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$PM_{2.5}$ Exposure and Health Symptoms in Elderly Residents: A Case Study in Jakarta during the COVID-19 Pandemic

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Abstract

The deterioration of air quality in Jakarta, Indonesia, has become a growing public concern. Exposure to polluted air is known to be hazardous to public health, particularly for sensitive groups such as elderly citizens. $PM_{2.5}$ (fine particulate matter with an aerodynamic diameter < 2.5 µm) is among the most dangerous pollutants commonly found in urban atmospheres. This study assessed the relationship between atmospheric $PM_{2.5}$ exposure and health-related symptoms among elderly citizens living in Jakarta, Indonesia. $PM_{2.5}$ concentrations in ambient air were measured using a High Volume Air Sampler with a $PM_{2.5}$ size-selective inlet for a week in an outdoor location at a nursing home during the Covid-19 pandemic. Health-related symptoms of elderly citizens were collected using a systematic interview method. Both sets of data were collected simultaneously for cross-sectional analysis. Based on the sampling data, $PM_{2.5}$ concentrations in the area ranged from 15.4 to 42.9 µg/Nm^3 (at standard conditions); the Air Pollution Standard Index ranged from 49.9 to 84.3; and the Air Quality Index was moderate for 6 out of 7 (85.7%) days. Results showed that sensitive groups, including elderly citizens, are very likely to be negatively affected by polluted air. The chi-square test results imply that emerging health-related symptoms are significantly affected by elderly citizen characteristics, such as age, gender, smoking habit, and residence time, rather than by the Air Quality Index.

1. Introduction

Solid particles (dust) and liquid particles are prevalent in the surrounding air. Due to their small size, these particles can easily enter the respiratory system of living organisms, including humans. Such particles, particularly $PM_{2.5}$, pose significant health risks. $PM_{2.5}$ particles can cause visual disturbances such as eye irritation and, if inhaled, can lead to nasal congestion, runny nose, and continuous sneezing. Additional adverse effects of $PM_{2.5}$ concentration include itchy throat, skin irritation, headaches, and nausea [1]. Individuals with sensitive health conditions are particularly vulnerable to the impacts of $PM_{2.5}$ particles, even under "Medium" Air Pollution Standard Index conditions.

$PM_{2.5}$ particles are extremely small, making them difficult to filter through the fine hairs in the nose, allowing them to reach deep into the respiratory system. These particles can adhere to the lung alveoli, hindering the lungs' ability to perform efficient gas exchange. Research has linked $PM_{2.5}$ particles to 5% of deaths from lung, bronchial, and tracheal cancers [2]. The $PM_{2.5}$ parameter quality standard in Indonesia is regulated by Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management. The $PM_{2.5}$ quality standard set by this regulation is 55 µg/m³ for 24 hours of measurement and 15 µg/m³ for annual measurement.

The decline in air quality in Jakarta is largely attributable to the rapid development of infrastructure, transportation, and industrial activities, which generate significant emissions. According to a survey by the National Statistical Agency, Jakarta had a population of 11,063,221 residents in 2019, making it the 6th most densely populated province in Indonesia [3]. In 2015, the transportation sector contributed 46% of $PM_{2.5}$ pollution in DKI Jakarta, followed by industrial activities at 43%, power generation at 9%, and residential combustion at 2% [4]. Meteorological factors such as humidity, wind speed, and temperature also significantly affect the concentration of $PM_{2.5}$ in ambient air [4].

Long-term monitoring conducted from 2010 to 2019 showed that the annual average PM2.5 concentrations in DKI Jakarta consistently exceeded national ambient air quality standards, with levels increasing yearly [5]. However, during the COVID-19 pandemic, air quality measurements taken at a site in South Jakarta indicated that $PM_{2.5}$ concentrations were within national standards, ranging from 22.30 μg/m³ to 58.66 μg/m³. This improvement is likely linked to large-scale social restrictions that reduced emissions from transportation and industrial activities [6]. These findings highlight the influence of human activity on air quality and underscore the importance of localized air quality assessments. Literature [7] provided evidence of the short-term effects of outdoor air pollution—including NO_2, PM_{10}, $PM_{2.5}$, SO_2, CO, and EC/OC—on the elderly, identifying them as a segment of the population particularly vulnerable or responsive to air pollutants. However, factors such as smoking, occupation, comorbidities, medical treatments, and the surrounding neighborhood environment must be considered as potential confounders or modifiers in assessing these impacts [7].

Many elderly individuals live in nursing homes for various reasons, including economic, health, and social factors, therefore our study location was at one of the largest nursing homes in Jakarta Selatan, housing around 308 elderly residents. The residents are categorized based on their independence and spiritual health into four groups: vulnerable, psychotic, potentially independent, and independent. The aim of measuring outdoor air quality at the nursing home is to assess the air quality level and its impact on the health of the elderly residents. The data collected can serve as a reference for implementing measures to protect the health of the residents.

2. Methodology

The sampling method used in this study follows the guidelines outlined in Indonesian National Standard (SNI) 7119.14:2016, titled *Ambient Air – Part 14: Test Method for Particles ≤ $_{2.5}$ μm ($PM_{2.5}$) Using HVAS Equipment with the Gravimetric Method.* The sampling process involved collecting airborne particles on filter media over a specified duration, followed by weighing the filters under controlled conditions to determine the mass concentration of $PM_{2.5}$. This study used a cross-tabulation method to analyze the relationship between $PM_{2.5}$ pollution, meteorological factors, and health complaints among the elderly residents of the nursing home. Data on $PM_{2.5}$ concentrations, health complaints due to air pollution, and supporting meteorological factors were collected simultaneously. The cross-tabulation approach was chosen to provide a snapshot of the current situation, enabling an analysis of the relationships between the variables involved. The results of this analysis can inform the management of the air quality control system in the area around the nursing home. Sampling was conducted at a single point location to represent ambient air quality in the surrounding study area.

2.1. $PM_{2.5}$ Sampling

Ambient air quality was measured using a High-Volume Air Sampler (HVAS) with $PM_{2.5}$ size-selective inlet (Tisch Environmental, Model No. TE-5170 VFC+X, U.S.A) positioned outside the nursing home building but still within its vicinity. Health complaints data were obtained through interviews with the elderly residents of the nursing home. The ambient air parameters measured included $PM_{2.5}$ concentration, while meteorological factors such as air temperature, humidity, and wind speed were also recorded. The reference standard for sampling, including filter preparation and the sampling process, was SNI 7119.14:2016 (Ambient Air-Part 14: Test method for Particles with a size of 2.5 μm or $PM_{2.5}$). The sampling location was near the Budi Mulia 3 Mosque, chosen due to its higher population density and compliance with SNI 19-7119.6-2005 standards. Sampling was conducted in one session per day for a week, between 10:00 and 16:00 WIB, aligning with the operational hours of the nursing home management and the peak activity hours of the residents. The sampling schedule is detailed in Table 1.

Table 1. $PM_{2.5}$ Sampling Period

No.	Date	Time
1.	Saturday, 6th March 2021	6 Hours
2.	Sunday, 7th March 2021	5 Hours 55 Minutes
3.	Tuesday, 9th March 2021	5 Hours
4.	Wednesday, 10th March 2021	6 Hours
5.	Thursday, 11th March 2021	6 Hours
6.	Friday, 12th March 2021	5 Hours 30 Minutes
7.	Monday, 15th March 2021	6 Hours

2.2. *$PM_{2.5}$ Concentration*

The analysis of $PM_{2.5}$ concentration data involved several calculation steps based on the methodology outlined in SNI 7119.14:2016 (Ambient Air – Part 14: Method of Testing Particles with a Size of 2.5 µm utilizing High Volume Air Sampler (HVAS) equipment with the gravimetric method).
Under typical conditions, the flow rate correction can be determined using the equation:

$$Q_s = Q_0 \left[\frac{T_s \times P_0}{T_0 \times P_s}\right]^{0.5} \qquad (1)$$

Description:
Q_s = volume flow rate corrected at standard condition [298K; 760 mmHg] (Nm^3/min)
Q_0 = test volume flow rate (m^3/min)
T_s = standard temperature, 298 K
T_0 = average actual temperature (273 + $T_{measured}$) when Q_0 measured
Ps = barometric pressure standard, 101.3 kPa (760 mmHg)
P0 = average actual average barometric pressure when Q_0 measured

The volume of the air sample can be determined using the following formula:

$$V = \frac{\Sigma_{i=1}^{n} \times Q_1}{n} \times t \qquad (2)$$

Description:
V = air volume (Nm^3);
Q1 = flowrate recording (Nm^3/min);
n = number of flow rate records;
t = test sampling duration (min).

The concentration of $PM_{2.5}$ can be calculated by the equation:

$$C = \frac{(w_2 - w_1) \times 10^6}{V} \qquad (3)$$

Description:
C = mass concentration of suspended particles (µg/Nm^3);
W1 = initial filter weight (g); W2 = final filter weight (g);
V = volume of air test sample in standard conditions (Nm^3);
10^6 = gram conversion (g) to microgram (µg)

The Canter equation can be used to convert a $PM_{2.5}$ value to a 24-hour $PM_{2.5}$ concentration:

$$C_1 = C_2 \left(\frac{t_2}{t_1}\right)^P \qquad (4)$$

Description:
C_1 = average air concentration by sampling time t_1 (µg/m^3);
C_2 = average air concentration of the measurement results with the length of sampling t_2 (µg/m^3);
t_1 = standard sampling time (24 hours)
t_2 = length of time for sampling measurement results (hour)
p = conversion factor (0.17-0.2)

2.3. Air Pollution Standard Index

According to Minister of Environment and Forestry Number 14 of 2020 concerning the Air Pollutant Standard Index, the concentration of $PM_{2.5}$ concentration in measurements carried out for 24 hours is converted to the Air Pollution Standard Index value. The equation for converting the $PM_{2.5}$ concentration value to the Air Pollution Standard Index value is [11]:

$$I = \frac{I_a - I_b}{X_a - X_b}(X_x - X_b) + I_b$$

Description:

I : Air Pollution Standard Index
I_a : Air Pollution Standard Index upper limit value
I_b : Air Pollution Standard Index lower limit value
X_a : Upper limit ambient concentration (µg/Nm^3)
X_b : Lower limit ambient concentration (µg/Nm^3)
X_x : Real ambient concentration measurement results (µg/Nm^3)

2.4. Meteorological Factors

Meteorological factors measured included wind speed, humidity, and temperature. Data collection for meteorological factors and $PM_{2.5}$ concentration was conducted simultaneously. A thermo-hygrometer was used to measure air humidity and temperature around the sampling location, while an anemometer was employed to measure wind speed.

2.5. Interview

The population analysed in this study comprised all elderly individuals residing in the nursing home, totalling 308 people. For inclusion in the data analysis, the elderly individuals needed to meet specific qualifications for interview, namely being healthy and active. The nursing home categorizes its elderly residents into four categories: vulnerable, psychotic, potentially independent, and independent. The vulnerable category includes elderly individuals who can no longer care for themselves, while the psychotic category consists of those with unstable mental health. The potentially independent category comprises elderly individuals who have both physical and mental health but still require supervision from orphanage staff. Finally, the independent category encompasses elderly individuals with good physical and mental health. For this research sample, individuals categorized as "independent" were deemed appropriate as they possess both mental and physical health.

2.6. Cross-tabulation Analysis

Statistical analysis included correlation tests to identify meteorological factors influencing $PM_{2.5}$ concentration and basic and multiple linear regression methods for relationship modelling [9]. Data validity was assessed through the Shapiro-Wilk normality test for small sample sizes [8], heteroscedasticity tests using scatterplots, and the chi-square test to analyse relationships between $PM_{2.5}$ and health complaints [10]. Independent variables such as age, duration of stay, smoking habits, Air Pollution Standard Index, and gender were analysed against health complaints. Multiple linear regression equations help establish the relationship between dependent and independent variables [9]. To analyze the relationship between $PM_{2.5}$ parameters and health complaints, cross-tabulation and the chi-square test were employed.

3. Results and discussions

3.1. $PM_{2.5}$ Concentration

Ambient air quality was measured at the nursing home seven times, with each measurement lasting six hours from 10:00 to 16:00 WIB. Because the test cannot be completed in 24 hours, the results of the 6-hour measurement are transformed to 24 hours using the Canter equation (Equation 4). The Canter equation was used to convert the data so that it could be compared to the $PM_{2.5}$ pollution quality standard, which was completed within 24 hours, and the Air Pollution Standard Index value was calculated (Table 2).

Table 2. $PM_{2.5}$ Concentration and Air Pollution Standard Index

Day	$PM_{2.5}$ Concentration (µg/Nm^3)*	Air Pollution Standard Index	Category
Saturday	32.99	71.92	Moderate
Sunday	42.90	84.34	Moderate
Monday	28.06	77.81	Moderate
Tuesday	37.69	56.94	Moderate
Wednesday	21.04	65.02	Moderate
Thursday	27.49	49.92	Good
Friday	15.43	65.74	Moderate

The negative effects of $PM_{2.5}$ include premature death for individuals with heart disease, heart attacks, asthma, decreased lung function, and increased symptoms of respiratory tract irritation [12]. Referring to Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, the $PM_{2.5}$ quality standard in Indonesia is 55 µg/Nm^3 for 24-hour measurements and 15 µg/Nm^3 for annual measurements [13]. $PM_{2.5}$ is a mixture of solid particles with a small amount of liquid, characterized by a light mass and very small size, which allows it to remain suspended in the air easily [14]. In general, particulate pollution arises from three fundamental processes: materials handling, combustion, and gas conversion reactions in the atmosphere [15]. According to [16], $PM_{2.5}$ particles are dispersed in the air due to chemical reaction processes at the source. Due to its smaller size, $PM_{2.5}$ pose the greatest risk to the health than other larger particles [17].

As shown in Figure 1, the concentration of $PM_{2.5}$ in the nursing home area is below the quality standard. The Air Pollution Standard Index calculation is based on the Ministry of Environment and Forestry Regulation Number 14 of 2020 [18]. The "Moderate" category is predominant in the measurement data. For example, on Sunday, the $PM_{2.5}$ concentration was 42.9 µg/Nm^3, resulting in an Air Pollution Standard Index value of 84.3, which falls within the "Moderate" classification. The prevalence of the "Moderate" category suggests that while air quality in the nursing home area is generally acceptable, there are occasional days when air pollution levels may pose minor health concerns for sensitive individuals, particularly elderly residents.

3.2. Comparison of $PM_{2.5}$ with other Monitoring Station

The United States Embassy in Jakarta Air Monitor provided data for this study. The measurement methods employed follow federation standards or equivalent to those recognized by the US-EPA, and the supporting data supplied by the US Embassy Jakarta Air Monitor is considered complete. According to the standard document EPA-454/B-16-00 on Monitoring $PM_{2.5}$ in Ambient Air Using Designated Reference or Class I Equivalent Methods, the gravimetric method is used to sample the ambient air quality measurement $PM_{2.5}$ [19].

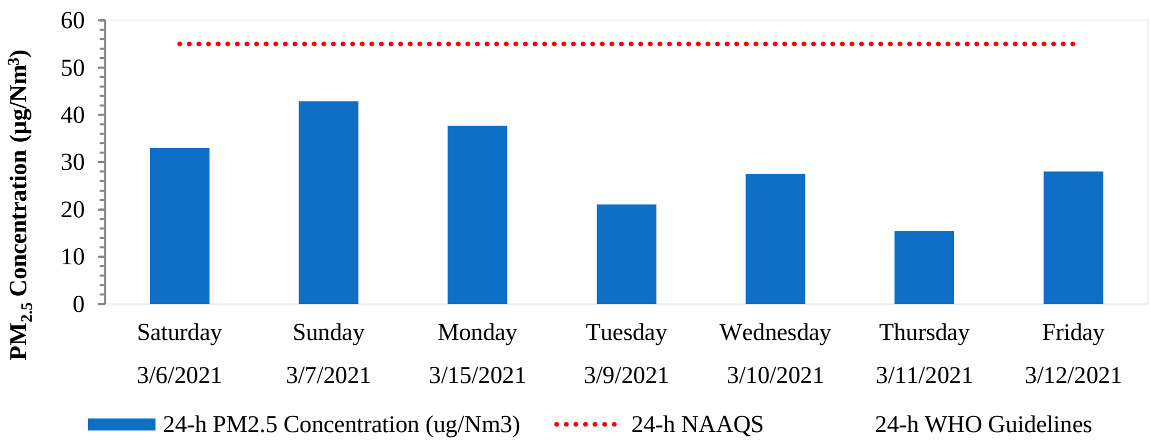

Figure 1. Compliance of ambient outdoor $PM_{2.5}$ concentrations with the NAAQS and WHO Guidelines

Table 3. Comparation of Measured Value with U.S. Embassy Jakarta Air Monitor Data

No.	Date	$PM_{2.5}$ (µg/Nm^3)*	$PM_{2.5}$ (µg/Nm^3)**	Difference (µg/Nm^3)	% Difference
1	Saturday, 6th March 2021	32.99	42.00	9.01	12.01
2	Sunday, 7th March 2021	42.90	49.00	6,10	6,64
3	Tuesday, 9th March 2021	37.69	41.00	3,31	1.21
4	Wednesday, 10th March 2021	21.04	27.00	5,96	12.41
5	Thursday, 11th March 2021	27.49	35,00	7.51	12.03
6	Friday, 12th March 2021	15,43	15,00	0.43	1.43
7	Monday, 15th March 2021	28.06	31.00	5,94	9.57

* Sampling data

** U.S Embassy Jakarta Air Monitor Data [18]

The variance between the data collected from the U.S. Embassy Jakarta Air Monitor and the research data is relatively small, ranging from 4.21% to 12.41% (Table 3). A correlation test was conducted to assess measurement accuracy by comparing the sampling data with the U.S. Embassy data (Figure 1). The test produced an R-squared value of 0.938, indicating a very strong correlation between the two datasets. Statistically, this means that 93.8% of the variability in PM2.5 concentration measurements is explained by the relationship between the two data sources. This high R-squared value suggests that the sampling measurements are both reliable and representative of air quality conditions monitored by the U.S. Embassy Jakarta Air Monitor. Details of the $PM_{2.5}$ concentration measurements are presented in Figure 2.

3.3. Health Complaints related to Air Quality from Elderly Residents

Relationship between $PM_{2.5}$ concentration, measured by the Air Pollution Standard Index, and health complaints among the elderly residents of the nursing home are evaluated by the health complaints survey (Table 4). The analysis shows that 10.71% of health complaints were reported in the "good" Air Pollution Standard Index category, while a substantial 78.57% were reported in the "moderate" Air Pollution Standard Index category. Conversely, among those without health complaints, 3.57% were in the "good" Air Pollution Standard Index category and 7.14% in the "moderate" Air Pollution Standard Index category. These figures suggest a correlation between increasing $PM_{2.5}$ concentration levels and the incidence of health complaints among the elderly.

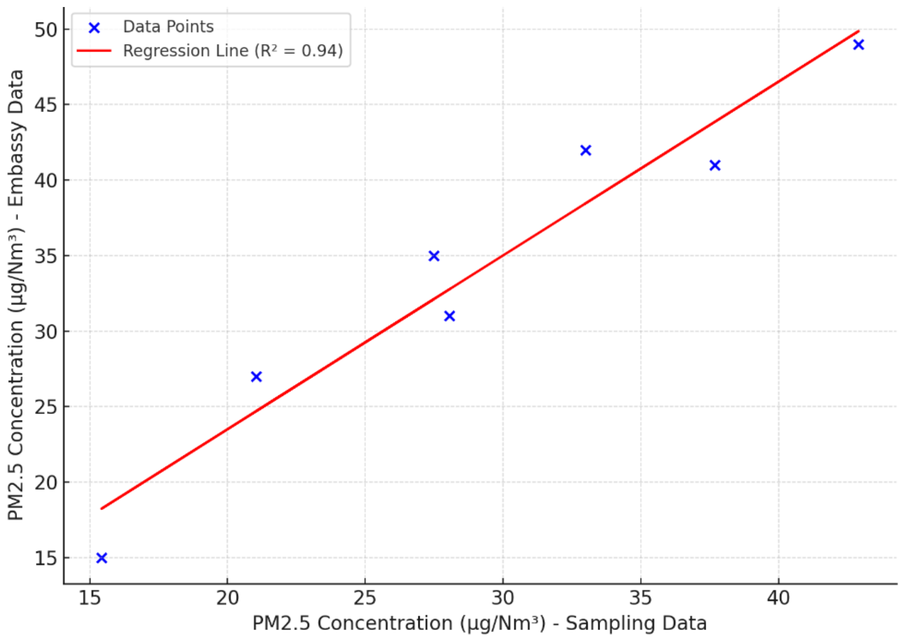

Figure 2. Correlation Test Results for Sampling Data and U.S Embassy Jakarta Air Monitor Data

Table 4. Health Complaints Survey

Air Pollution Standard Index	Health Complaints			
	Yes		No	
	n	%	n	%
Good	6	10.71	2	3,57
Moderate	44	78.57	4	7.14
Total	**50**	**89.29**	**6**	**10.71**

The linear regression analysis (Figure 3) shows a moderately strong positive relationship, as indicated by a correlation coefficient of 0.722. However, the R Square is slightly lower (0.5219), reflecting the small sample size of seven observations, which limits the generalizability of the results. Meanwhile, the ANOVA results (Table 5) show that the regression model approaches statistical significance, with an F-statistic of 5.457 and a p-value (Significance F) of 0.067. While this p-value is slightly above the conventional threshold of 0.05, it suggests a marginally significant relationship between $PM_{2.5}$ and health complaints. The small sample size (7 data points) likely contributes to the lack of strong statistical significance and reduces the reliability of the findings. This analysis indicates a potential association between $PM_{2.5}$ concentrations and health complaints among the elderly, but further studies with larger datasets are necessary to confirm these findings and strengthen the statistical power.

Table 6 provides a comprehensive statistical analysis, showing that age, gender, and smoking status have significant correlations with health complaints, with asymptotic significance values (2-sided) less than 0.05. This underscores that these personal characteristics are critical determinants of health outcomes among the elderly. However, the Air Pollution Standard Index category's asymptotic significance value is greater than 0.05, indicating that $PM_{2.5}$ concentration levels, as measured during the study period, did not show a statistically significant direct correlation with health complaints. This suggests that while $PM_{2.5}$ levels are an important environmental factor, the immediate health complaints observed are more strongly influenced by age, gender, and smoking status. Indoor pollutants, which can be more concentrated and involve longer exposure durations, are likely to have a greater impact on health [20].

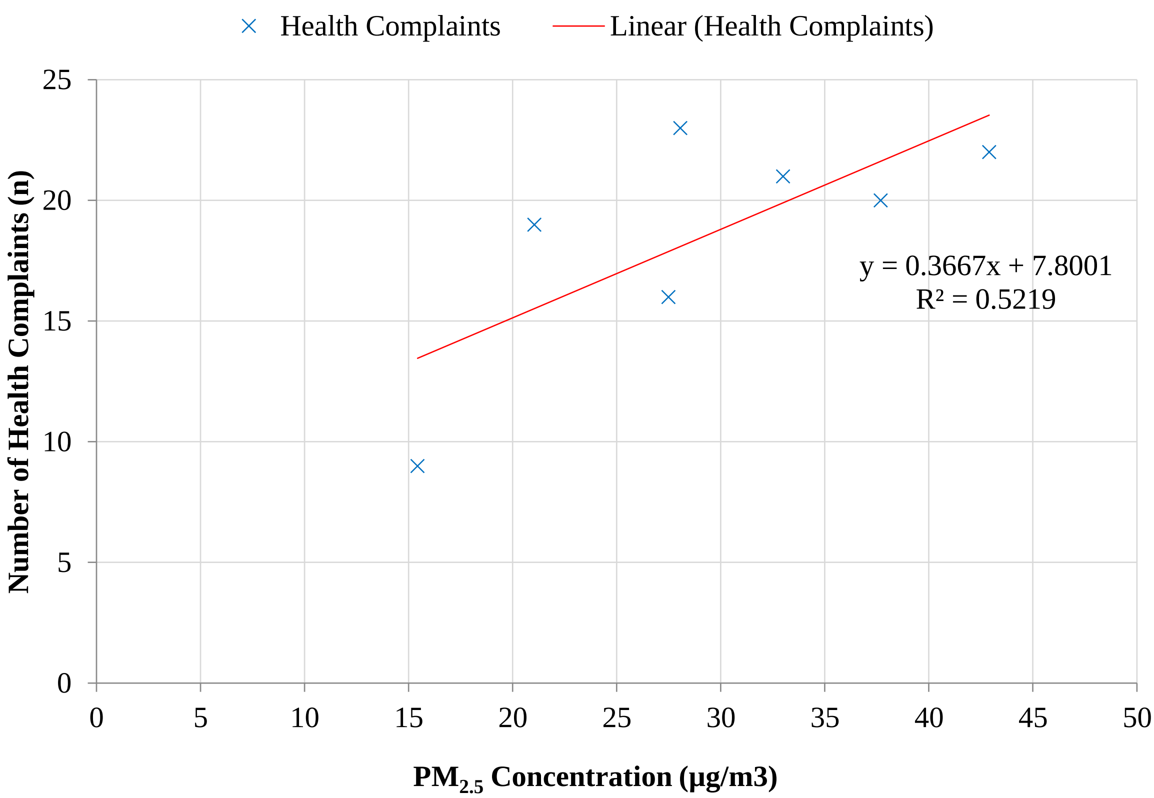

Figure 3. Linear Regression Test between Number of Health Complaints (n) and $PM_{2.5}$ Concentration

Table 5. ANOVA Result of the Linear Regression

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	71.86739753	71.86739753	5.457159747	0.066706594
Residual	5	65.84688818	13.16937764		
Total	6	137.7142857			

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Table 6. Cross-tabulation Data

Characteristics	Health Complaints			
	Yes		No	
	n	%	n	%
Air Pollution Standard Index				
Good	6	12	2	33,3
Moderate	44	88	4	66,7
Unhealthy	0	0	0	0
Very Unhealthy	0	0	0	0
Dangerous	0	0	0	0
Total	*50*	*100*	*6*	*100*
Age				
< 60 years old	3	6	4	67
≥60 years old	47	94	2	33
Total	*50*	*100*	*6*	*100*
Gender				
Male	18	36	5	83
Female	32	64	1	17
Total	*50*	*100*	*6*	*100.0*
Smoker				
Yes	9	18	4	67
Not	41	82	2	33
Total	*50*	*100*	*6*	*100*
Residence time				
< 5 years	41	82	2	33
≥ 5 years	9	18	4	67
Total	*50*	*100*	*6*	*100*

Table 7. Chi-Square Test

Category	Asymptotic Significance (2-sided)	Relationship with Health Complaints
Air Pollution Standard Index	0.223	Not statistically significant
Gender	0.026	Statistically significant
Smoke	0.000	Statistically significant
Age	0.020	Statistically significant
Residence time	0.029	Statistically significant

It also highlighted that most health issues were reported by individuals over 60 years old, with 94% of the 47 observations falling into this age group. This finding aligns with established knowledge that the immune system weakens with age, making older individuals more susceptible to health problems (Oktara, 2008) [21]. Additionally, the data show that elderly females reported more health problems, with 32 observations underscoring the role of anatomical, physiological, and hormonal factors in health outcomes. Moreover, the data indicate that non-smoking elderly residents are significantly affected by passive smoking. Elderly non-smokers reported more health concerns, which can be attributed to their exposure to second-hand smoke from smoking residents. Passive smoking is known to cause a range of health issues, exacerbating the vulnerability of non-smoking elderly individuals.

The chi-square test reveals relationships between air quality, elderly characteristics, and health complaints (Table 7). Age is a significant factor, with a p-value < 0.05, indicating that health complaints increase with age. This aligns with existing research showing immune system decline in older adults (Oktara, 2008) [21]. Gender also influences health complaints, with women reporting more issues than men ($p < 0.05$), likely due to anatomical, physiological, and hormonal differences. Smoking status is another key factor, with non-smokers in nursing homes affected by passive smoking ($p < 0.05$). Finally, PM2.5 levels, as indicated by the Air Pollution Standard Index, do not correlate significantly with health complaints ($p > 0.05$), suggesting that age, gender, and smoking status are more critical than ambient $PM_{2.5}$ levels.

3.4. Meteorological Factors Related to Air Quality

Multiple linear regression analysis using SPSS Version 26 examines the relationship between meteorological factors (Table 8) and $PM_{2.5}$ concentration. As shown in Table 9, the Sig. the F Change value of 0.008 indicates a significant relationship between temperature, humidity, wind speed, and $PM_{2.5}$ concentration. The Pearson correlation coefficient ($R = 0.986$) suggests a strong positive correlation. Humidity and wind speed are directly positively correlated with $PM_{2.5}$ levels, while temperature has an inverse relationship, with higher temperatures associated with lower $PM_{2.5}$ concentrations.

Table 8. Meteorological Factors and $PM_{2.5}$ Concentration Measurement Results

Date	**Humidity (%)**	**Wind Speed (m/s)**	**Temperature (°C)**	**$PM_{2.5}$ Concentration (µg/Nm^3)**
Saturday, March 6th 2021	57.25	1.95	30.23	32.99
Sunday, March 7th 2021	59.83	3.04	29.75	42.90
Monday, March 15th 2021	59.28	2.00	29.88	37.69
Tuesday, March 9th 2021	50.75	1.88	30.78	21.04
Wednesday, March 10th, 2021	51.58	1.90	30.65	27.49
Thursday, March 11st, 2021	48.45	1.28	30.80	15.43
Friday, March 12th, 2021	51.08	1.93	30.63	28.06

Table 9. Meteorological Factors in Multiple Linear Regression Against $PM_{2.5}$ Concentration

Category	Result
Equation	$Y= 1.508X_1 + 1.958X_2 -1.186X_3$
X_1 (Humidity)	1.508
X_2 (Wind speed)	4.958
X_3 (Temperature)	-1.186
R (*Pearson correlation*)	0.986
Sig. F Change	0.008
Sig.	0.008

4. Conclusion

This case study measured $PM_{2.5}$ levels in an outdoor area of a nursing home in Jakarta during the COVID-19 pandemic and found that the levels remained below the regulatory threshold of 55 µg/m³. However, daily variations were observed, with the highest concentration recorded at 42.90 µg/m³. The analysis reveals that age, gender, and smoking status significantly influence health complaints among the elderly, with older individuals (≥60 years), females, and non-smokers exposed to passive smoking reporting higher complaints. Although $PM_{2.5}$ concentration shows a moderately strong positive correlation with health complaints (R^2 = 52.2%), the relationship is not statistically significant (p = 0.067), likely due to the small sample size. Similarly, the Air Pollution Standard Index categories indicate a concentration of health complaints in the "moderate" pollution category, but no statistically significant relationship was found. Meteorological factors, including humidity, wind speed, and temperature, strongly correlate with $PM_{2.5}$ levels (p = 0.008), with humidity and wind speed showing positive relationships and temperature an inverse one. These findings highlight the importance of addressing both individual characteristics and environmental factors, emphasizing the need for further studies with larger datasets and targeted interventions to mitigate health risks among the elderly. This study is limited by its focus on a single nursing home and a short one-week measurement period, which may not capture long-term trends. Health complaints relied on self-reported data, introducing potential biases. Additionally, the study did not fully consider independent meteorological variations, other indoor $PM_{2.5}$ sources, or the impact of outdoor pollution on indoor air quality. Broader studies with more comprehensive data are needed for greater generalizability and deeper insights.

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