditions during the sampling period and cannot be generalized to the entire Paal Dua area. Periodic monitoring with broader spatial and temporal coverage is recommended. The study provides information on particulate matter distribution across locations with different emission sources and urban configurations.

Keywords: Ambient Air Quality; Total Suspended Particulate (TSP); Particulate Matter 10 (PM₁₀); Particulate Matter 2.5 (PM_{2.5}); High Volume Air Sampler (HVAS)

INTRODUCTION

Air is an essential component for the survival of living organisms; however, its quality is increasingly affected by the rapid growth of human activities, particularly in urban areas. The growing number of motor vehicles, industrial activities, and domestic activities constitutes major sources of air emissions, contributing to a progressive deterioration of ambient air quality in many urban environments (Amin et al., 2024). Among the various air pollutants, particulate matter is one of the most widely used

indicators for assessing air quality because its presence is closely associated with anthropogenic emission sources and public health risks. In particular, PM₁₀ and PM_{2.5} are highly sensitive parameters for characterizing ambient air quality. The incorporation of these two parameters into air quality index calculations has been reported to alter the classification of air quality from “good” to “moderate” in several areas (Rita et al., 2016).

Particulate matter is commonly classified according to aerodynamic particle size, including Total Suspended Particulate (TSP), PM₁₀, and PM_{2.5}. TSP

generally represents suspended particles with diameters of up to approximately 100 μm , whereas PM10 and PM2.5 refer to particles with aerodynamic diameters of less than 10 μm and 2.5 μm , respectively (Yulinawati et al., 2015). The World Health Organization (WHO, 2024) defines particulate matter as a complex mixture of solid and liquid particles suspended in the atmosphere. Particle size plays a critical role in determining their deposition and penetration within the human respiratory system. PM10 can be inhaled and deposited primarily in the respiratory tract, whereas the substantially smaller PM2.5 particles can penetrate deeper into the lungs and reach the alveolar region. Some of these fine particles may subsequently enter the bloodstream, thereby posing greater potential health risks. Long-term exposure to PM2.5 has been associated with adverse respiratory and cardiovascular outcomes, as well as an increased risk of lung cancer (EPA, 2023). These health implications underscore the importance of continuous and periodic particulate matter monitoring as an essential component of air pollution control and public health protection.

Paal Dua, an urban area in Manado City, has experienced rapid development accompanied by increasing population density, traffic intensity, commercial activities, and construction. These activities may contribute to elevated particulate matter concentrations in ambient air. Nevertheless, air quality monitoring in this area remains limited, consistent with previous findings indicating a lack of comprehensive air quality data in eastern Indonesia (Santoso et al., 2019). Based on the authors' literature review, no published study has specifically measured and compared TSP, PM10, and PM2.5 concentrations at multiple locations in Paal Dua with distinct emission sources and urban configurations. This represents an important research gap, particularly

because differences in traffic intensity, commercial activities, surrounding structures, and local environmental conditions may influence the spatial distribution of particulate matter.

Therefore, this study was conducted to establish baseline data on TSP, PM10, and PM2.5 concentrations in Paal Dua and to provide an initial assessment of their spatial variability across locations with different environmental characteristics. The findings are expected to contribute scientific information that can support local authorities and communities in developing appropriate strategies for ambient air quality management and particulate pollution control. Accordingly, this study aimed to determine and analyze TSP, PM10, and PM2.5 concentrations at three sampling sites in Paal Dua, Manado City; compare their concentrations among sites with different environmental characteristics; and evaluate their compliance with the applicable ambient air quality standards stipulated in Government Regulation No. 22 of 2021, Annex VII.

MATERIALS AND METHODS

Study Variables

The primary variables investigated in this study were the concentrations of Total Suspended Particulate (TSP), PM10, and PM2.5, expressed in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). Supporting variables included meteorological conditions, namely air temperature ($^{\circ}\text{C}$), atmospheric pressure (kPa), relative humidity (%), wind speed (m/s), and wind direction. Meteorological parameters were recorded at hourly intervals throughout the sampling period at each sampling site. Operationally, particulate matter concentration was defined as the difference between the filter mass before and after sampling divided by the volume of air sampled under standard conditions.

Instruments and Materials

The primary equipment consisted of a TISCH High Volume Air Sampler (HVAS) equipped with particle-size-selective inlets for TSP, PM₁₀, and PM_{2.5}, Whatman GF/A filter papers, an analytical balance with a readability of 0.1 mg, and an AQMS Weather Station for continuous meteorological measurements. All sampling and analytical procedures were conducted in accordance with the relevant Indonesian National Standards (SNI).

Sampling and Measurement Procedures

Data collection consisted of preparation and field-sampling stages. During the preparation stage, the HVAS was checked to ensure that it was properly calibrated, while the analytical balance was placed in a temperature- and humidity-controlled laboratory environment. Each filter was labeled, conditioned in a closed environment, and stored in a clean container to minimize contamination. The filters were conditioned at a temperature of 15–35°C and relative humidity of ≤50% for approximately 24 h before weighing to obtain the initial filter mass (W₁).

During field sampling, the HVAS was operated at a flow rate of 1.1–1.7 m³/min for 24 h at each sampling site. Airflow rate, air temperature, and atmospheric pressure were recorded hourly. The procedures for TSP, PM₁₀, and PM_{2.5} measurements followed SNI 7119.3:2017, SNI 7119.15:2016, and SNI 7119.14:2016, respectively. All three methods are based on the gravimetric principle but differ in the specifications of the particle-size-selective inlet.

After 24 h of sampling, the filters were removed using clean gloves and placed in clean containers before being transported to Water Laboratory Nusantara (SGS WLN Manado) for laboratory analysis. The filters were subsequently reconditioned under the same temperature and relative humidity

conditions before being weighed to obtain the final mass (W₂).

In this study, both W₁ and W₂ were measured once for each filter. Field and laboratory blank procedures were not performed. These procedures constitute methodological limitations because the absence of replicate weighing and blank corrections prevents quantitative evaluation of measurement uncertainty. Future studies should incorporate duplicate or triplicate weighing and appropriate field and laboratory blanks to improve data reliability and enable a more robust assessment of measurement uncertainty.

Data Analysis

The particulate matter concentrations were quantitatively determined using the gravimetric method based on the difference between the initial and final filter masses and the volume of air sampled. The particulate matter concentration was calculated using the following equation:

$$C = (W_2 - W_1) \times 10^6 / V_{\text{std}}$$

where (C) is the particulate matter concentration (μg/m³), (W₁) is the initial filter mass before sampling (g), (W₂) is the final filter mass after sampling (g), and (V_{std}) is the volume of sampled air under standard conditions (m³). The standard conditions were defined as 298 K and 101.3 kPa. The (V_{std}) value was obtained by correcting the measured air volume based on the actual airflow rate, air temperature, and atmospheric pressure recorded during the sampling period.

The particulate matter concentrations obtained at each sampling site were subsequently compared descriptively with the applicable ambient air quality standards stipulated in Government Regulation No. 22 of 2021, Annex VII, to determine their compliance status. Hourly wind speed and wind

direction data recorded at each sampling site were also analyzed descriptively and evaluated in relation to the observed particulate matter concentration patterns. Particular attention was given to the interpretation of the spatial distribution of PM_{2.5}, including differences in concentration among sampling sites that could potentially be associated with prevailing wind direction and surrounding environmental conditions.

Further quantitative statistical analyses, such as correlation tests between particulate matter concentrations and meteorological variables, were not performed because of the limited number of sampling sites and sampling days ((n=3)). Consequently, interpretations regarding the potential influence of wind direction, wind speed, and surrounding environmental conditions on particulate matter concentrations, particularly PM_{2.5}, are presented as descriptive and interpretative findings rather than statistically validated causal relationships.

RESULTS AND DISCUSSION

Sampling was conducted from 16 to 21 August 2025 using a High Volume Air Sampler (HVAS) operated continuously for 24 h at each sampling site, following the procedures specified in SNI 7119.3:2017. The resulting particulate matter concentrations were calculated using the gravimetric method described in the Materials and Methods section.

Particulate Matter Concentrations at the Three Sampling Sites

The calculated concentrations of Total Suspended Particulate (TSP), PM₁₀, and PM_{2.5} at the three sampling sites, together with their comparison with the applicable ambient air quality standards, are presented in Table 1.

$$C = \frac{(w_2 - w_1) \times 10^6}{V_{std}}$$

Table 1. Concentrations of Particulate Matter and Their Compliance with Ambient Air Quality Standards

Sampling Site	Parameter	Concentration (µg/m ³)	Ambient Air Quality Standard (µg/m ³)	Description
Site 1	TSP	24,46	230	Complies
	PM ₁₀	10,89	75	Complies
	PM _{2,5}	3,83	55	Complies
Site 2	TSP	7,66	230	Complies
	PM ₁₀	3,35	75	Complies
	PM _{2,5}	0,24	55	Complies
Site 3	TSP	6,19	230	Complies
	PM ₁₀	1,38	75	Complies
	PM _{2,5}	0,48	55	Complies

Based on Table 1, the highest concentrations of TSP, PM₁₀, and PM_{2.5} were observed at Site 1, whereas Sites 2 and 3 exhibited comparatively lower concentrations. To quantitatively assess this pattern, the proportions of PM₁₀ and PM_{2.5} relative to TSP were calculated for each sampling site. At Site 1, PM₁₀ and

PM_{2.5} accounted for 44.5% and 15.7% of the TSP concentration, respectively. At Site 2, the corresponding proportions were 43.7% for PM₁₀ and 3.1% for PM_{2.5}. At Site 3, the PM₁₀ fraction decreased to 22.3%, whereas the PM_{2.5} fraction increased slightly to 7.8% of TSP. These variations indicate that the decrease in

particulate concentrations from Site 1 to Sites 2 and 3 did not occur proportionally across particle-size fractions. This finding suggests that differences in emission-source characteristics and atmospheric dispersion processes may contribute to the spatial variability in particulate composition, rather than the observed pattern simply reflecting a linear decrease with decreasing particle size.

The observation that smaller particulate fractions were associated with lower concentrations in this study should be interpreted as a site-specific pattern rather than as a universal relationship. The concentration of particulate matter collected within each size fraction is governed by the combined effects of emission-source characteristics and proximity, meteorological conditions during sampling, and the collection efficiency of size-selective inlets across the respective particle-size ranges. The consistently observed concentration pattern of $TSP > PM_{10} > PM_{2.5}$ across all three sampling sites is consistent with the characteristics of the emission sources in the study area, which were predominantly associated with motor-vehicle activity and

road-dust resuspension. These sources generally contribute larger amounts of coarse particles than fine particles (Eka et al., 2016; Kim et al., 2015).

Influence of Traffic Activity on TSP and PM_{10}

The higher TSP and PM_{10} concentrations observed at Site 1 may be associated with its proximity to a major roadway and a market area, where vehicle and pedestrian activities were more intensive than at the other sampling sites. Motor-vehicle activity is an important contributor to ambient particulate matter through both exhaust emissions and the resuspension of road dust induced by vehicle movement (Eka et al., 2016; Kim et al., 2015). The PM_{10} concentration exhibited a pattern similar to that of TSP, with the highest value recorded at Site 1. This pattern may be attributed to the greater intensity of traffic activity around the major roadway and market area, which can enhance both the direct emission and resuspension of coarse particulate matter (Kim et al., 2015).

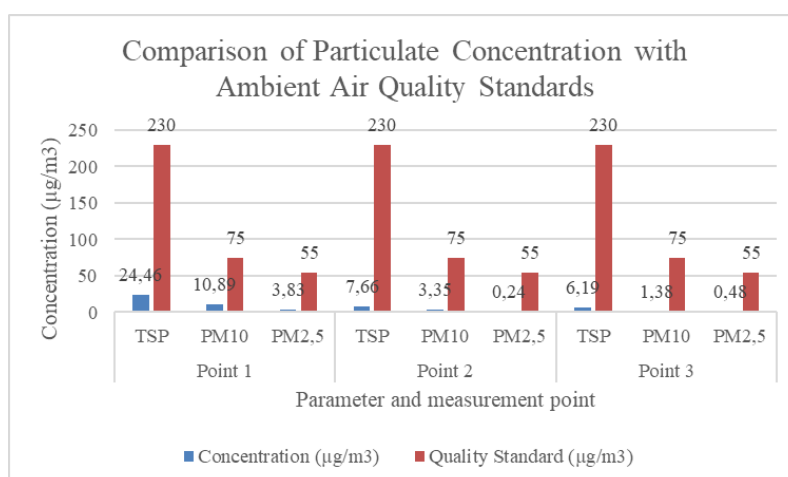


Figure 1. Comparison of Particulate Matter Concentrations at Each Sampling Site

Anomalous $PM_{2.5}$ Distribution and the Influence of Meteorological Conditions

A distinct spatial pattern was observed for $PM_{2.5}$, with the concentration at Site 3 ($0.48 \mu g/m^3$) exceeding that at

Site 2 ($0.24 \mu g/m^3$), despite Site 3 exhibiting the lowest TSP and PM_{10} concentrations among the three sampling sites. To further examine this pattern, hourly wind speed and wind direction data

recorded at each site were descriptively evaluated. At Site 1, the prevailing wind direction was from the southwest sector, accounting for 29.2% of the sampling period, with a mean wind speed of 1.16 m/s. At Site 2, winds predominantly originated from the north, accounting for 87.5% of the sampling period, with a mean wind speed of 1.03 m/s. At Site 3, no single wind direction was dominant; however, winds from the east–southeast–south sectors collectively accounted for 70.8% of the sampling period. The mean wind speed at Site 3 was 1.00 m/s, the lowest among the three sampling sites.

Based on these descriptive patterns, the higher $PM_{2.5}$ concentration at Site 3 compared with Site 2 coincided with the lower wind speed and the predominance of winds from the east–southeast–south sectors at Site 3. These conditions may have facilitated the transport of particulate matter from potential upwind source areas toward the sampling location. In addition, the presence of office buildings surrounding Site 3 may have locally modified airflow and reduced dispersion, potentially contributing to the accumulation of fine particulate matter. However, these interpretations remain descriptive and are not supported by quantitative analyses of the relationship between wind characteristics and particulate concentrations. Given the limited number of sampling sites and measurement days ($n = 3$), statistical analyses such as correlation testing would have limited inferential power. Therefore, the potential influence of wind direction and building-induced accumulation should be regarded as plausible hypotheses consistent with the observed data rather than as statistically established causal relationships. Further investigations involving a larger number of sampling sites and longer monitoring periods are required to validate these hypotheses.

As fine particles, $PM_{2.5}$ generally remain suspended in the atmosphere for

longer periods than larger particles, such as TSP and PM_{10} , making their spatial distribution more sensitive to atmospheric transport and meteorological conditions, particularly wind direction and speed (Safira, 2022). Wind speeds recorded at the three sites were relatively low, ranging from 1.00 to 1.16 m/s, and remained below 2 m/s. This condition should be interpreted within the broader meteorological context of the dry-season measurements conducted in August 2025. The mean air temperature across the three sites ranged from 22.3 to 24.6°C and exhibited a typical diurnal pattern, increasing during the daytime and decreasing during the early morning hours. Mean relative humidity ranged from 80.2% to 81.5% and generally exhibited an inverse pattern to air temperature, while atmospheric pressure remained relatively stable at approximately 689 mmHg throughout the measurement period and across all sites. The combination of low wind speeds and relatively high relative humidity, particularly during nighttime and early-morning periods, may have reduced mechanical dispersion and favored the retention or accumulation of particulate matter near local emission sources (Ilham, 2021). This meteorological setting may partly explain the pronounced spatial differences observed in TSP and PM_{10} concentrations, as coarse particles are generally more strongly influenced by proximity to local emission and resuspension sources. In contrast, the distribution of finer particles such as $PM_{2.5}$ may be more strongly affected by atmospheric transport, local dispersion conditions, and accumulation processes.

Compliance with Ambient Air Quality Standards under Government Regulation No. 22 of 2021, Appendix VII

Overall, despite the variation in particulate concentrations among the sampling sites, all measured TSP, PM_{10} ,

and PM_{2.5} concentrations were substantially below the ambient air quality standards stipulated in Government Regulation No. 22 of 2021, Appendix VII. These findings indicate that particulate concentrations during the sampling period remained below the applicable regulatory limits; however, they should not be interpreted as representing the overall ambient air quality conditions in the Paal Dua area.

This limitation is important because measurements were conducted only once at each sampling site. Therefore, the observed concentrations represent the atmospheric conditions on the respective sampling days and may have been influenced by short-term meteorological variability and site-specific daily activities, as described in the Methods section. Consequently, longer-term and repeated measurements across different meteorological conditions and periods of activity are required to provide a more representative assessment of ambient particulate pollution in the Paal Dua area.

Comparison with Previous Studies and Potential Explanations for the Low Particulate Concentrations

Compared with studies conducted in other urban areas, the particulate concentrations observed in the present study were relatively low. For comparison, Sangga et al. (2020), who investigated SO₂, NO₂, and CO concentrations in Wanea District, Manado City, reported relatively low pollutant concentrations that were classified within the good air-quality category. This finding is broadly consistent with the relatively low pollutant concentrations observed in the present study in the Paal Dua area. In contrast, Hildayani (2023) reported moderate TSP concentrations (blue ISPU category) in the boiler area of the Punagaya Coal-Fired Power Plant (PLTU), South Sulawesi, which were substantially higher than the

maximum TSP concentration recorded in the present study (24.46 µg/m³ at Site 1). This difference is consistent with the contrasting emission-source characteristics of the two study areas, namely a coal-combustion industrial environment in the study by Hildayani et al. (2024) compared with an urban environment predominantly characterized by traffic and commercial activities in the present study.

Several factors may account for the relatively low particulate concentrations observed in the present study. First, the Paal Dua area does not contain major large-scale industrial emission sources; consequently, particulate emissions at the sampling locations are more likely to be dominated by vehicular traffic and small-to medium-scale commercial activities rather than by industrial combustion processes, which can generate substantially higher particulate concentrations. Second, as a coastal city, Manado may benefit from relatively effective atmospheric circulation that facilitates pollutant dispersion, although the wind speeds recorded during the sampling period were relatively low. Third, because measurements were conducted only once at each sampling site, the results may reflect atmospheric conditions during days characterized by relatively favorable meteorological conditions and activity patterns for pollutant dispersion. Therefore, particulate concentrations may differ under other meteorological and activity conditions.

These potential explanations should be interpreted cautiously because they are based on observational and contextual evidence rather than on quantitative source-apportionment or statistical analyses. Further investigations involving repeated measurements across different seasons, meteorological conditions, and levels of human activity are needed to determine the relative contribution of these factors to particulate concentrations in the Paal Dua area

CONCLUSION

Based on the results of this study, particulate concentrations at the three sampling sites in the Paal Dua area of Manado City ranged from 6.19–24.46 $\mu\text{g}/\text{m}^3$ for TSP, 1.38–10.89 $\mu\text{g}/\text{m}^3$ for PM_{10} , and 0.24–3.83 $\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$. Site 1 consistently recorded the highest concentrations for all three parameters, which may be associated with its proximity to a major roadway and market area. However, this interpretation is based on descriptive patterns and has not been statistically verified. Site 3 recorded the lowest TSP and PM_{10} concentrations, but its $\text{PM}_{2.5}$ concentration was higher than that at Site 2. Descriptively, this pattern coincided with the predominance of winds from the east–southeast–south sectors and the presence of surrounding buildings, although these

potential influences require further investigation.

All measured particulate concentrations at the three sampling sites remained below the ambient air quality standards stipulated in Government Regulation No. 22 of 2021, Appendix VII, during the August 2025 measurement period. These findings are limited to TSP, PM_{10} , and $\text{PM}_{2.5}$ measured during a specific sampling period at each site and therefore should not be generalized as a comprehensive or long-term representation of ambient air quality in the Paal Dua area. Further monitoring involving repeated measurements across different seasons, meteorological conditions, and levels of human activity is recommended to provide a more representative assessment of particulate pollution in the area.

REFERENCES

- Amin, M., Yusuf, F., & Rahman, A. (2024). Emisi dan dampaknya terhadap kualitas udara perkotaan. *Jurnal Lingkungan Hidup Indonesia*.
- Eka Fitriani, A., dkk. (2016). Analisis karakterisasi konsentrasi dan komposisi partikulat udara.
- Environmental Protection Agency (EPA). (2023). *Health effects of particulate matter (PM_{2.5} and PM₁₀)*. United States Environmental Protection Agency.
- Hildayani, & Nadir, M. (2024). Analysis of Air Quality Changes at Punagaya Steam Power Plant based on Total Suspended Particulate (TSP) parameters. *Indonesian Journal of Contemporary Multidisciplinary Research (MODERN)*, 3(1), 229–240.
- Ilham, M. (2021). Pengaruh faktor meteorologi terhadap konsentrasi polutan PM₁₀ di kawasan industri. *Jurnal Ilmu Lingkungan*.
- Kim, K. H., Kabir, E., & Kabir, S. (2015). A review on the human health impact of airborne particulate matter. *Environment International*, 74, 136–143.
<https://doi.org/10.1016/j.envint.2014.10.005>
- Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup.
- Rita, D., dkk. (2016). Kualitas Udara (PM₁₀ dan PM_{2.5}) untuk Melengkapi Kajian Indeks Kualitas Lingkungan Hidup. *Jurnal Ecolab*, 10(1), 1–7.

- Safira, N. (2022). Karakteristik partikulat berdasarkan ukuran dan dampaknya terhadap kesehatan. *Jurnal Kesehatan Lingkungan*
- Sangga, B. 2020. *Analisis Kualitas Udara Ambien Berdasarkan Konsentrasi SO₂, NO₂, dan CO di Kecamatan Wanea Kota Manado*. Jurnal Ilmu Lingkungan Tropis.
- Santoso, M., Putra, A., & Lestari, P. (2019). Kualitas udara di wilayah Indonesia Timur: Tantangan dan keterbatasan data. *Atmospheric Environment Indonesia*.
- SNI 7119.14:2016 — Udara ambien Bagian 14: Cara uji partikel dengan ukuran $\leq 2,5 \mu\text{m}$ (PM_{2,5}) menggunakan peralatan High Volume Air Sampler (HVAS) dengan metoda gravimetri.
- SNI 7119.15:2016 — Udara ambien Bagian 15: Cara uji partikel dengan ukuran $\leq 10 \mu\text{m}$ (PM₁₀) menggunakan peralatan High Volume Air Sampler (HVAS) dengan metoda gravimetri.
- SNI 7119.3:2017. Udara ambien bagian 3: Pengukuran partikel tersuspensi total dengan metode gravimetri.
- World Health Organization (WHO). (2024). Health consequences of air pollution on populations. <https://www.who.int/news/item/25-06-2024-what-are-health-consequences-of-air-pollution-on-populations>
- Yulinawati H., Rita., Diah L., Esrom H., Muhayatun S., 2015. *Indeks Kualitas Udara*. Bahan Diskusi. Fakultas Arsitektur Lansekap dan Teknologi Lingkungan, Universitas Trisakti. Jakarta