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The association of PM_{2.5} and sun exposure with depression in Jakarta, Indonesia

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ABSTRACT

Background and purpose: Depression is a mental disorder with a high prevalence among young adults in Indonesia. Environmental factors such as sunlight and PM_{2.5} potentially influencing risk of depression. This study aimed to determine the levels of sunlight and PM_{2.5} exposure and their association with depression among young adults in urban Jakarta.

Methods: This study used a cross-sectional design conducted in Penjaringan, North Jakarta during December 2023 to November 2024. Sample was 90 young adults recruited using consecutive sampling methods. Data were collected using structured questionnaire to assess sun exposure and the Patient Health Questionnaire-9 (PHQ-9) to assess depression. The PM_{2.5} air-quality monitoring data was obtained from the World Air Quality Index (AQICN) platform. Data were analyzed descriptively and analytically using frequency distributions and the Chi-square test.

Results: The mean age of respondent were 21.92 years old, 62.2% were male and 75.6% were working. Overall, 45.6% had high PM_{2.5} exposure, while 53.3% had low sun exposure and 45.6% had depression. PM_{2.5} exposure was significantly associated with depression (OR=2.66; 95%CI: 1.13-6.25), whereas sun exposure was not (OR=1.47; 95%CI: 0.64-3.39).

Conclusion: The study identified substantial PM_{2.5} exposure and depressive symptoms among young adults, with higher PM_{2.5} exposure significantly associated with depression. Public health interventions should prioritize reducing air pollution and promoting healthier urban environments alongside mental health programs

Keywords: PM_{2.5}, air pollution, sunlight exposure, depression, young adults.

INTRODUCTION

Depression represents a major global public health challenge, affecting more than 280 million people worldwide and serving as a major contributor to global disability-adjusted life years (DALYs).¹ In Indonesia, national health data from the 2018 Basic Health Research (*Riskesdas*) reveals a substantial mental health burden, with depression affecting 6.1% of the population aged 15 and older—equating to over 12 million individuals.

Depression was reported to be more prevalent among women than men (8.4% vs 3.6%), and was also higher in urban (6.5%) than rural areas (5.45%). Urbanized provinces, particularly DKI Jakarta, exhibit elevated prevalence rates.² Across demographic segments, adolescents and young adults aged 15–24 years demonstrate the highest vulnerability, with a depression prevalence reaching 6.2%.

The onset of depression during young adulthood can have profound and long-lasting effects across personal, social, and economic domains.³ Cognitive difficulties, including impaired concentration, memory, and executive functioning, may affect academic performance and unemployment.^{3,4} Depression can also contribute to social withdrawal and difficulties in maintaining family and peer relationships. Moreover, untreated depression is associated with an increased risk of substance use, physical health problems, self-harm, and suicide.^{5,6} Collectively, these consequences may disrupt important developmental milestones and contribute to long-term social and economic vulnerability.

While psychosocial and socioeconomic stressors are well-established contributors to depression, growing evidence suggests that environmental factors, particularly sunlight exposure and ambient fine particulate matter (PM_{2.5}), may also play an important role.^{7–9} Sunlight promotes Vitamin D synthesis and serotonin regulation, both of which contribute to mental health. However, excessive sunlight exposure may induce oxidative stress and potentially increase the risk of depression.^{7,10,11}

Particulate matter (PM_{2.5}), a fine air pollutant, can trigger systemic inflammation and oxidative stress, which may affect brain function and increase the risk of depression.¹¹ The processes may disrupt the Mitogen-Activated Protein Kinase/cAMP Response Element-Binding Protein/Brain-Derived Neurotrophic Factor (MAPK/CREB/BDNF) signaling pathways, resulting in reduced Brain-Derived Neurotrophic Factor (BDNF) and phosphorylation of cAMP Response Element-Binding Protein (CREB). These molecular changes may impair neuroplasticity, neuronal survival, and mood regulation, thereby contributing to depressive symptoms.¹²

In urban areas such as Jakarta, high PM_{2.5} concentrations often exceed WHO safe thresholds, potentially increasing the environmental health burden among local populations, especially young adults.¹³ To date, the relationship between sunlight, PM_{2.5}, and depression at a young adult remains relatively underexplored, particularly in Indonesia. This research will address this gap and provide evidence to support more effective public health strategies for preventing depression in urban areas.

This study aimed to measure daily PM_{2.5} concentrations and individual sun exposure, assess the prevalence and severity of depressive symptoms among young adults, and examine the associations between PM_{2.5} exposure, sun exposure, and depression.

METHOD

This was a quantitative study employed a cross-sectional design. It was carried out in Rukun Warga (RW) 16, Penjaringan, Pluit, North Jakarta. Data were collected from December 2023 to November 2024. A total of 90 sample of young adults who met the eligibility criteria were recruited in study site using *consecutive sampling*.

Sun exposure was assessed using a questionnaire measuring the duration of exposure time and the area of skin exposed, with exposure levels categorized as less or adequate. The questionnaire demonstrated convergent validity through meaningful correlations with objective indicator of UV exposure, such as 25-hydroxyvitamin D (25(OH)D) levels, in several study populations.¹⁴⁻¹⁶ Depression levels were measured in participants using the Patient Health Questionnaire-9 (PHQ-9), with respondents classified as depressed or non-depressed based on their total scores.¹⁷

PM_{2.5} exposure levels were derived from secondary air-quality monitoring data obtained from the World Air Quality Index (AQICN) platform. This platform provides real-time, interactive visualization of global Air Quality Index (AQI) data across more than 100 countries. By consolidating live measurements from official environmental protection agencies, weather services, and community monitoring networks, it maps localized atmospheric conditions using spatial mapping tiles. Users can track ambient air pollution, including fine particulate matter PM_{2.5} through a standardized color-coded scale ranging from Good (AQI 0–50) to Hazardous (AQI 300+).¹³

Data were analysed descriptively presenting frequency distributions such as the level of sun exposure, PM_{2.5}, and depression. Bivariable analysis was performed using the Chi-square test to assess associations between sun exposure and PM_{2.5} with depression.

This study has been approved by The Research Ethics Commission of The Faculty of Medicine and Health Sciences, Atma Jaya Indonesian Catholic University, with number: 12/04/KEP-FKIKUAI/2024.

RESULT

As presented in Table 1, a total of 90 participants from RW 16, Penjaringan, Pluit, North Jakarta were included in the study. The mean age was 21.92 with 2.37 years standard deviation, ranging from 18 to 25 years. More than half of the participants were aged 22–25 years (56.7%). The two third of participants were male (62.2%). Most participants were employed (75.6%), while 24.4% were students or unemployed.

Regarding environmental exposure (Table 2), 45.6% of participants experienced high PM_{2.5} exposure, while 54.4% experienced low exposure. More than half of the participants had inadequate sun exposure (53.3%), whereas 46.7% had adequate exposure. Overall, 45.6% (n=41) of participants were classified as having depression, while 54.4% (n=49) were classified as non-depressed.

Table 3 showed the association between environmental exposures and depression. Among participants with low PM_{2.5} exposure, 17 (34.69%) were depressed, compared with 24 (58.53%) among those with high PM_{2.5} exposure. Participants with high PM_{2.5} exposure had 2.66 times higher odds of experiencing depression than those with low exposure (OR=2.66; 95%CI: 1.13–6.25). This association was statistically significant (p=0.024).

Table 1. Socio-demographic characteristics of respondents

Variable (n = 90)	Frequency	Percentage (%)
Age (years)		
Mean (SD)	21.92 (2.37)	
Min – max	18 – 25	
Age group (years)		
18 – 21	39	43.3
22 – 25	51	56.7
Gender		
Male	56	62.2
Female	34	37.8
Work		
Student/Not working	22	24.4
Working	68	75.6

Table 2. Distribution of environmental exposure and depression status

Variable (n = 90)	Frequency	Percentage (%)
PM_{2.5} Exposure		
High	41	45.6
Low	49	54.4
Sun Exposure		
Adequate	42	46.7
Less	48	53.3
Depression Status		
Depressed	41	45.6
Not Depressed	49	54.4

Table 3. The relationship between sun exposure and PM_{2.5} with depression among young adults in Jakarta, Indonesia

Variable	Depression		OR	95%CI	p
	Yes n (%)	No n (%)			
PM_{2.5}					
Low	17 (34.69)	32 (82.05)	ref		
High	24 (58.53)	17 (41.46)	2.66	1.13 – 6.25	0.024*
Sun Exposure					
Adequate	17 (40.48)	25 (59.52)	ref		
Less	24 (50.00)	24 (50.00)	1.47	0.64 – 3.39	0.365

*statistically significant, p<0.05

In contrast, participant with less sunlight exposure presented a higher proportion of depression (50.00%) than those receiving adequate sunlight exposure (40.48%). Although less sun exposure had 1.47 times higher odds of depression than those with adequate exposure (OR=1.47; 95%CI: 0.64–3.39), this association was not statistically significant (p=0.365). Therefore, the study did not find sufficient evidence of an association between sun exposure and depression.

DISCUSSION

This study confirms that, although the National Waste Management Information System (SIPSN) administrative data does not fully reflect the volume of food waste at the *Warung Tegal* level, and direct quantitative analysis is limited by tools and resources, the three *Warung Tegal* in this study have demonstrated alignment between operational practices and the behavioral mechanisms described in the Theory of Planned Behavior and Social Cognitive Theory.

This study identified a considerable mental health burden among young adults in RW 16, Penjaringan, Pluit, North Jakarta, with 45.6% of participants classified as having depression. According to Indonesia's Basic Health Research (Riskesmas 2018), the national depression prevalence among young adults aged 15–24 stands at 6.2%. However, the elevated rate observed in this study aligns with findings from high-density, metropolitan urban communities in other city in Indonesian and other developing countries, where youth mental health burdens frequently range between 30% to 50% due to cumulative environmental, economic, and lifestyle stressors.^{18,19}

The substantial proportion of participants exposed to high levels of fine particulate matter (PM_{2.5}; 45.6%) reflects the broader challenge of air pollution in densely populated and rapidly urbanizing cities. Urban areas such as Jakarta are characterized by high population density, heavy traffic, industrial activities, and port-related emissions, all of which can contribute to elevated ambient PM_{2.5} concentrations.^{20,21} Jakarta has been reported to experience relatively high PM_{2.5} concentrations compared with other major metropolitan areas in Asia.²²

A comparative study of Asian cities reported an average PM_{2.5} concentration of approximately 50.4 µg/m³ in Jakarta in 2020, compared with 43 µg/m³ in Beijing and 42.4 µg/m³ in Hanoi.²³ Earlier spatial analyses also identified substantial spatial variation in PM_{2.5} across DKI Jakarta, indicating that exposure is influenced by local environmental and land-use characteristics.²⁰ In Penjaringan, the proximity to the Tanjung Priok port corridor, industrial areas, and major arterial roads may further contribute to residents' exposure to particulate air pollution. These conditions highlight the importance of continuous air-quality monitoring and urban-level strategies to reduce PM_{2.5} exposure, particularly among populations living and working in highly urbanized environments.

In contrast, 53.3% of participants reported inadequate sun exposure despite Jakarta's tropical location and year-round high solar radiation. Limited sunlight exposure in Jakarta may be shaped more by structural, behavioral, and built-environment factors. Dense urban development, narrow alleyways, limited open spaces, and predominantly indoor activities may restrict opportunities for direct sunlight exposure.^{24,25} A previous study reported that limited sunlight exposure is found in two-thirds of high-density residential communities, with severe daylight deprivation affecting over half (52.04%) of the population on an hourly basis.²⁵ In this study, 75.6% of participants were employed, which may further limit daytime outdoor exposure because of occupational routines.

The findings also observed association between PM_{2.5} exposure and depression. This finding is biologically plausible, as PM_{2.5} can induce systemic inflammation and oxidative stress, which may affect the central nervous system and contribute to neuroinflammation, altered neurotransmitter regulation, and impaired neuroplasticity. These mechanisms provide a possible explanation for the observed relationship between air pollution exposure

and depression in this urban population. The results of this study are in line with previous large-scale epidemiological studies and comprehensive analyses that consistently show that long-term exposure to PM_{2.5} is positively associated with an increased risk of depression, with an estimated increased risk of approximately 7–18% for every 10 µg/m³ increase in PM_{2.5} concentrations.^{8,26,27} Biologically, PM_{2.5} can trigger inflammation and oxidative stress, which contributes to the development of depression through mechanisms such as damage to the blood-brain barrier and activation of the HPA axis.^{28,29}

In contrast, sun exposure was not significantly associated with depression. Although depression was more common among participants with less sun exposure than among those with adequate exposure (50.0% vs. 40.5%), the association was not statistically significant. The direction of the association may suggest a potential relationship between lower sunlight exposure and depression, but the wide confidence interval and inclusion of the null value indicate substantial uncertainty around the estimate.

Several factors may have contributed to this finding, including the relatively small sample size, variation in individual outdoor activities and lifestyles, and limitations of self-reported sun exposure. In addition, sunlight exposure may be influenced by factors such as clothing, time of day, duration of exposure, and indoor versus outdoor activities, which may not be fully captured in this study the questionnaire.^{24,30} Sunlight plays an important role in Vitamin D synthesis, circadian rhythm regulation, and the function of neurotransmitters such as serotonin, all of which have an impact on mental health.^{31,32}

These findings highlight the importance of mitigating air pollution and promoting adequate sun exposure to reduce the risk of depression. More research is needed to clarify the relationship between environmental exposure and mental health.

The coexistence of substantial PM_{2.5} exposure, limited sun exposure, and a high prevalence of depression highlights the importance of considering the urban environment as part of the broader context of youth mental health. Public health strategies should therefore complement individual-level mental health services with environmental approaches, including air pollution reduction, improved access to open and green spaces, and urban design that promotes healthier living environments.

STUDY LIMITATIONS

This study has several limitations that should be considered when interpreting the findings. First, PM_{2.5} exposure was estimated based solely on participants' residential locations and did not account for exposure at workplaces, schools, or other frequently visited locations. Furthermore, information on the frequency and duration of PM_{2.5} exposure was not available, limiting the ability to characterize individual-level exposure and establish temporal or causal relationships with depression.

Second, participants' occupational characteristics were not assessed in detail beyond employment status and general work location. This may be important because certain occupations, particularly those in transportation, construction, and industrial sectors, may involve substantially greater exposure to PM_{2.5} than others. Third, both PM_{2.5} and sun exposure were categorized into nominal exposure groups, rather than measured using continuous or more precise exposure metrics. This categorization may have reduced variability and limited the ability to examine dose–response relationships.

Several potential confounding factors may affect the relationship between PM_{2.5} exposure and sunlight with depression. These confounding factors include chronic health conditions such as diabetes mellitus and cardiovascular disease, which are known to be associated with the risk of depression and exposure to air pollutants. For sun exposure, factors such as physical activity, Vitamin D status, as well as protective behaviors to sunlight exposure such as sunscreen use may influence both the sunlight exposure level and risk of risk of depression. The absence of adjustment for these factors may have introduced bias into the observed associations.

Given the cross-sectional design, these findings indicate associations rather than causal effects. Future research should incorporate more detailed individual-level exposure assessments, including activity patterns and the frequency and duration of PM_{2.5} exposure. The use of objective and more precise exposure measurements may improve the accuracy of exposure estimates and strengthen the scientific validity of the findings. These approaches could provide deeper insights into the relationship between environmental exposures and mental health.

CONCLUSION

This study found that young adults in the study area experienced substantial PM_{2.5} exposure and limited individual sun exposure, alongside a considerable burden of depressive symptoms. Higher PM_{2.5} exposure was significantly associated with depression, whereas individual sun exposure was not significantly associated with depression. These findings highlight the importance of incorporating air-quality management into urban mental health strategies, while further research is needed to clarify the potential role of sunlight exposure.

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AUTHOR CONTRIBUTION

VCCL, RI, and V contributed to the conception and design of the research, ensuring a systematic and relevant research framework. VCCL also plays an important role in data acquisition, analysis, and interpretation, resulting in meaningful findings. VCCL, RI, V wrote the first draft of the manuscript. NH and YA critically revised the manuscript and provided constructive feedback that strengthened its scientific quality. All authors reviewed and approved the final version of the manuscript and agreed to be accountable for the integrity and accuracy of the work.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

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REFERENCES

1. Chen XD, Li F, Zuo H, Zhu F. Trends in prevalent cases and disability-adjusted life-years of depressive disorders worldwide: findings from the Global Burden of Disease Study from 1990 to 2021. *Depress Anxiety*. 2025;2025:5553491.
2. Ministry of Health Republic of Indonesia. Laporan riset kesehatan dasar (Riskesdas) 2018 [Basic health research report 2018]. Jakarta: Badan Penelitian dan Pengembangan Kesehatan, Kementerian Kesehatan Republik Indonesia; 2018.
3. Clayborne ZM, Varin M, Colman I. Systematic review and meta-analysis: adolescent depression and long-term psychosocial outcomes. *J Am Acad Child Adolesc Psychiatry*. 2019;58(1):72–79.
4. Akhtar A, Nwofe E, Shafiq S, et al. Understanding cognitive dysfunction in depression: perspectives and practices of UK health and social care professionals, a qualitative study. *BMJ Open*. 2026;16:e109285.
5. Copeland WE, Alaie I, Jonsson U, Shanahan L. Associations of childhood and adolescent depression with adult psychiatric and functional outcomes. *J Am Acad Child Adolesc Psychiatry*. 2021;60(5):604–611.
6. Singhal A, Ross J, Seminog O, Hawton K, Goldacre MJ. Risk of self-harm and suicide in people with specific psychiatric and physical disorders: comparisons between disorders using English national record linkage. *J R Soc Med*. 2014;107(5):194–204.
7. Wang J, Wei Z, Yao N, Li C, Sun L. Association between sunlight exposure and mental health: evidence from a special population without sunlight in work. *Risk Manag Healthc Policy*. 2023;16:1049–57.
8. Rajkumar RP. The relationship between ambient fine particulate matter (PM_{2.5}) pollution and depression: an analysis of data from 185 countries. *Atmosphere*. 2023;14(3):597.
9. Remes O, Mendes JF, Templeton P. Biological, psychological, and social determinants of depression: a review of recent literature. *Brain Sci*. 2021;11(12):1633.
10. Sari M, Yuniarti E. The effect of sun exposure on the effectiveness of the serotonin hormone: literature review. *J Biol Trop*. 2023;23(4):91–7.
11. Lin J, Yang H, Zhang Y, Cao Z, Li D, Sun L, et al. Association of time spent in outdoor light and genetic risk with the incidence of depression. *Transl Psychiatry*. 2023;13(1):40.
12. Li H, Guo X, Li P, Gao X, Song X, Chen X, et al. Particulate matter induces depression-like behavior through systemic inflammation and brain-derived neurotrophic factors. *Environ Int*. 2024;194:108883.
13. World Air Quality Index Project. Real-time air quality index (AQI) [Internet]. Available from: <https://aqicn.org>
14. Husna K, Widajanti N, Sumarmi S, Firdaus H. Correlation of sun exposure score and vitamin D intake with serum 25(OH)D levels in older women. *J Penyakit Dalam Indones*. 2021;8(2):63–71.
15. Kusumastuty I, Handayani D, Tjahjono HA, Sari EP, Rahayuningtyas SK, Saputra AB. The relationship between sun exposure, nutritional status, and food intake on vitamin D levels in children and adolescents with type 1 diabetes mellitus. *Amerta Nutr*. 2021;5(1):41.
16. Sari EP. The relationship between sun exposure and nutritional status on vitamin D levels of children and adolescents with type 1 diabetes mellitus at the outpatient polyclinic of Dr. Saiful Anwar Hospital Malang [thesis]. Malang: Universitas Brawijaya; 2020.
17. Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. *J Gen Intern Med*. 2001;16(9):606–613.

18. Mridha MK, Hossain MM, Khan MSA, Hanif AAM, Hasan M, Mitra D, et al. Prevalence and associated factors of depression among adolescent boys and girls in Bangladesh: findings from a nationwide survey. *BMJ Open*. 2021;11(1):e038954.
19. Asih DR, Askin ANH, Nisa H. Factors associated with depression and anxiety in young adults in metropolitan city. *J Riset Kesehatan*. 2023;12(1):22–27.
20. Driejana, Sari NK, Santoso M, Lestiani DD. Intra-city particulate elemental characteristics and variabilities in Jakarta. *Environ Sci Atmos*. 2025;5(11):1243–1262.
21. Santoso M, Lestiani DD, Damastuti E, Kurniawati S, Kusmartini I, Atmodjo DPD, et al. Long term characteristics of atmospheric particulate matter and compositions in Jakarta, Indonesia. *Atmos Pollut Res*. 2020;11(12):2215–2225.
22. Health Effects Institute. Air quality and health in cities: a state of global air report [Internet]. Boston: Health Effects Institute; 2022. Available from: <https://www.stateofglobalair.org/resources/reports/cities-2022>
23. Lam YF, Chang JMH, Loo BPY, Zhang HS, Leung KKM, Axhausen KW. Screening approach for short-term PM_{2.5} health co-benefits: a case study from 15 metropolitan cities around the world during the COVID-19 pandemic. *Atmosphere*. 2022;13(1):18.
24. Koh DH, Park JH, Lee SG, Kim HC, Jung H, Kim I, et al. Assessment of sunlight exposure across industries and occupations using blood vitamin D as a biomarker. *J Occup Health*. 2022;64(1):e12318.
25. Zhang X, Yan M, Luo S, Yang P, Wei K, Ma L, et al. How severe is sunlight deprivation in urban residential communities? A perspective from architectural and vegetation shading. *Sustain Cities Soc*. 2026;149:107731.
26. Borroni E, Pesatori AC, Bollati V, Buoli M, Carugno M. Air pollution exposure and depression: a comprehensive updated systematic review and meta-analysis. *Environ Pollut*. 2022;292(Part A):118245.
27. Poowaruttanawiwit P, Chantim C, Arunrodpanya F, Dedmad K, Soputaon J. The link between PM_{2.5} exposure and depression: a systematic review. *J Basic App Pharmacol*. 2023;3(2):O81–95.
28. Marbun FK, Tarigan SB, Sudarti S. Tinjauan analisis manfaat dan dampak sinar ultraviolet terhadap kesehatan manusia [Review of the benefits and impact analysis of ultraviolet light on human health]. *Jurnal Penelitian Inovatif*. 2023;3(3):605–612.
29. Li W, Lin G, Xiao Z, Zhang Y, Li B, Zhou Y, et al. A review of respirable fine particulate matter (PM_{2.5})-induced brain damage. *Front Mol Neurosci*. 2022;15:967174.
30. Patwardhan VG, Mughal ZM, Chiplonkar SA, Webb AR, Kift R, Khadilkar VV, et al. Duration of casual sunlight exposure necessary for adequate vitamin D status in Indian men. *Indian J Endocrinol Metab*. 2018;22(2):249–255.
31. Yang T, Wang J, Huang J, Kelly FJ, Li G. Long-term exposure to multiple ambient air pollutants and association with incident depression and anxiety. *JAMA Psychiatry*. 2023;80(4):305–313.
32. Rhie SJ, Jung EY, Shim I. The role of neuroinflammation on pathogenesis of affective disorders. *J Exerc Rehabil*. 2020;16(1):2–9.

