Original Article

Associations of Air Pollutants in East Jakarta with Community-Acquired Pneumonia (CAP) Hospitalization Rates in Persahabatan Hospital in 2023

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Abstract

Background: Pneumonia is an acute inflammation of the lung parenchyma with a prevalence of 2% in Indonesia. Risk factors for community-acquired pneumonia (CAP) include host factors, pathogens, and environmental factors such as air pollution. According to various international studies, several air pollution parameters have been linked to CAP, including particulate matter (PM), particularly PM_{10} and $PM_{2.5}$, sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2). This study aimed to assess the relationship between air pollutant levels and CAP hospitalization rates at Persahabatan Hospital in 2023.

Methods: This retrospective cohort study was conducted at Persahabatan Hospital, involving all adult patients diagnosed with CAP who were hospitalized during 2023. Subjects were selected based on inclusion and exclusion criteria. Air pollutant data were obtained from the official website of the Department of Environment, DKI Jakarta. Statistical analysis included Pearson or Spearman correlation tests, followed by multiple linear regression.

Results: A total of 729 subjects met the inclusion criteria. Most patients were over 56 years old (61.3%), had more than one comorbidity (73%), had a high pneumonia severity index (PSI) score between 91 and 130 (46.1%), and were unemployed (55.3%). The highest number of CAP hospitalizations occurred in October (88 patients, 12%), coinciding with the highest recorded $PM_{2.5}$ level (API=125, unhealthy category) and O_3 level (API=28.4, good category) a month before in September. Statistical analysis showed a significant relationship between $PM_{2.5}$ levels 7 days prior to admission (b=0.732; P<0.001), alongside a negative relation from the mean of O_3 level during the admission month (b= -1.601; P=0.009) with the number of CAP hospitalizations.

Conclusion: Average $PM_{2.5}$ levels measured 7 days prior to hospitalization have a significant positive association with the number of CAP admissions, alongside a negative relation of average O_3 levels during the month of hospitalization, at Persahabatan Hospital in 2023.

Keywords: air pollutants, API, CAP

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INTRODUCTION

Pneumonia is an acute inflammation of the pulmonary parenchyma caused by various microorganisms such as bacteria, viruses, fungi, and parasites. The prevalence of pneumonia in Indonesia is around 2%, and it is more common in the age group over 55 years. The symptoms are usually non-specific, including cough, changes in sputum characteristics, fever, chest pain, and shortness of breath. Age, smoking habits, nutritional status, and comorbidities of the host are several factors that affect the risk of pneumonia. In addition, environmental factors such as air pollution, humidity, seasonal changes, and others can also increase the risk of pneumonia.[1,2]

According to the World Health Organization (WHO), globally, air pollution causes about 7 million deaths per year due to ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), lung cancer, and acute respiratory tract infections (ARI), including pneumonia. WHO global air quality guidelines stated that the assessment of the risk caused by air pollution would be based on the assessment of each individual's personal exposure, which requires pollution measurements in each microenvironment and the amount of time spent there, which is not possible in the meantime.[1–6]

Therefore, some studies used the daily concentrations captured by single monitors to assess the acute effects of air pollution, such as mortality and hospital admissions. Several studies have shown that air pollutants such as particulate matter (PM), nitrogen dioxide (NO_2), and nitrogen oxides (NOx) might increase the risk of pneumonia, especially in smokers. A study by Wang et al in the UK stated that long-term exposure to even low levels of air pollution can increase the risk of pneumonia.[1–6]

Jakarta is one of the cities with the highest air pollution levels in Indonesia and was ranked 5th globally in 2020 according to the World Air Quality Report based on data from IQAir. In 2022, Jakarta was ranked first with the highest $PM_{2.5}$ levels (36.2 μg/m3) in the Association of Southeast Asian Nations (ASEAN) for 5 consecutive years from 2018 to 2022. Based on the two-dimensional map, the highest $PM_{2.5}$ concentrations were found in West Jakarta and South Jakarta, followed by East Jakarta, Central Jakarta, and the lowest in North Jakarta.[7]

Several local studies in Indonesia show that air pollution is associated with various lung health problems, such as decreased lung function, asthma, COPD, and lung cancer.[8] When viewed from the number of pneumonia visits in adult patients at the Persahabatan Hospital during the coronavirus disease (COVID-19) pandemic, decreased by up to 59% compared to 2019. But, the number of visits increased again in 2023, reaching 613 outpatient visits and 1606 inpatient visits.[9,10]

Until now, no studies have linked air pollution exposure with the number of pneumonia visits in adult patients in Indonesia. A study by Habibi et al showed a correlation between exposure to air pollution and the number of COPD exacerbations, although the correlation was not statistically significant. Another study by Andari et al found that there was a relationship between the PM_{10} in the air pollutant standards index (API) value and the number of asthma exacerbation visits at the emergency department in Persahabatan Hospital.[9,10]

Multiple international studies also mentioned that several air pollution parameters are linked to increased risk of patient hospitalization and mortality due to pneumonia in adults. A study by Zhang et al in China observed a significant relationship between short-term exposure to $PM_{2.5}$, PM_{10}, NO_2, and SO_2 and hospital visits for pneumonia. A pooled cohort study in Europe by Liu et al, ELAPSE (Effects of Low-Level Air Pollution: A Study in Europe), showed that long-term exposure to low levels of NO_2 and black carbon (BC) may increase the risk of mortality from pneumonia and related infectious diseases in adults.[11,12]

Based on these particular findings, this study was conducted to find the relationship between these air pollutant levels ($PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, and O_3), including which pollutants are most relevant to the number of community-acquired pneumonia (CAP) hospitalizations in Hospital Persahabatan, Jakarta.

METHODS

This retrospective cohort study was conducted at Persahabatan Hospital Jakarta in October 2024 and continued until completion. Ethical approval was obtained from the Health Research Ethics Committee of Persahabatan National Respiratory Center Hospital (Approval No. 0233/KEPK-RSUPP/10/2024).

The sample consisted of an accessible population that met the inclusion criteria of the study, such as adult patients aged over 18 years; patients residing in East Jakarta and living within 20 km of the air quality monitoring station (AQMS) 4 DKI Lubang Buaya, East Jakarta; and patients diagnosed with community-acquired pneumonia (CAP) based on the pneumonia severity index (PSI). Patients with prolonged bed rest and comorbid infections in other organs (e.g., decubitus ulcers, diabetic ulcers, urinary tract infections, etc.); and patients with other pulmonary infections (e.g., pulmonary tuberculosis, pulmonary mycosis, COVID-19, etc.) were excluded from the study.

The patients who met the criteria and were admitted to the inpatient wards of Persahabatan Hospital from January 2023 to December 2023 will be samples of the study, with the sampling method being a total sampling method. Patient data will be linked to air pollutant levels based on API, followed by univariate analysis and linear regression.

Air pollutant levels were presented as the average over 7 days, 3 days before, and on the day of the patient's hospital visit, diagnosed as CAP. Monthly average pollutant levels were also calculated. Numerical data included age and air pollutant levels. If normally distributed numerical data were presented as mean±standard deviation, while data distribution was not normally shown as median (minimum-maximum values). Categorical data, such as demographic characteristics, were presented as percentages.

Pearson or Spearman correlation tests were used to analyze the relationship between air pollutant levels and the incidence of CAP. Subsequently, bivariate analysis was conducted on each demographic characteristic variable to identify those with a potential influence ($P<0.05$), followed by linear regression analysis using the stepwise method. In this analysis, $P<0.05$ was considered statistically significant. All statistical analyses were performed using SPSS software version 30.

RESULTS

Based on the medical records, there were 1606 inpatients diagnosed with pneumonia according to the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10). After applying several exclusion criteria, 729 patients were found to meet the inclusion criteria for this study (Figure 1).

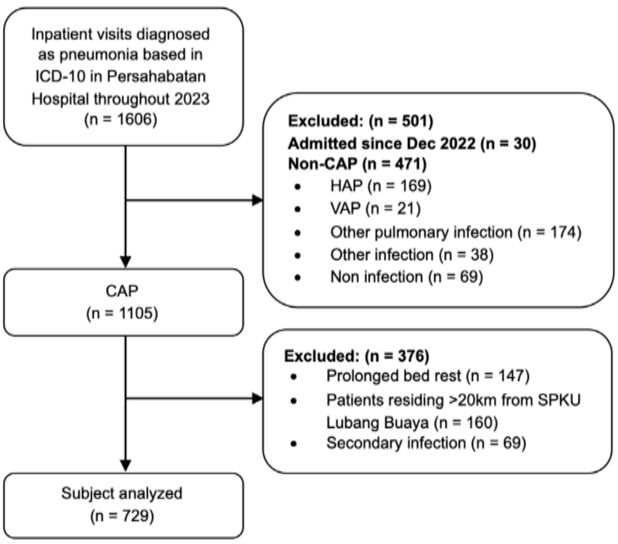

Figure 1. Study Diagram

Table 1. Demographic Characteristics of CAP patients (n=729)

Characteristics	n	%
Age		
≤56 years old	282	38.7
>56 years old	447	61.3
Gender		
Male	402	55.1
Female	327	44.9
Employment		
Unemployed	403	55.3
Indoors	189	25.9
Outdoors	137	18.8
Body Mass Index		
Very underweight	86	11.8
Underweight	58	8.0
Normal	396	54.2
Overweight	69	9.5
Obese	120	16.5
Comorbidities		
None	23	3.1
1 comorbidity	174	23.9
>1 comorbidities	532	73
Smoker		
Non-smoker	393	53.9
Ex-smoker	104	14.3
Active smoker	232	31.8
Brinkman Index		
Light smoker	16	6.9
Mild smoker	72	31.0
Heavy smoker	144	62.1
Distance from AQMS		
0.0–10 km	387	53.1
10–20 km	342	46.9
Season		
Rainy season	378	51.9
Dry season	351	48.1
CAP severity		
PSI ≤70	110	15.1
PSI 71–90	160	21.9
PSI 91–130	336	46.1
PSI >130	123	16.9

Note: AQMS=Air Quality Monitoring Station; CAP=community-acquired pneumonia; PSI=Pneumonia Severity Index

Demographic characteristics of this study are presented in Table 1. The data showed the majority of the subjects were over 56 years old (61.3%). The median age of the subjects was 60 years old, with the youngest being 19 years old and the oldest 94 years old. Based on gender, male subjects were slightly dominant (55.1%). In terms of body mass index (BMI), most of the subjects had a normal BMI category (18.5–25 kg/m^2), with 54.2%. The median of BMI was 22.2 kg/m^2, with the lowest BMI at 11.7 kg/m^2 and the highest BMI at 68.5 kg/m^2. Most of the subjects were unemployed, with 55.3%.

Most of the subjects had more than one comorbidity (73%) and were predominantly non-smokers (53.9%). Among those who were active smokers, most were classified as heavy smokers (Brinkman Index ≥600 cigarettes/year) at 61.8%. Based on the PSI score, the subjects were more common in the range of 91–130, found 46.1%.

Additionally, the median distance between the patients' residences and the AQMS DKI 4 Lubang Buaya, East Jakarta, was 9.82 km, with the closest distance being 700 meters and the farthest 19.9 km. Most of the subjects lived less than10 km from AQMS, at 53.1%. The number of patients during the rainy season was slightly higher at 51.9%, compared to the dry season.

Based on data from the Department of Environment, DKI Jakarta, air pollutant levels in East Jakarta in 2023 were included in the medium (51–100) and unhealthy (101–200) API categories. The worst air pollutant levels at AQMS DKI 4 Lubang Buaya occurred in September, which even reached very unhealthy levels (201–300), and in October, with the average levels of air pollutants throughout the month in the unhealthy category (101–200).

In addition, it was found that the highest average pollutant level of $PM_{2.5}$ occurred in September and the highest level of PM_{10} pollutant in October. However, it should be noted that from the end of March to early September 2023, the PM_{10} pollutant measuring device was damaged, so there were some missing data on PM_{10} air pollutant levels in that period. The highest levels of air pollutants SO_2, CO, O_3, and NO_2 occurred in January, May, September, and November, respectively (Figure 2). Daily air pollutant levels are also shown in Figure 3.

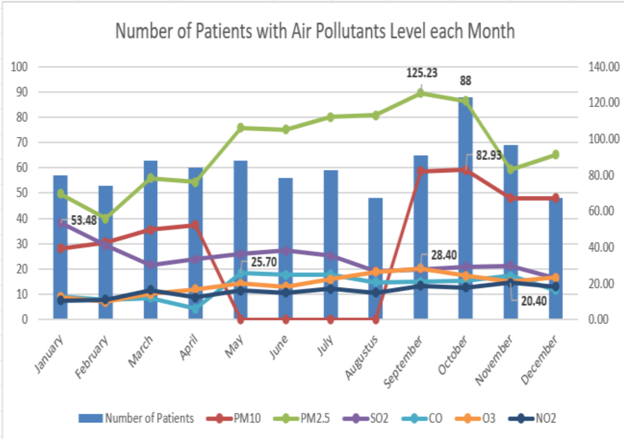

Figure 2. East Jakarta API Profile each Month and Number of CAP Patients Hospitalization at Persahabatan Hospital in 2023

The association between air pollutant levels and the number of CAP hospitalizations was carried out by conducting a Pearson or Spearman correlation test according to the data distribution. The average/median level of each air pollutant per month was associated with the number of CAP patients hospitalized in that month. In addition, a correlation test was conducted between average or median levels of air pollutants on the day of admission, 3 days before admission, and 7 days before admission, with the number of CAP patients. Several studies reported various results of air pollutant exposure lag time from day 0 to 7 days before admission.

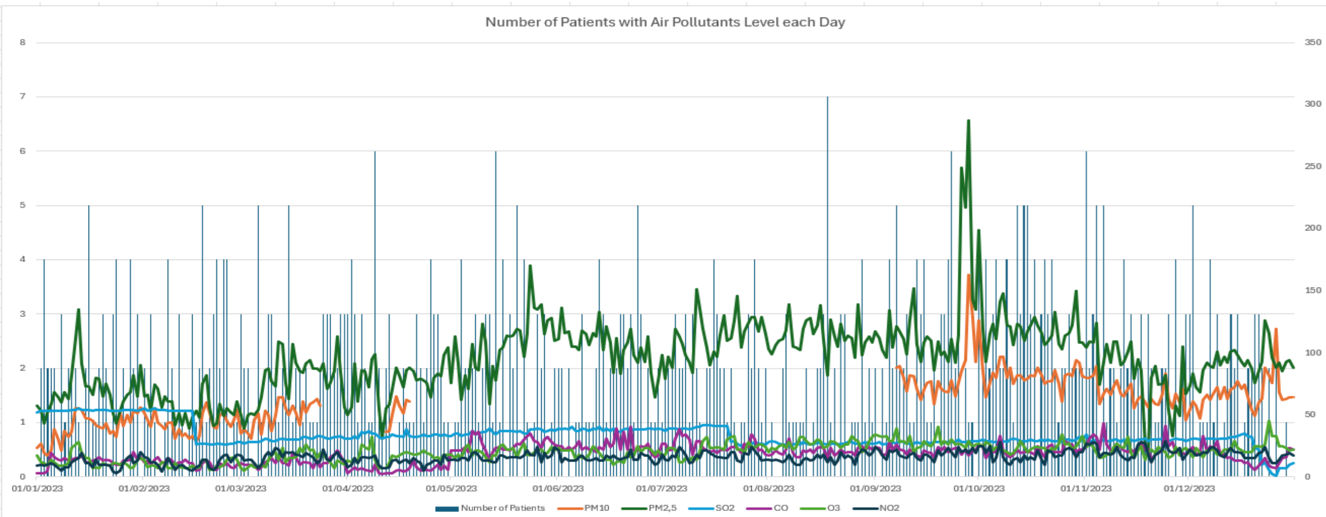

Figure 3. East Jakarta API Profile each Day and Number of CAP Patients Hospitalization at Persahabatan Hospital in 2023

Table 2. Average/Median and Correlation of Air Pollutant Levels with CAP Hospitalization Rates

Air Pollutants	Mean±SD or Median (Min-Max)	Correlation (r)	*P*
PM_{10}			
PM_{10} on the day of admission	58.99±16.89	0.626	0.097
PM_{10} 3 days before admission	61.43±16.42	0.704	0.051
PM_{10} 7 days before admission	60.73±17.16	0.725	0.042
PM_{10} during the month of admission	60.46±16.95	0.604	0.113
$PM_{2.5}$			
$PM_{2.5}$ on the day of admission	85.93±22.67	0.372	0.234
$PM_{2.5}$ 3 days before admission	88.70±22.33	0.424	0.169
$PM_{2.5}$ 7 days before admission	87.47±25.61	0.498	0.100
$PM_{2.5}$ during the month of admission	87.56±24.19	0.335	0.286
SO_2			
SO_2 on the day of admission	30.19 (26.54-53.51)	-0.084	0.795
SO_2 3 days before admission	30.03 (27.52-53.39)	-0.235	0.462
SO_2 7 days before admission	30.07 (27.52-53.09)	-0.333	0.290
SO_2 during the month of admission	31.61 (23.12-53.48)	-0.084	0.795
CO			
CO on the day of admission	15.64±6.49	0.238	0.457
CO 3 days before admission	15.66±5.96	0.192	0.550
CO 7 days before admission	15.89±6.20	0.150	0.642
CO during the month of admission	15.51±6.27	0.249	0.435
O_3			
O_3 on the day of admission	18.29±6.49	0.225	0.482
O_3 3 days before admission	18.91±6.48	0.251	0.431
O_3 7 days before admission	18.45±6.68	0.253	0.428
O_3 during the month of admission	18.76±6.44	0.204	0.525
NO_2			
NO_2 on the day of admission	15.74±3.95	0.297	0.349
NO_2 3 days before admission	15.42±3.90	0.367	0.241
NO_2 7 days before admission	15.68±4.02	0.321	0.308
NO_2 during the month of admission	15.59±3.81	0.395	0.204

In this study, lag times of air pollutant exposure were chosen from the shortest period (day 0), the longest (day 7), and the median (day 3). From the results of the correlation test of average air pollutant levels per month, there were 3 air pollutant levels that showed a positive moderate correlation with the number of CAP patient hospitalizations but were not statistically significant. These pollutants include PM_{10} (r=0.604; *P*=0.113), $PM_{2.5}$ (r=0.335; *P*=0.286) and NO_2 (r=0.395; *P*=0.204).

Moderate and weak positive correlations that were not statistically significant were also obtained from the analysis of the average PM_{10} and $PM_{2.5}$ levels on the day of admission, with correlation values of 0.626 (*P*=0.097) and 0.372 (*P*=0.234), respectively. Air pollutant levels 3 days prior to admission were found to have a strong correlation in PM_{10} levels (r=0.704; *P*=0.051) and weak correlations in both $PM_{2.5}$ levels (r=0.424; *P*=0.169) and NO_2 levels (r=0.367; *P*=0.241). However, these three correlations were also not statistically significant.

Statistically significant strong correlation values were obtained at 7 days prior to admission in PM_{10} levels (r=0.725; *P*=0.042). However, it should be noted that there were missing data on PM_{10} levels from May to August, so the value of the correlation was doubtful. In addition, weak correlation values that were also not statistically significant were obtained at 7 days before admission for $PM_{2.5}$ levels (r=0.498; *P*=0.100) and NO_2 levels (r=0.321; *P*=0.308). Negative correlation values were obtained at SO_2 levels 7 days before admission but were not significant statistically (r= -0.333; *P*=0.290). The complete correlation test results are shown in Table 2.

The results of multiple linear regression analysis using the stepwise method showed that

$PM_{2.5}$ levels at 7 days before admission had a significant positive effect (b=0.732; *P*<0.001) on the number of CAP hospitalizations. This effect was simultaneous with the average O3 level in the month of admission, which had a significant negative effect (b=-1.601; *P*=0.009). This regression model showed that the combination of $PM_{2.5}$ levels at 7 days prior to admission and average O_3 levels in the month of admission was able to explain 93.3% of the variation in the number of hospitalization visits in CAP patients (R^2=0.933; Adjusted R^2=0.906), with a standard error of 3.735 (Table 3).

Table 3. Multiple Linear Regression Analysis of Air Pollutant Levels

Variable	b (SE)	*P*
Constant	28.901 (5.004)	---
$PM_{2.5}$ 7 days before admission	0.732 (0.098)	<0.001
O_3 month of admission	-1.601 (0.390)	0.009

Note: R^2=0.933; Adjusted R^2=0.906

DISCUSSION

Based on data from Statistics Indonesia Jakarta, the ratio of East Jakarta's male and female population in 2023 was almost comparable, with about 1,545,822 males (50.19%) and 1,533,796 females (49.81%).[13] The subjects in this study were dominated by males (55.1%). These results are almost identical to a study conducted by Wu et al, which stated that more male patients were hospitalized for pneumonia (60%) in Beijing, China.[14] A study by Silveyra et al stated that men had a higher risk of pneumonia due to exposure to air pollution ($PM_{2.5}$, PM_{10}, and NO_2), especially in smokers.[15]

In this study, the age group was divided based on the retirement age of the Indonesian population, which is between 56 and 57 years, in accordance with Government Regulations No. 45 of 2015 concerning the Implementation of the Pension Security Program.[16] Most of the subjects of this study were >56 years old (61.3%) with a median age of 60 years in the age range of 19–94 years. This is in line with several previous studies by Wu et al, Chu et al, and Kim et al, which found that elderly patients (≥65 years) were associated with an increased risk of pneumonia admission due to exposure to $PM_{2.5}$ and PM_{10} compared to younger age groups.[14,17-18] A meta-analysis conducted by Kim et al found that patients aged ≥65 years had a 1.026 times higher risk of hospital admission for pneumonia with an increase in $PM_{2.5}$ levels of 10 μg/m3 and a 1.016 times increased risk with each 10 μg/m3 increase in PM_{10}.[18]

Most subjects in this study had a normal BMI (54.2%) with a median BMI of 22.2 kg/m2, the lowest BMI of 11.7 kg/m2, and the highest reached 68.[5] kg/m2. This value resembles the results of a study by Chu et al, which observed that patients with pneumonia due to $PM_{2.5}$ exposure had an average BMI of 23.19 kg/m^2.[17] Different results were seen in the study by Kaspersen et al, who found that obesity in women had a positive relationship with respiratory tract infections, including pneumonia.[5]

Patients with more than one comorbidity also dominated this study, accounting for 73% of all subjects. In this study, the most common comorbidities found included heart disease (320 patients), hypertension (245 patients), and type 2 diabetes mellitus (245 patients). Croft et al pointed out that an increase in $PM_{2.5}$ levels 1–7 days before admission was associated with an increase in the number of inpatient visits due to heart disease and ischemic stroke.[19] A similar meta-analysis by Kim et al found that an increase in $PM_{2.5}$ levels of 10 μg/m^3 was associated with an increased risk of admission due to respiratory tract infections and other cardiorespiratory diseases by up to 0.92% in the elderly ≥65 years.[18]

Most of the patients in this study were non-smokers (53.9%). However, of the 232 patients who were active smokers, the majority were heavy smokers, as many as 144 patients (61.2%). A previous study by Wang et al explained that exposure to air pollution in smokers was associated with a higher risk for pneumonia hospitalization rates than in those who were non-smokers. However, it wasn't clear whether there was a difference in risk between active smokers and ex-smokers.[3,4] Other studies have found that active smokers and passive smokers increase the risk of community pneumonia.[5]

The subjects of this study were dominated by patients who were unemployed (55.3%). This may be related to the age of the patients, who were mostly elderly (>56 years old) and had many comorbidities that made it difficult to do activities outside the house.

A study by Croft et al found an increase in visits to the emergency room due to negative culture pneumonia by 1–2% related to an increase in $PM_{2.5}$ concentration in the previous 1–7 days. In the next study, Croft et al stated that increased $PM_{2.5}$ concentrations were associated with an increase in air pollutant sources such as motor vehicle emissions and diesel emissions in the previous 0–3 days.[19]

Another study conducted by Scibor et al revealed that there was a strong and significant correlation between increased PM10 concentrations (R=0.78) and $PM_{2.5}$ (R=0.82) outdoors and indoors. The study mentioned that indoor air pollution increased simultaneously with outdoor pollution.[20] However, there is another method needed to assess indoor pollution, which is not the objective of this study. Blanc et al acknowledged that exposure to air pollutants in the workplace increased the risk of various respiratory diseases, including pneumonia, by 10%.[21]

The distance between the patient's house and AQMS DKI 4 Jakarta was measured using Google Maps. The median distance is 9.82 km, with the closest distance to AQMS being about 700 meters and the farthest being 19.9 km. A previous study by Habibi et al noted that there was a strong positive correlation between the rate of exacerbation of COPD in patients who lived within a distance of 0–10 km from the location of the AQMS, but it was not statistically significant.[9] This may be due to the fact that the level of air pollutants was only taken from one AQMS, which was in Lubang Buaya, so that there was no difference in air pollutant levels between distances of 0–10 km and 10–20 km. Based on the results of interviews with the Ministry of Environment and Forestry, the AQMS station in Jakarta was able to measure air pollutant levels up to a distance of 15–20 km.[10]

The number of inpatient visits in the rainy season (51.9%) was not much different from that in the dry season. This was different from the study conducted by Pirozzi et al, which found a significant relationship between $PM_{2.5}$ levels >12 µg/m^3 and NO_2 levels with pneumonia in winter. In the dry season, any increase in O_3 levels of 10 ppb in the previous 1–4 days increased the risk of pneumonia admission by 1.004.[22] Several studies suggest that the increase in the number of pneumonia visits during the rainy season was due to increased emissions from warming devices and decreased mucociliary clearance ability of the respiratory tract. However, other studies have also found that increases in air pollution levels are more noticeable in the dry season or the transition of seasons.[22]

Based on the 2023 Department of Environment, DKI Jakarta report, there was an increase in air pollutant levels in September and October, which was the transition period from dry season to rainy season. This happened due to an increase in the volume of vehicles during the rainy season and it depends on the intensity of rain. The increase in air pollutants, especially $PM_{2.5}$, occurred when there was no rain for several days.[23] A study by Chen et al explained that rain intensity might increase the concentration of air pollutants through the hygroscopic effect (humidity) and decrease the concentration through the washout process.[24] The highest monthly rain intensity in Lubang Buaya occurred in February and contributed to the overall decrease in the average level of air pollutants.[23]

The CAP severity in this study tended to be high, with a PSI score of 91–130 (46.1%). This might be influenced by the components of the PSI score, which include age, gender, and various comorbidities. A study by Safçi et al obtained that NO levels were negatively correlated with PSI scores (r=-0.199; *P*=0.01), while O3 levels were positively correlated with PSI scores (r=0.313; *P*=0.01).[25] This study analysis obtained a statistically significant positive correlation value on PM_{10} levels 7 days before admission (r=0.725; *P*=0.042). However, it should be noted that there were missing data on PM_{10} levels from May to August, so the value of the correlation is doubtful.

After multiple linear regression analysis, it was found that the correlation value was not significant. Yee et al conducted a meta-analysis stated that there was an increased risk of pneumonia admission by 0.4% (95% CI=0.2–0.4) for every increase in PM_{10} levels by 10 μg/m^3.[26] Chen et al conducted a study of *Pseudomonas aeruginosa* culture on human bronchial epithelial cell media exposed to PM with concentrations of 10, 50, 100, 200, and 400 μg/ml. Culture was carried out for 24 hours, and it was observed that there was a significant increase in bacterial colonization even in cells exposed to PM by 10 μg/ml compared to cells not exposed to PM. In the same study, it was found that there was damage to cell viability when exposed to PM with concentrations greater than 200 μg/ml.[27]

In this study, PM2.5 levels consistently showed a weak but statistically insignificant positive correlation. However, as visible from the results of multiple linear regression, it was found that $PM_{2.5}$ levels 7 days before admission were associated with an increase in the CAP hospitalization rates at Persahabatan Hospital. Similar results were obtained from a study by Pirozzi et al that showed a significant association between $PM_{2.5}$ levels >12 μg/m3 in the 4–5 days prior to admission and mortality.[22] Another study by Wu et al found that the risk of pneumonia admission increased with each increase in $PM_{2.5}$ levels by 10 μg/m^3 in the 0–2 days prior to admission.[14] A meta-analysis by Yee et al revealed that every increase in $PM_{2.5}$ levels by 10 μg/m^3 will increase the risk of pneumonia admission by 1.0% (95% CI=0.5–1.5).[26]

All the results of the SO_2 level analysis explained that there was no correlation between SO_2 levels and the rates of CAP hospitalizations. Different results were obtained from a meta-analysis by Yee et al, which acknowledged that there was an increase in the risk of pneumonia admission by 2.4% (95% CI=-2.0–7.1) for every increase in SO_2 levels of 10 ppb. Yee et al also noted that there was no significant difference between SO_2 exposure on the day of admission and 5 days before pneumonia admission.[26]

Another study by Li et al in China had a positive relationship between SO_2 exposure and the number of CAP outpatient visits. The study found an increase in odds ratio (OR) of 1.002–1.004 (95% CI=1.001–1.006), both on the day of the visit and 5 days before the visit.[28] Likewise, a study by Kaspersen et al in Denmark pointed out that SO_2 levels increased the risk of pneumonia, both caused by viruses and bacteria.[5]

The results of the CO level analysis also showed that there was no correlation between the average CO level and the rates of CAP hospitalizations. A meta-analysis by Yee et al obtained the opposite result; every 1 ppm increase in CO levels was associated with an increased risk of pneumonia admission by up to 4.2% (95% CI=0.6–7.9). This increased risk mainly occurs at 2 days and 5 days before admission. However, some studies that conducted sensitivity analysis stated that the relationship between CO levels and the number of pneumonia visits was not always statistically significant.[26] Another study by Li et al also noted that CO levels had a positive effect on the number of pneumonia outpatient visits, especially on the day of the visit, up to 2 days before the visit.[28] Kaspersen et al observed that the incidence of viral and bacterial pneumonia was associated with an increase in CO levels.[5]

According to the results of the correlation test in this study, there was no correlation between the average O_3 level and the rates of CAP inpatient visits. However, when linear regression analysis was performed, the results obtained pointed out that the average O_3 level in the month of admission had a statistically significant negative effect and was simultaneous with $PM_{2.5}$ levels on day 7 before admission.

It cannot be concluded that O_3 levels have a protective effect against CAP because many factors might affect these outcomes, such as confounding factors from the host or from the environment. Similar results were also obtained from the study by Zanobetti et al, O_3 levels were negatively related to pneumonia. Zanobetti mentioned that this could happen because indoor O_3 levels are usually very low, especially in winter when the ventilation is poor (e.g., closed windows), so exposure to air pollutants from outdoors would also be reduced.[29]

However, the results of other studies have found that increased O_3 levels actually increase the risk of pneumonia admission. One of them, a meta-analysis by Yee et al, acknowledged that, like other air pollutants, O_3 levels also increase the risk of pneumonia admission by 0.4% (95% CI=0–0.8) for every increase in O_3 levels by 10 ppb.[26] Another study by Safçi et al revealed that O_3 exposure was associated with an increase in PSI score (r=0.313) and the risk of death with an OR of 1.02 (95% CI=1.01–1.03) at 3 and 7 days before admission.[25]

In this study, no significant correlation was obtained between NO_2 levels and the rates of CAP hospitalizations. Similar results were observed from a study by Salimi et al, which also did not find a significant relationship between NO_2 levels and respiratory diseases, COPD, and pneumonia.[30] Different results were seen from a meta-analysis by Yee et al, which noted that every 10 ppb increase in NO_2 levels was associated with an increase in pneumonia admission by 4.2% (95% CI=0.6–7.9).[26] IT is also similar to the study of Kaspersen et al, which explained that NO_2 levels were associated with an increased incidence of pneumonia because they're more susceptible to bacterial and viral infections.[5]

LIMITATION

Some of the limitations of this study include that the study subjects only come from one hospital in East Jakarta, so the results of this study cannot be representative of the entire city of Jakarta. The large number of samples also increases the risk of selection bias due to missed selection of study subjects, errors in data entry, and errors in calculation or data analysis. Air pollutant data were only taken from one AQMS location and using API values, which were different from μg/m^3 that are broadly used in studies from other countries. In addition, there were reports that PM_{10} measuring devices were damaged from the end of April to early September, so that there was missing data on PM_{10} levels for those months. This might cause a risk of bias because there were some missing data, especially in the results of the PM_{10} level analysis. However, since this is the first study in Indonesia that aimed to find the association of air pollutant levels, including PM_{10}, with CAP, it could not be excluded from the analysis. Several confounding factors could affect air pollution levels in the environment, such as air temperature, humidity, precipitation, and wind direction and speed. Finally, there were no comparative data with other lung infectious diseases or with healthy subjects.

CONCLUSION

The average $PM_{2.5}$ level 7 days before admission had a simultaneous significant positive effect with the mean negative effect of the average O_3 level in the month of admission on the increase in CAP inpatient visits at Persahabatan Hospital in 2023. The highest levels of PM_{10} occurred in October (API=82.93, Moderate category), $PM_{2.5}$ in September (API=125.23, Unhealthy category), SO_2 in January (API=53.48, Moderate category), CO in May (API=25.70, Good category), O_3 in September (API=28.40, Good category), and NO_2 in November (API=20.40, Good category). The highest hospitalization rates of CAP in 2023 occurred in October, which was in line with the increase in $PM_{2.5}$ and O_3 levels that reached their peak in the previous month (September).

The demographic characteristics of the subjects in this study were mostly patients aged >56 years who had more than one comorbidity, high PSI scores between 91 and 130, and were unemployed. These factors might cause the results of the study to not be representative of the effects of outdoor air pollutant levels because most subjects might rarely engage in outdoor activity and rarely be exposed to outdoor air pollution.

It is necessary to develop a warning system from the Department of Environment, East Jakarta, to local health service facilities when there is a surge in air pollutant levels, especially $PM_{2.5}$ levels, if they reach API levels with unhealthy categories. It is necessary to conduct periodic education to the public regarding the impact of air pollutants on lung infections, especially CAP, as well as the importance of using personal protective equipment such as masks when there is a surge in air pollutant levels.

This study may be used as a reference for future research on populations that are routinely exposed to outdoor air pollution (office employees, hawkers, motor vehicle drivers, and so on), as well as collaborating with meteorology and environmental departments to determine the effects of environmental factors such as air temperature, humidity, rain intensity, wind speed, and direction.

REFERENCES

1. Perhimpunan Dokter Paru Indonesia. Pneumonia komunitas: Pedoman diagnosis dan penatalaksanaan di Indonesia. Jakarta: Perhimpunan Dokter Paru Indonesia; 2022. 4–64 p.
2. Perhimpunan Dokter Paru Indonesia. Pencegahan dan penanganan dampak kesehatan akibat polusi udara luar ruangan. Jakarta: Perhimpunan Dokter Paru Indonesia; 2019. 1–26 p.
3. Wang J, Li D, Ma Y, Tang L, Xie J, Hu Y, et al. Long-term exposure to ambient air pollutants and increased risk of pneumonia in the UK Biobank. Chest. 2023;164(1):39–52.
4. Sack C, Attia EF. What can big data teach us about air pollution and pneumonia? Chest. 2023;164(1):6–7.
5. Kaspersen KA, Antonsen S, Horsdal HT, Kjerulff B, Brandt J, Geels C, et al. Exposure to air pollution and risk of respiratory tract infections in the adult Danish population—a nationwide study. Clinical Microbiology and Infection. 2024;30(1):122–9.
6. 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.
7. IQAir. World's most polluted countries in 2023 PM2.5 Ranking [Internet]. 2023 [cited 2024 Feb 11]. Available from: https://www.iqair.com/world-most-polluted-cities
8. Solihah KI, Martono DN, Haryanto B. Analysis of spatial distribution of PM2.5 and human behavior on air pollution in Jakarta. In: IOP Conference Series: Earth and Environmental Science. 2021.
9. Habibi J, Susanto AD, Ratnawati. Hubungan kadar polutan udara di Jakarta Timur dengan angka eksaserbasi penyakit paru obstruksi kronik (PPOK) di Rumah Sakit Rujukan Respirasi Nasional (RSRRN) Persahabatan tahun 2019. [Jakarta]: Universitas Indonesia; 2021.
10. Andari F, Susanto AD, Wiyono WH. Hubungan polutan udara Jakarta Timur dengan angka kunjungan eksaserbasi asma di IGD Rumah Sakit Rujukan Respirasi Nasional (RSRRN) Persahabatan tahun 2019. [Jakarta]: Universitas Indonesia; 2021.
11. Zhang J, Ren D, Cao X, Wang T, Geng X, Li X, et al. Ambient air pollutants and hospital visits for pneumonia: A case-crossover study in Qingdao, China. BMC Public Health. 2021;21(1):66.
12. Liu S, Lim YH, Chen J, Strak M, Wolf K, Weinmayr G, et al. Long-term air pollution exposure and pneumonia-related mortality in a large pooled European cohort. Am J Respir Crit Care Med. 2022;205(12):1429–39.
13. Badan Pusat Statistik Provinsi DKI Jakarta. Provinsi DKI Jakarta dalam angka. Indonesia; 2024.
14. Wu J, Wu Y, Tian Y, Wu Y, Wang M, Wang X, et al. Association between ambient fine particulate matter and adult hospital admissions for pneumonia in Beijing, China. Atmos Environ. 2020;231:117497.
15. Silveyra P, Fuentes N, Rivera L. Understanding the intersection of environmental pollution, pneumonia, and inflammation: Does gender play a role? In: Chroneos Z, editor. Contemporary Topics of Pneumonia. London: IntechOpen; 2017. p. 1–34.

16. Indonesia. Peraturan Pemerintah (PP) nomor 45 tahun 2015 tentang penyelenggaraan program jaminan pensiun. 45 Indonesia; 2015.
17. Chu H, Xin J, Yuan Q, Zhang X, Pan W, Zeng X, et al. Evaluation of vulnerable PM2.5-exposure individuals: a repeated-measure study in an elderly population. Environmental Science and Pollution Research. 2018;25(12):11833–40.
18. Kim HJ, Lee HW, Park J, Lee CH, Lee CH. Short-term exposure to fine particulate matter and pneumonia-related hospitalizations: A systematic review and meta-analysis. Environmental Research Letters. 2019;15(12):123012.
19. Croft DP, Zhang W, Lin S, Thurston SW, Hopke PK, Van Wijngaarden E, et al. Associations between source-specific particulate matter and respiratory infections in New York State adults. Environ Sci Technol. 2020;54(2):975–84.
20. Scibor M, Balcerzak B, Galbarczyk A, Targosz N, Jasienska G. Are we safe inside? Indoor air quality in relation to outdoor concentration of PM10 and PM2.5 and to characteristics of homes. Sustain Cities Soc. 2019;48:101537.
21. Blanc PD, Redlich CA, Annesi-Maesano I, Balmes JR, Cummings KJ, Fishwick D, et al. The occupational burden of nonmalignant respiratory diseases an official American thoracic society and european respiratory society statement. Am J Respir Crit Care Med. 2019;199(11):1312–34.
22. Pirozzi CS, Jones BE, Van Derslice JA, Zhang Y, Paine R, Dean NC. Short-term air pollution and incident pneumonia a case-crossover study. Ann Am Thorac Soc. 2018;15(4):449–59.
23. Dinas Lingkungan Hidup Provinsi DKI Jakarta. Laporan akhir: Kajian pemantauan kualitas udara di Provinsi DKI Jakarta. Perdinan, Mustofa I, Sugiarto Y, Anwar M, Infrawan D, Aprilia S, et al., editors. Jakarta: Dinas Lingkungan Hidup Provinsi DKI Jakarta; 2023. 1–215 p.
24. Chen Z, Chen D, Zhao C, Kwan M po, Cai J, Zhuang Y, et al. Influence of meteorological conditions on PM2.5 concentrations across China: A review of methodology and mechanism. Environ Int. 2020;139:105558.
25. Safçi SB, Aybal E, Gungor O. Impact of air pollutants and meteorological parameters on severe pneumonia in older adults: A retrospective cohort study. Anti-Aging Eastern Europe. 2025;4(1):45–55.
26. Yee J, Cho YA, Yoo HJ, Yun H, Gwak HS. Short-term exposure to air pollution and hospital admission for pneumonia: A systematic review and meta-analysis. Environ Health. 2021;20(1):6.
27. Chen X, Liu J, Zhou J, Wang J, Chen C, Song Y, et al. Urban particulate matter (PM) suppresses airway antibacterial defence. Respir Res. 2018;19(1):5.
28. Li R, Jiang N, liu Q, Huang J, Guo X, Liu F, et al. Impact of air pollutants on outpatient visits for acute respiratory outcomes. Int J Environ Res Public Health. 2017;14(1):47.
29. Zanobetti A, Schwartz J. Air pollution and emergency admissions in Boston, MA. J Epidemiol Community Health (1978). 2006;60(10):890–5.
30. Salimi F, Morgan G, Rolfe M, Samoli E, Cowie CT, Hanigan I, et al. Long-term exposure to low concentrations of air pollutants and hospitalisation for respiratory diseases: A prospective cohort study in Australia. Environ Int. 2018;121(Pt 1):415–20.