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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 PM2.5 potentially influencing risk of depression. This study aimed to determine the levels of sunlight and PM2.5 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 PM2.5 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 PM2.5 exposure, while 53.3% had low sun exposure and 45.6% had depression. PM2.5 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 PM2.5 exposure and depressive symptoms among young adults, with higher PM2.5 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-FKIKUAJ/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 (Riskesdas 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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