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Oxidative Stress Levels of Fine Particulate Matter ($PM_{2.5}$) and Urinary Glutathione of Microbus Drivers

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Abstract

Urinary glutathione levels are known to be an early indicator of oxidative stress in travelers. This study analyzed the association between particulate matter ($PM_{2.5}$) exposure on the road and urine glutathione levels in Jakarta's microbus drivers. This cross-sectional study involved 96 microbuses (one of Jakarta's public transportations) drivers of nine routes in Kampung Melayu Bus Station, Jakarta, Indonesia. An anthropometric assessment and a structured questionnaire were employed. Along with the participants driving on the road, real-time personal equipment measuring $PM_{2.5}$ exposure concentrations was used. Total glutathione levels were measured using a colorimetric method. A correlation test and linear regression analysis were used to examine the effect of $PM_{2.5}$ exposure on total glutathione levels. The average $PM_{2.5}$ exposure concentration was 90.9±1.8 μg/m^3, with a maximum concentration of 114.7 μg/m^3. The average urinary glutathione level was 1.3±0.5 μM. The regression analysis showed that $PM_{2.5}$ was associated with urinary glutathione levels after controlling for body mass index and smoking status. To concluded, the drivers experienced exposure to an extremely high level of $PM_{2.5}$ that could influence the glutathione levels.

Keywords: driver, microbus, particulate matter 2.5, public transportation, urinary glutathione

Introduction

Particulate matter (PM) is a type of air pollution that is hazardous to human health. When inhaled, PM particles penetrate deep into the respiratory system (alveoli) and move to organs outside the lungs, including the central nervous system, due to their small size (2.5 μm or less). $PM_{2.5}$ can act as an initiator in producing reactive oxygen species (ROS).[1] It can reduce the activity of the enzyme glutathione peroxidase, resulting in oxidative stress, which is defined as an imbalance of ROS and antioxidant enzymes in the body, causing damage to tissue, proteins, deoxyribonucleic acid (DNA), and fats, all of which contribute to the occurrence of diseases in humans such as cancer, asthma, arteriosclerosis, and respiratory disease.[2,3] Glutathione (GSH) is a secondary antioxidant that prevents chain reactions by collecting free radicals, and ROS plays a function in tissue oxidative stress prevention.[4,5] A Canadian study stated that a decline in GSH was linked to a 12% increase in lung cancer fatalities.[6] When oxidant defenses are insufficient, tiny particles cause an inflammatory and cytotoxic response in the human lung, as well as systemic inflammation and thrombosis. Pollutant effects on the airways (indirect pathway) or direct systemic transport of pollutant compounds following deposition in the lungs might cause systemic oxidative stress and inflammation.[7]

The yearly averages of PM_{10} (82 μg/m^3) and $PM_{2.5}$ (45 μg/m^3) in Jakarta,[8] are significantly higher than the World Health Organization (WHO) guidelines,[9] of 15 μg/m^3 and 5 μg/m^3, respectively. In 2017 and 2018, there were 198 days and 196 days of poor air quality, respectively.[10,11] A previous study stated that the transportation sector was responsible for around 80% of air pollution in metropolitan areas.[12] Public transportation drivers on the road for lengthy periods are exposed to high levels of $PM_{2.5}$, which can cause health concerns.[13] A previous study on microbus drivers in Kampung Melayu Bus Station showed a decrease in lung function at 30.7%, with obstructive pulmonary disorders at 9.7%.[14] Kampung Melayu Bus Station is a city terminal in East Jakarta Municipality, the Special Capital Region of Jakarta, Indonesia, that serves 23 transportation routes, including large, medium, and microbuses; nine of which are microbus routes that depart and reenter the

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terminal: M01, M01A, M02, M18, M26, M27, M28, M31, and M32. This study aimed to determine whether there was an association between $PM_{2.5}$ exposure and lower urine GSH levels in Jakarta microbus drivers.

Method

A cross-sectional design was used to evaluate urine GSH levels of 96 microbus drivers as well as ambient $PM_{2.5}$ personal concentrations on nine microbus routes departing from and returning to Kampung Melayu Bus Station, M01 (14.4 km), M01A (18.4 km), M02 (20.8 km), M18 (25.8 km), M26 (34.6 km), M27 (15.6 km), M28 (28.2 km), M31 (30 km), and M32 (24.8 km). A sampling design for the correlation test was implemented to calculate the sample size. The participants in this study were selected randomly from nine microbus routes. Measurements were made on individual data and length of exposure. Individual data consisted of age, body mass index (BMI), smoking status, alcohol consumption status, and supplement intake status. The length of $PM_{2.5}$ exposure consisted of working experience (year) and working hours. Individual data were gathered through individual interviews and observations using a modified questionnaire adapted from prior studies.[15,16] Anthropometry was used to determine body weight and height. The round trip distance in kilometers for each transportation route was collected from the data presented on Google Maps.

$PM_{2.5}$ levels were measured using real-time Air Visual Pro Monitoring equipment with a one-minute interval for each round of the route. A 5-mL urine sample was collected from each participant and analyzed following the enzymatic recycling test method as stated in the manufacturer's instructions using the Glutathione Assay (Colorimetric) Kit (Cat. # 786-075, G-Bioscience Geno Technology, Inc., USA). Data were analyzed by univariate, bivariate, and multivariate analyses. The BMI, smoking, alcohol consumption, and supplement intake status were analyzed univariately. Pearson's correlation and linear regression were applied to examine the relationship between variables and the effect of $PM_{2.5}$ exposure on total GSH levels after other factors were taken into account. The p-value was <0.05 with 95% CI. The data were presented as a boxplot showing the average distribution of $PM_{2.5}$ concentrations on nine microbus routes. The correlation of independent variables ($PM_{2.5}$ concentration, age, working experience, working hours, BMI, smoking status, alcohol consumption status, and supplement intake) to total GSH was also presented in tables.

Result

The participants' $PM_{2.5}$ concentrations while driving and urine GSH levels were successfully obtained. Mean $PM_{2.5}$ levels varied from 51.10 μg/m^3 to 119.95 μg/m^3, with an average of 90.85 μg/m^3 (95% CI = 87.14–94.56 μg/m^3). The data revealed that the microbus M28 route had the highest $PM_{2.5}$ concentration (average 114.8 g/m^3) of the nine routes studied (Figure 1). Microbus M31 (30 km) has the longest round trip mileage among the nine routes, while Microbus M01 (14.4 km) has the shortest. The average urine GSH level was likewise determined to be 1.29 μM, with a range of 0.5–3.16 μM

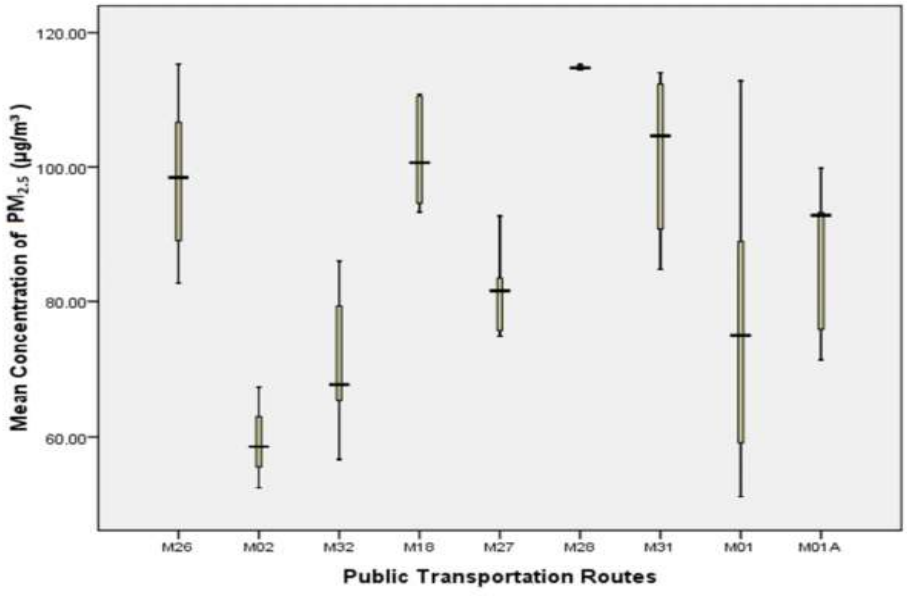

Figure 1. The Average $PM_{2.5}$ Concentration by Transportation Route

Table 1. Characteristics of the Participants

Variable	Category	n = 96	%
Body mass index	>25 (overweight)	33	34.4
	≤25 (not overweight)	63	65.6
Smoking status	Smoking	61	63.5
	Nonsmoking	35	36.5
Alcohol consumption status	Yes	14	14.6
	No	82	85.4
Supplement intake status	Yes	17	17.7
	No	79	82.3

Table 2. The Association of $PM_{2.5}$ Concentration, Age, Working Experience, and Working Hours to Glutathione Levels

Variable	r	R^2	p-value
$PM_{2.5}$ concentration	-0.208	0.043	0.042
Age	0.099	0.01	0.338
Working experience	0.130	0.017	0.206
Working hours	0.075	0.006	0.465

Table 3. The Association of Body Mass Index, Smoking Status, Alcohol Consumption, and Supplement Intake with Glutathione Levels

Variable	Category	Mean	SD	Mean diff.	p-value	95% CI
Body mass index	>25 (overweight)	1.43	0.58	0.20	0.07	-0.01–0.42
	≤25 (not overweight)	1.22	0.47			
Smoking status	Smoking	1.32	0.56	0.07	0.51	-0.14–0.29
	Nonsmoking	1.25	0.43			
Alcohol consumption status	Yes	1.25	0.65	-0.05	0.74	-0.35–0.25
	No	1.30	0.49			
Supplement intake status	Yes	1.43	0.49	-0.17	0.23	-0.44–0.11
	No	1.26	0.61			

Notes: SD = Standard Deviation, CI = Confidence Interval

(95% CI = 1.19–1.39 μM), and 39.6% of participants had GSH levels above the normal. Most individuals (63.5%) were smokers, with almost half (50.8%) smoking 10–20 cigarettes daily. More than a third of participants (34.4%) were overweight, 14.6% drank alcohol, and 17.7% took supplements or antioxidants (Table 1). The average age of the participants was 44.7 years, with an average of 16.9 years of work experience and 9.1 hours of work routine.

The statistical association between $PM_{2.5}$ levels and GSH levels had a low power (r = 0.21) and a negative trend. This result suggested that rising $PM_{2.5}$ concentrations were accompanied by lower GSH levels (R^2 = 0.04). Age, work experience, and working hours had a weak relationship with GSH levels (r = 0.09, 0.13, and 0.08, respectively) (Table 2).

There were no statistically significant relationships between GSH levels and BMI, smoking status, alcohol consumption status, or supplement intake (p-values = 0.07, 0.51, 0.74, and 0.23) (Table 3). After controlling for BMI and smoking status in an inverse relationship, the regression model revealed a 9.2% influence of $PM_{2.5}$ exposure on GSH levels. In other words, the lower the GSH level, the higher the $PM_{2.5}$ concentration (Table 4).

Table 4. Regression Model of Concentration of $PM_{2.5}$, Body Mass Index, and Smoking Status

Variable	Coeff. β	p-value	r	R^2
$PM_{2.5}$ concentration	-0.006	0.026	0.303	0.092
Body mass index	-0.222	0.043		
Smoking status	-0.098	0.362		

Discussion

The $PM_{2.5}$ concentrations on all microbus roundtrip routes to Kampung Melayu Bus Station exceeded the national air quality threshold of 55 μg/m^3 daily exposure,[17] and were found to be six times higher than the WHO 2021 daily $PM_{2.5}$ concentration recommendation (15 μg/m^3).[9] About 80% of air pollution in metropolitan areas is influenced by the transportation sector.[12] In the long term, exposure to $PM_{2.5}$ in air pollution will affect the health of public transport drivers.[13] Traveling by public transportation exposes people to extremely high $PM_{2.5}$ concentrations, with a median of 119 μg/m^3(IQR = 104–122 μg/m^3).[18] Similar risks were observed in 2017 in the Republic Democratic of Congo, where the average $PPM_{2.5}$ concentration on the highway was 94.72±27.49 μg/m^3, and in India, where the average $PM_{2.5}$ concentration on the highway was 72.13 mg/m^3.[19,20]

In this study, the high $PM_{2.5}$ concentration could be influenced by the number of vehicles on the road. The data from Statistics Indonesia in 2019 showed that the number of vehicles in Jakarta was the second highest in

Indonesia, thus it is necessary to reduce the number of vehicles on the road drastically.[21] The entry of $PM_{2.5}$ resulting from the combustion of material transportation fuel and road ash into the microbus will be influenced by the situation of public transportation with an always-open passenger door, as well as the opening of passenger and driver windows. Participants with GSH levels less than or equal to the average were found to be greater than those with GSH levels beyond the typical means, according to this study. Compared to GSH levels in people continually exposed to mercury in the village of Lebak Situ Village, Lebak District, Banten Province,[16] the results of this study were lower.

GSH levels in autistic children were shown to be lower than those who have not, which was exacerbated by an oxidative stress-inducing environment.[22] The GSH is an antioxidant in response to environmental exposure by lowering its concentration, interfering with immune cell function regulation, and causing failure to combat ROS.[23] Antioxidant enzymes (such as glutathione peroxidase/GPx) play a critical function in the cell's oxidative stress defense mechanism. According to Brucker's study, the GPx enzyme activity was statistically lower in taxi drivers than in the control group.[24]

The negative connection between $PM_{2.5}$ concentration and GSH levels found in this study suggested that high $PM_{2.5}$ exposure from microbus drivers lowers GSH levels in the body. The finding was consistent with the previous study, which demonstrated that air pollution lowers antioxidant activity in the body.[25] The GSH helps protect the body from oxidative damage caused by ROS produced by the body's metabolism when $PM_{2.5}$ is breathed into the alveoli,[25] and it can react with ROS in a nonenzymatic way. GSH is the major nonenzymatic antioxidant effective in protecting cells against reactive oxygen products and toxins, and GSH is involved in responses to various stresses. GPx uses GSH as an electron donor to reduce organic hydroperoxides, decreasing the amount of GSH in the body and thereby causing oxidative stress.[26]

Although this study included a higher proportion of smokers, no association between smoking and GSH levels were observed. The results differed from a previous study which found a decrease in glutathione S-transferase and glutathione peroxidase antioxidant activity in smokers compared to nonsmokers.[27,28] Adult male smokers produce more ROS than nonsmokers and those who have stopped smoking, resulting in lower GSH levels in smokers.[25] The non-significant association discovered in this study could be influenced by glutathione reductase activity, which is favorably correlated with smoking exposure. A study by Kamceva, *et al.*, showed a significant difference in the activity of GPx among active smokers and nonsmokers. The number of cigarettes smoked is essential in increasing oxidative damage and reducing antioxidant defense.[28]

All participants' characteristics, such as BMI, alcohol consumption, and supplement intake, had no significant relationship with their GSH levels. However, certain epidemiological and clinical investigations have discovered an association between obesity and oxidative stress, as measured by various biomarkers.[29,30] A previous study has found a positive linear relationship between obesity and oxidative stress.[31] Compared to BMI classifications of overweight and obese, people with normal and low BMI are less likely to have lipid peroxidation due to oxidative stress.[31] Although the drivers' BMIs were not overweight, their sedentary lives, lack of physical activity, and irregular eating patterns endangered their health. This study's finding supports a previous study that found no association between age and GSH levels in mercury-exposed employees.[16] The findings of this study, however, were inversely related to Venkateshappa's study, finding that GSH levels decreased with age. This condition indicates that the capacity for detoxification in cells decreases as humans age.[32]

A study in South Korea has linked elevated levels of the liver enzyme γ-glutamyltranspeptidase (γ-GTP) to an increase in $PM_{2.5}$ pollutant concentrations.[33] The levels of γ-GTP are influenced by $PM_{2.5}$ concentrations, which are higher in participants who drank alcohol once a week than those who did not. Elevated liver enzymes have been linked to an increased risk of cardiovascular disease, metabolic diseases, and diabetes.[33] A study in Turkey shows that GSH levels were significant in patients with type 2 diabetes mellitus (p-value<0.005).[34] This conflicting conclusion could be influenced by the number of drivers who did not consume alcohol which was higher than the number of drivers who did. Data on alcohol intake gathered through direct interviews with participants was deemed a taboo topic for discussion because of the negative stigma connected with it, such as being associated with sin. As a result, participants' unwillingness to further discuss this topic was this study's shortcoming.

Drivers' work experiences showed no significant relationship with GSH levels. This finding differed from a previous study by Tan, *et al.*, showing that an increase in the work time of traffic police officers by one hour per day for one year was associated with a decrease in GSH level.[4] According to a study by Ledda, *et al.*, there was a negative association between total GSH and pesticide exposure in agricultural workers after pesticide exposure. Total GSH levels were lower in workers exposed to pesticides, with an exposure duration of 3.7±1.4 hours/day, compared to organic farmers who were not exposed to pesticides.[35] According to this study's result, the average working experience of participants, was expected to be long, and $PM_{2.5}$ exposure was likely to be chronic.

However, the findings showed that tenure positively correlates with GSH levels. This was most likely because the participants were generally in their 40s, had no record of chronic diseases, and lived a non-alcoholic lifestyle. As a result, antioxidants in the body could respond to environmental exposure without being influenced by long working hours.

This study had several strengths in terms of objectives and data collection. A study examining the effect of $PM_{2.5}$ exposure on oxidative stress conditions with total GSH biomarkers conducted in Indonesia is still relatively few, especially using urine samples. Data collection using urine biomarkers, which is non-invasive sampling, minimizes the use of tools that contain organic/metal and minimizes the artificial formation of oxidative damage to the molecules in the sample. Furthermore, urinary levels of biomarkers provide a graded index of redox balance over time compared to blood levels.[36] In contrast, similar studies often use serum or plasma for total GSH testing (invasive testing).[37-39] The $PM_{2.5}$ concentration data were collected by following the driver along the transportation route departing and returning to the terminal, providing an overview of the $PM_{2.5}$ exposure drivers always receive during their activities. Total GSH analysis was carried out by experienced laboratory assistants in trusted educational laboratories. In this study, the total GSH value obtained was very good, as indicated by optimizing the linear sample with the total GSH standard curve ($R^2 = 0.9946$).[40]

The limitations of this study were time constraints that made it impossible to use a cohort or case-control design to prove a cause–effect relationship between variables in assessing $PM_{2.5}$ exposure and total GSH levels in the driver's urine. It is recommended to reduce the time spent on the road and the number of vehicles on the road to reduce $PM_{2.5}$ exposure to the drivers. Further study for analyzing the cause–effect relationship between $PM_{2.5}$ exposure concentration and GSH level by implementing a cohort design will provide insight into the finding.

Conclusion

Microbus, a public transportation in Jakarta, Indonesia, drivers are exposed to extremely high $PM_{2.5}$ levels along every nine routes, resulting in GSH levels of 0.5–3.16 μM. On-the-road $PM_{2.5}$ personal exposure influences the GSH levels of microbus drivers after controlling for BMI and smoking status. The higher the $PM_{2.5}$ exposure concentration on the road, the lower the GSH levels among those exposed to $PM_{2.5}$ for a long time. $PM_{2.5}$ exposure can harm the health of microbus drivers by causing oxidative stress and a drop in urine GSH levels. This study suggests that the time spent on the road and the number of vehicles on the road should be drastically reduced. Further study for analyzing the cause–effect relationship between $PM_{2.5}$ exposure concentration and GSH level by implementing a cohort design will clarify the finding.

Abbreviations

PM: Particulate Matter; ROS: Reactive Oxygen Species; DNA: Deoxyribonucleic Acid; GSH: Glutathione; WHO: World Health Organization; BMI: Body Mass Index; GPx: Glutathione Peroxidase; γ-GTP: γ-glutamyltranspeptidase.

Ethics Approval and Consent to Participate

Ethical approval was granted by the Faculty of Public Health, Universitas Indonesia (No.: Ket-482/UN2.F10/PPM.00.02/2019).

Competing Interest

The author declares that there are no significant competing financial, professional, or personal interests that might have affected the performance or presentation of the work described in this manuscript.

Availability of Data and Materials

The generated dataset is available to share from the corresponding author upon a reasonable request.

Authors' Contribution

PS contributed to conceptualizing, designing, and preparing the initial draft and framework, interpreting the data, and revising the final manuscript. AK contributed substantially to the concept. BH contributed to critically reviewing the manuscript's content and submitting and revising the manuscript.

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References

1. Rajagopalan S, Brook RD. Air pollution and type 2 diabetes: mechanistic insights. Diabetes. 2012; 61 (12): 3037–45.
2. Hong Z, Guo Z, Zhang R, Xu J, Dong W, Zhuang G, et al. Airborne fine particulate matter induces oxidative stress and inflammation in human nasal epithelial cells. Tohoku J Exp Med. 2016; 239 (2): 117–25.
3. Commodore AA, Zhang JJ, Chang Y, Hartinger SM, Lanata CF, Mäusezahl D, et al. Concentrations of urinary 8-hydroxy-2′-deoxyguanosine and 8-isoprostane in women exposed to woodsmoke in a cookstove intervention study in San Marcos, Peru. Environ Int. 2013; 60: 112–22.
4. Tan C, Lu S, Wang Y, Zhu Y, Shi T, Lin M, et al. Long-term exposure to high air pollution induces cumulative DNA damages in traffic policemen. Sci Total Environ. 2017; 593–594: 330–6.

5. Jan AT, Azam M, Siddiqui K, Ali A, Choi I, Haq QM. Heavy metals and human health: mechanistic insight into toxicity and counter defence system of antioxidants. Int J Mol Sci. 2015; 16 (12): 29592–630.
6. Weichenthal S, Crouse DL, Pinault L, Godri-Pollitt K, Lavigne E, Evans G, et al. Oxidative burden of fine particulate air pollution and risk of cause-specific mortality in the Canadian Census Health and Environment Cohort (CanCHEC). Environ Res. 2016; 146: 92–9.
7. Gromadzińska J, Wąsowicz W. Health risk in road transport workers. Part I. Occupational exposure to chemicals, biomarkers of effect. Int J Occup Med Environ Health. 2019; 32 (3): 267–80.
8. World Health Organization. WHO Global ambient air quality database (update 2018). Geneva: World Health Organization; 2018.
9. World Health Organization. WHO global air quality guidelines: particulate matter (pm2.5 and pm10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021.
10. Jakarta Open Data. Data indeks standar pencemar udara tahun 2017. Jakarta: Dinas Lingkungan Hidup Provinsi DKI Jakarta; 2017.
11. Jakarta Open Data. Indeks Standar Pencemar Udara (ISPU) Tahun 2018. Jakarta: Dinas Lingkungan Hidup Provinsi DKI Jakarta; 2018.
12. Haryanto B. Climate change and urban air pollution health impacts in Indonesia. In: Akhtar R, Palagiano C, editors. Climate Change and Air Pollution. Cham: Springer International Publishing; 2018. p. 215–39.
13. Pratiwi DA, Haryanto B. Effect of particulate matter 2.5 exposure to urinary malondialdehyde levels of public transport drivers in Jakarta. Rev Environ Heal. 2020; 35 (3): 295-300.
14. Fendi, Uyainah A, Subekti I, Abdullah M. Penurunan fungsi paru pengemudi mikrolet di Jakarta Timur dan karakteristik yang menyertainya. Indonesian Journal of CHEST Critical and Emergency Medicine. 2015; 2 (2): 61-6.
15. Sisinta T. Kadar malondialdehyde (MDA) sebagai biomarker oxidative stress akibat pajanan PM2,5 pada siswa Sekolah Menengah Pertama Negeri 16 Bandung, Provinsi Jawa Barat [Thesis]. Depok: Universitas Indonesia; 2017.
16. Fauzia S. Total Glutathione (GSH) pada masyarakat terpajan merkuri di kawasan pertambangan emas skala kecil (PESK) Desa Lebak Situ, Kabupaten Lebak, Banten [Thesis]. Depok: Universitas Indonesia; 2016.
17. Presiden Republik Indonesia. Peraturan Pemerintah (PP) Republik Indonesia Nomor 22 Tahun 2021 Tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup. Jakarta: Sekretariat Kabinet Republik Indonesia; 2021.
18. Both AF, Westerdahl D, Fruin S, Haryanto B, Marshall JD. Exposure to carbon monoxide, fine particle mass, and ultrafine particle number in Jakarta, Indonesia: Effect of commute mode. Sci Total Environ. 2013; 443: 965–72.
19. Mbelambela EP, Hirota R, Eitoku M, Muchanga SMJ, Kiyosawa H, Yasumitsu-Lovell K, et al. Occupation exposed to road-traffic emissions and respiratory health among Congolese transit workers, particularly bus conductors, in Kinshasa: a cross-sectional study. Environ Heal Prev Med. 2017; 22:11.
20. Yang X, Jiang L, Zhao W, Xiong Q, Zhao W, Yan X. Comparison of Ground-Based PM2.5 and PM10 Concentrations in China, India, and the U.S. Int J Environ Res Public Health. 2018; 15 (7): 1382.
21. Kepolisian Republik Indonesia. Jumlah kendaraan bermotor menurut provinsi dan jenis kendaraan (unit), 2019. Jakarta: Badan Pusat Statistik; 2019.
22. González-Fraguela ME, Hung MLD, Vera H, Maragoto C, Noris E, Blanco L, et al. Oxidative stress markers in children with autism spectrum disorders. British J Med Med Res. 2013; 3 (2): 307–17.
23. Yuniastuti A. Dasar Molekuler glutation dan peranya sebagai antioksidan. In: Iswari RS, editor. Semarang: FMIPA Press Universitas Negeri Semarang; 2016. p. 1–64.
24. Brucker N, Moro AM, Charão MF, Durgante J, Freitas F, Baierle M, et al. Biomarkers of occupational exposure to air pollution, inflammation and oxidative damage in taxi drivers. Sci Total Environ. 2013; 463-464: 884–93.
25. Holguin F. Oxidative stress in airway diseases. Ann Am Thorac Soc. 2013; 10 Suppl: S150–7.
26. Yildirim Z, Ucgun NI, Yildirim F. The role of oxidative stress and antioxidants in the pathogenesis of age-related macular degeneration. Clinics. 2011; 66 (5): 743–6.
27. Chełchowska M, Gajewska J, Ambroszkiewicz J, Mazur J, Ołtarzewski M, Maciejewski TM. Influence of oxidative stress generated by smoking during pregnancy on glutathione status in mother-newborn Pairs. Antioxidants. 2021; 10 (12): 1866.
28. Kamceva G, Arsova-Sarafinovska Z, Ruskovska T, Zdravkovska M, Kamceva-Panova L, Stikova E. Cigarette smoking and oxidative stress in patients with coronary artery disease. Open Access Maced J Med Sci. 2016; 4 (4): 636–40.
29. Vona R, Gambardella L, Cittadini C, Straface E, Pietraforte D. Biomarkers of oxidative stress in metabolic syndrome and associated diseases. Oxidative Med Cellular Longevity; 2019.
30. Monserrat-Mesquida M, Quetglas-Llabrés M, Bouzas C, Capó X, Mateos D, Ugarriza L, et al. Peripheral blood mononuclear cells oxidative stress and plasma inflammatory biomarkers in adults with normal weight, overweight and obesity. Antioxidants. 2021; 10 (5): 813.
31. Sahi N, Jain S, Ranawat N. A comparative study between two communities & regional variation in level of MDA with respect to waist hip ratio and BMI in response to an exclusive fibre Diet. J Medical Sci Clin Res. 2017; 5 (10): 29170–6.
32. Venkateshappa C, Harish G, Mahadevan A, Srinivas Bharath MM, Shankar SK. Elevated oxidative stress and decreased antioxidant function in the human hippocampus and frontal cortex with increasing age: implications for neurodegeneration in Alzheimer's disease. Neurochem Res. 2012; 37 (8): 1601–14.
33. Kim KN, Lee H, Kim JH, Jung K, Lim YH, Hong YC. Physical activity- and alcohol-dependent association between air pollution exposure and elevated liver enzyme levels: an elderly panel study. J Prev Med Public Health. 2015; 48 (3): 151–69.
34. Alisik M, Neselioglu S, Erel O. A colorimetric method to measure oxidized, reduced and total glutathione levels in erythrocytes. J Lab Med. 2019; 43 (5): 269–77.
35. Ledda C, Cannizzaro E, Cinà D, Filetti V, Vitale E, Paravizzini G, et al. Oxidative stress and DNA damage in agricultural workers after exposure to pesticides. J Occup Med Toxicol. 2021; 16: 1.
36. Il'yasova D, Scarbrough P, Spasojevic I. Urinary biomarkers of oxidative status. Clin Chim Acta. 2012; 413 (19–20): 1446–53.
37. Khajehnasiri F, Mortazavi SB, Allameh A, Akhondzadeh S, Hashemi

H. Total antioxidant capacity and malondialdehyde in depressive rotational shift workers. J Environ Public Health. 2013; 2013: 150693.
38. Buchtova Z, Lackova Z, Kudr J, Zitka Z, Skoda J, Zitka O. Capillary blood GSH level monitoring, using an electrochemical method adapted for micro volumes. Molecules. 2018; 23 (10): 2504.
39. Shamshad S, Priyadarsini IA, Shameela S, Chakrapani IS, Ahmed MO. Oxidative stress in traffic police of Kurnool Town. European J Pharmaceutic Med Res. 2015; 2 (7): 353–7.
40. Sidebang P. Pajanan particulate matter (PM2,5) terhadap kadar total glutathione (GSH) pada sopir angkutan kota Terminal Kampung Melayu Tahun 2019 [Thesis]. Depok: Universitas Indonesia; 2016.