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Association between $PM_{2.5}$ and PM_{10} with Acute Respiratory Infection in North and East Jakarta

Philomena Larasati Adilasari[1*], Onny Setiani[2], Mursid Raharjo[2]

[1] Master of Environmental Health, Universitas Diponegoro, Semarang, Indonesia
[2] Department of Environmental Health, Universitas Diponegoro, Semarang, Indonesia

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Corresponding Author:
Philomena Larasati Adilasari
larasadilasari29@gmail.com

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Abstract: The 2023 data showed that the highest daily average PM_{10} was recorded in DKI2 Kelapa Gading at 69 µg/m³. Acute Respiratory Infection (ARI) prevalence was high in Koja, Cilincing, Tanjung Priok, and Kelapa Gading districts. This study analyzed the association of $PM_{2.5}$ and PM_{10} to ARI incidence in Kelapa Gading, Koja, Tanjung Priok, Cilincing, Pulogadung, and Cakung. This analytical observational and spatial analysis study used particulate concentration data, sampled using Particle Counter HT-9600, meanwhile, ARI incidence data were taken from the sub-district health center. Particulate Matter sampled from all sub-districts, represented by one spot at 09.00-16.00 in each sub-district. Bivariate analysis used Spearman correlation and spatial autocorrelation. Kelapa Gading was the district that had the highest average particulate concentration. East Kelapa Gading and Pegangsaan Dua were the sub-districts with average particulate concentrations above the National Ambient Air Quality Standard. $PM_{2.5}$ were associated with the incidence of ARI ($p = 0.046$), while PM_{10} were not associated with the incidence of ARI ($p = 0.065$). $PM_{2.5}$ ($Z = 2.640$; $p = 0.008$; $I = 0.215$) and PM_{10} ($Z = 2.684$; $p = 0.007$; $I = 0.219$) had positive spatial autocorrelation and were cluster patterned, meaning that there were similar values in adjacent locations.

Keywords: Acute respiratory infection; PM_{10}; $PM_{2.5}$

Introduction

Air pollution remains an environmental problem with an estimated 6.7-7 million people dying from air pollution each year (Data, 2021). Air pollution-related deaths are mostly caused by fossil fuel combustion, including cardiovascular disease, respiratory disease and cancer. A total of 37% of deaths associated with outdoor air pollution factors are caused by ischemic heart disease and stroke, 18% by chronic lung disease, 23% by acute respiratory infections (lower respiratory tract), and 11% by respiratory cancer (WHO, 2022).

Acute Respiratory Infection (ARI) is an infection characterized by a cough accompanied by rapid and short breathing and can cause death (Dagne et al., 2020). ARI is highly contagious in vulnerable groups: infants, toddlers, and the elderly. ARI is included in the top 10 most common diseases in health facilities, such as rhinitis, influenza, and pneumonia (Direktorat Pencegahan Pengendalian Penyakit Menular, 2022). The latest data from the Directorate of Communicable Disease Prevention and Control of the Ministry of Health in 2023 stated that ARI cases trend in Indonesia from January to September 2023 was quite high, around 1.5-1.8 million cases nationally. Three provinces with the highest ARI cases were Central Java, West Java, and DKI Jakarta (Mediakom, 2024).

Average daily concentrations of PM_{10} and $PM_{2.5}$ in 2023 at all DKI Jakarta Ambient Air Quality Monitoring Stations had exceeded the WHO AQG values (the annual WHO AQG value for PM_{10} is 15 µg/m3 and for PM2.5 is 5 µg/m3). Data from five Ambient Air Quality Monitoring Stations in DKI Jakarta showed that the highest daily average of PM_{10} was recorded in DKI2

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Kelapa Gading at 69 µg/m3. DKI2 Kelapa Gading was once the area with the highest percentage of days with pollutant concentrations exceeding the 24-hour National Ambient Air Quality Standard value during 2023 for PM_{10} at around 40%. For $PM_{2.5}$ conditions, DKI2 Kelapa Gading has a daily average concentration of 36 µg/m3, seven times the WHO AQG standard (Turyanti et al., 2023).

Data from DKI Jakarta ARI data in 2023 and Indonesian Statistics Center population data (Badan Pusat Statistik Kota Jakarta Utara, 2024) that Koja district had the highest ARI prevalence in North Jakarta in 2023, at 28% (95,418 cases), followed by Cilincing district at 24% (106,729 cases), Tanjung Priok district at 21% (84,156 cases), and Kelapa Gading district at 18% (25,133 cases). These showed that the districts surrounding Kelapa Gading also had a high prevalence of ARI.

Districts directly adjacent to Kelapa Gading Sub-district: Koja, Tanjung Priok, Cilincing (North Jakarta area), Pulogadung, and Cakung (East Jakarta area) have facilities that potentially can emit air contaminants, such as industrial areas located in Cilincing and Cakung, also transportation facilities in Pulogadung, Cakung, and Tanjung Priok. The high concentration of PM_{10} in SPKUA DKI2 Kelapa Gading, industrial and transportation activities in the surrounding districts, and high ARI prevalence data in several districts around Kelapa Gading make it necessary to conduct further research that describes which locations potentially have higher particulate concentrations and analyzes the association between particulate concentrations, especially PM_{10} and $PM_{2.5}$ with the incidence of ARI in Kelapa Gading, Koja, Tanjung Priok, Cilincing, Pulogadung, and Cakung districts.

This study aimed to analyze statistically and spatially the association of $PM_{2.5}$ and PM_{10} to ARI incidence in Kelapa Gading, Koja, Tanjung Priok, Cilincing, Pulogadung, and Cakung districts.

Method

This study was an analytic observational study. $PM_{2.5}$ and PM_{10} concentration sampling points were the entire area of Kelapa Gading (146,701 residents), Koja (341,261 residents), Tanjung Priok (419,791 residents), Cilincing (453,521 residents), Pulogadung (309,037 residents), and Cakung Subdistrict (596,213 residents) represented by one spot at 09.00-16.00 in each sub-district. Samples were taken hourly. Sampling of $PM_{2.5}$ and PM_{10} concentrations used purposive sampling consists of industries, roads, and public places (based on the condition of the sub-district).

This study was conducted on September 3 - October 14, 2024. Particulate concentration was measured using Particle Counter HT-9600. The ARI data came from each sub-district urban health center. Spatial analysis using ArcGIS (mapping and Moran Index spatial autocorrelation analysis). Statistical analysis using SPSS with Spearman correlation analysis. This research had obtained ethical permission from the Health Research Ethics Commission of the Faculty of Public Health Universitas Diponegoro with number 353/EA/KEPK-FKM/2024.

Result and Discussion

From the $PM_{2.5}$ concentration distribution map, areas that had average $PM_{2.5}$ concentrations above the quality standard (55 µg/m^3) were West Kelapa Gading, East Kelapa Gading, Jatinegara Kaum, and South Rawa Badak. Meanwhile, majority of Cakung and Pulogadung areas were included in the moderate category. From the PM_{10} concentration distribution map, the area that had an average PM_{10} concentration above the quality standard (75 µg/m^3) was the East Kelapa Gading area, while most of the Kelapa Gading, Koja, Cakung, and Pulogadung areas were included in the moderate category.

The area with the highest average $PM_{2.5}$ concentration during the study was East Kelapa Gading sub-district (78 µg/m^3), while the area with the lowest average $PM_{2.5}$ concentration during the study was Sukapura sub-district (16 µg/m^3). The area with the highest average PM_{10} concentration during the study was East Kelapa Gading sub-district (90 µg/m^3), while the area with the lowest average PM_{10} concentration during the study was Sukapura sub-district (19 µg/m^3). Kelapa Gading district was the district with the highest average particulate concentration, and East Kelapa Gading and Pegangsaan Dua sub-districts were the sub-districts with average particulate concentrations above the National Ambient Air Quality Standard ($PM_{2.5}$: 55 µg/m^3, PM_{10}: 75 µg/m^3).

Table 1. Frequency Distribution

Variable	Minimum	Maximum	Mean	Median	Standard Deviation
$PM_{2.5}$	16	78	36	32	13.8
PM_{10}	19	90	42	37	15.7
ARI Incidence	491	11.342	2.754	1.586	3.061

The area with the highest total ARI prevalence in July-September 2024 was Pulogadung sub-district followed by Papanggo sub-district, while the area with the lowest total ARI prevalence in July-September 2024 was East Cakung sub-district followed by Warakas sub-district. Areas with a high prevalence of ARI, and high average particulate matter concentrations were West Kelapa Gading, Jatinegara, East Pisangan, and Cipinang sub-districts.

Table 2. Particulate Concentration Average and ARI Incidence

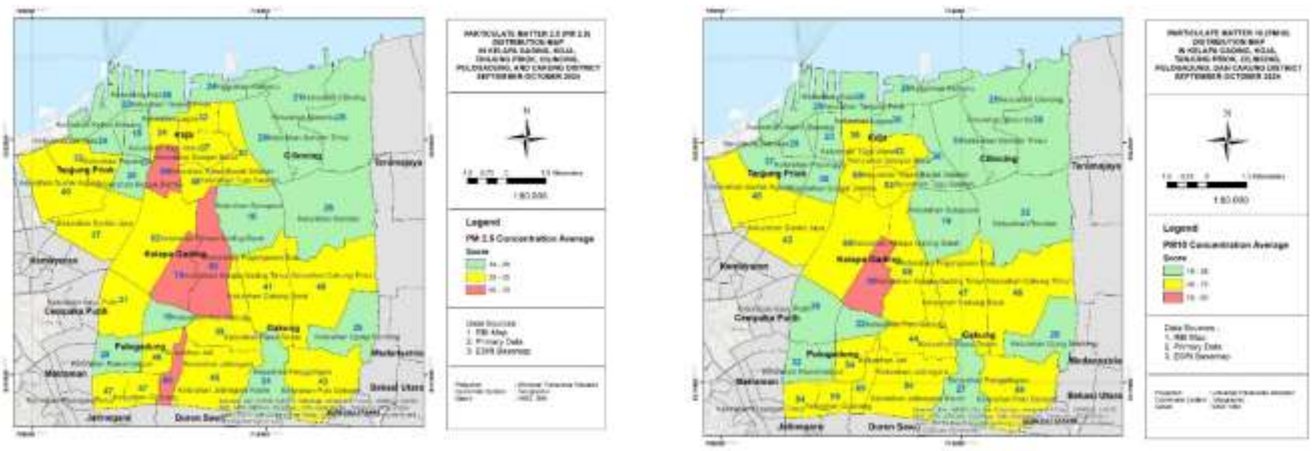
District	Sub-district	$PM_{2.5}$ Average (µg/m³)	PM_{10} Average (µg/m³)	ARI Cases	ARI Prevalence (%)
Kelapa Gading	Pegangsaan Dua	60	69	746	1.21
Kelapa Gading	East Kelapa Gading	78	90	510	1.27
Kelapa Gading	West Kelapa Gading	52	60	7.154	15.96
Koja	South Rawa Badak	58	65	931	1.69
Koja	South Tugu	46	53	906	1.74
Koja	North Tugu	37	42	1.028	1.17
Koja	Lagoa	32	36	817	1.23
Koja	North Rawa Badak	34	39	1.431	3.25
Koja	Koja	26	30	1.210	3.43
Tanjung Priok	Kebon Bawang	19	23	2.803	4.43
Tanjung Priok	Sunter Agung	40	45	2.767	3.13
Tanjung Priok	Sunter Jaya	37	42	2.407	2.99
Tanjung Priok	Papanggo	32	37	9.899	19.66
Tanjung Priok	Sungai Bambu	26	30	1.022	2.74
Tanjung Priok	Tanjung Priok	22	25	1.586	3.67
Tanjung Priok	Warakas	24	28	491	0.86
Cilincing	Cilincing	21	25	11.342	18.91
Cilincing	Sukapura	16	19	2.064	3.00
Cilincing	Marunda	25	30	2.561	6.34
Cilincing	Kalibaru	24	28	2.339	2.62
Cilincing	East Semper	28	34	1.211	2.58
Cilincing	Rorotan	26	32	2.083	3.51
Cilincing	West Semper	30	36	4.677	5.27
Pulogadung	Pulogadung	19	22	9.982	23.35
Pulogadung	Jati	46	54	747	1.88
Pulogadung	East Pisangan	47	54	2.085	4.11
Pulogadung	Rawamangun	28	32	1.587	3.45
Pulogadung	Kayu Putih	31	36	1.212	2.42
Pulogadung	Cipinang	47	55	1.705	3.54
Pulogadung	Jatinegara Kaum	60	69	795	2.53
Cakung	Jatinegara	45	54	11.162	10.34
Cakung	Penggilingan	24	27	3.657	2.73
Cakung	Pulogebang	43	49	2.943	2.28
Cakung	Ujung Menteng	26	29	868	2.15
Cakung	East Cakung	40	46	504	0.64
Cakung	West Cakung	41	47	1.521	2.02
Cakung	Rawaterate	39	44	1.154	3.73

Description:
ARI case data taken from July-September 2024 subdistrict health center data.
Average particulate concentration derived from 8 hours of measurement (09.00-16.00)

Table 3. Spearman Correlation Result

Variable	P Value	Correlation Coefficient	Description
$PM_{2.5}$	0.046	0.331	Associated
PM_{10}	0.065	0.306	Not associated

Among the two independent variables, only the $PM_{2.5}$ concentration variable was associated with the ARI incidence variable, with a weak association, so it can be said that $PM_{2.5}$ concentration can be a risk factor for ARI incidence. Meanwhile, in the result for spatial autocorrelation, $PM_{2.5}$ and PM_{10} concentrations had a positive spatial autocorrelation value, with a cluster pattern of particulate concentration data distribution.



(a) (b)

Figure 1. Mapp location observation: (a) $PM_{2.5}$ Distribution Map; and (b) PM_{10} Distribution Map.

Table 4. Spatial Autocorrelation Moran's I Test Result

Variable	Z score	P Value	Moran's I	Pattern	Spatial Autocorrelation
$PM_{2.5}$	2.640	0.008	0.215	Cluster	Positive
PM_{10}	2.684	0.007	0.219	Cluster	Positive

The research areas with industries are Cilincing district, such as Sukapura, Marunda, Rorotan, East Semper sub-districts (Kawasan Berikat Nusantara Marunda and Kawasan Berikat Nusantara Sukapura, as well as industries along the Cakung-Cilincing road), Cakung district in Rawaterate, Jatinegara, and East Cakung sub-districts (Jakarta Industrial Estate Pulogadung and industries in the East Cakung area), and Koja sub-district in Koja district (Pertamina Lubricants and Bogasari). Interestingly, not all areas with large industries had high average particulate matter concentrations. The average concentrations of $PM_{2.5}$ and PM_{10} in Kawasan Berikat Nusantara Sukapura were very low, at 16 and 19 $\mu g/m^3$. Meanwhile, the average concentrations of $PM_{2.5}$ and PM_{10} in Kawasan Berikat Nusantara Marunda, Rorotan, and East Semper sub-districts were only around 24-30 $\mu g/m^3$. The average concentrations of $PM_{2.5}$ and PM_{10} in Jatinegara and Rawaterate sub-districts, which are close to the Jakarta Industrial Estate Pulogadung, were quite high, at 39-54 $\mu g/m^3$. Meanwhile, the average concentrations of $PM_{2.5}$ and PM_{10} in the East Cakung area were 40 and 46 $\mu g/m^3$.

Another interesting finding was the high average $PM_{2.5}$ and PM_{10} concentrations in non-industrial areas, such as Kelapa Gading district, Pulogadung district, and the majority of Koja district. Kelapa Gading district, in all three sub-districts, had a high average concentration of $PM_{2.5}$ and PM_{10}, with $PM_{2.5}$ ranging from 52-78 $\mu g/m^3$, while for PM_{10} ranging from 60-90 $\mu g/m^3$, where these averages were close to, and even exceed the national quality standards.

The results of this study stated that there was an association between $PM_{2.5}$ and ARI incidence, meaning that the higher the concentration of $PM_{2.5}$ in an area, the more ARI incidence that occurs in that area. However, the correlation coefficient is 0.331, which means it's weakly associated. This finding indicated that there was still an increase in the incidence of ARI in high average $PM_{2.5}$ concentrations areas, although it's not very significant. Meanwhile, PM_{10} concentration was not associated with ARI incidence according to this study. This means that PM_{10} concentration was not a risk factor for ARI incidence.

The results of this study are in line with a study from Taiwan, that stated $PM_{2.5}$ concentration had a significant positive effect on the rate of hospital visits for respiratory illnesses. Specifically, every 1 $\mu g/m^3$ increase in $PM_{2.5}$ concentration would lead to a 1.316 increase (i.e., e0.84 - 1 = 1.316) in the odds ratio of hospital visit rates for respiratory illness (controlling for other variables) (Wang et al., 2021). In South Korea, an increase in $PM_{2.5}$ concentration was associated with an increase in acute lower respiratory tract infection hospitalizations for South Korean children by 1.20% (95% CI: 0.71, 1.71) (Oh et al., 2021). Fine particles of $PM_{2.5}$ settle on the surface of the bronchi and alveoli before being internalized into lung cells such as epithelial cells and alveolar macrophages. After that, $PM_{2.5}$ will trigger oxidative stress and interfere with the normal function of cells or may even induce apoptosis through different mechanisms, such as autophagy, and then induce an inflammatory response, which plays a major role in respiratory damage (Thangavel et al., 2022).

$PM_{2.5}$ is sourced from motor vehicles, power plants, industries, home stoves/wood fires, firework smoke, and cigarette smoke (Mustafa et al., 2023). Areas that do not have industrial areas but have high average $PM_{2.5}$ concentrations indicate that the PM concentrations come from motor vehicles that are busy passing by. Kelapa Gading district is adjacent to several toll roads and is dominated by large and heavily traveled roads, resulting in frequent traffic jams. Meanwhile, PM_{10} comes from dust at construction sites, landfills and agriculture, forest fires and burning bushes/garbage, industrial sources, wind-blown dust from open land, pollen, and bacterial debris (Board, 2024). The concentration of PM_{10} in the medium to high category in Cakung District can be said to come from smoke from industrial activities.

Regarding PM_{10} concentrations and the incidence of ARI, the results of this study were not in line with existing theories because PM_{10} exposure is associated with the formation of Reactive Oxygen Species (ROS), cytotoxicity, inflammation, and DNA damage, resulting in neutrophil recruitment and changes in endothelial permeability. PM_{10} also modulates the innate immune system and several genes associated with metabolic pathways, resulting in susceptibility to various pathogens and promoting infection and replication of pathogens (Loaiza-Ceballos et al., 2022). An increase in PM_{10} concentration of 10 g/m^3 was associated with an 8% (95% CI 1%-15%) and 20% (95% CI 4%-38%) increase in the likelihood of a GP visit for ARI within 24 hours for women and girls, and Māori of both sexes (Gurney et al., 2022). Another study stated that PM_{10} was positively associated with respiratory disease hospitalization within a 30-day lag under various lag patterns, with lag 25 showing the strongest association (RR = 1.001742, CI 1.001029, 1.002456). Females were more likely than males to be hospitalized due to PM_{10} exposure (Zulkifli et al., 2024).

Exposure to industrial air pollutants (total particle pollution) was associated with mortality from respiratory diseases in children under one year of age (Genowska et al., 2023). Industrially generated particulate concentrations come from particle-bound heavy metals in power plants, mining, smelters, and chemical plants (Potter et al., 2021). Particles generated by industry include Zn, Mn, Pb, Cu, V, As, Ni, Cd, and Hg. Coal combustions, motor vehicle emissions, and mining activities increase Mn, As, and Ni in atmospheric particulates. Mining activities can produce mineral dust blown into the atmosphere by the wind (Ou et al., 2022). In a study of the brick industry in Nganjuk, East Java, $PM_{2.5}$ particles came from the fuel used to burn bricks, such as corn cobs, rice hulls, firewood, and sawdust (Ridayanti et al., 2022). Toxic air pollutants can cause respiratory and immune system problems, reduced health performance, bronchitis, asthma, changes in heart rate, and increased risk of lung cancer (Mohammadi et al., 2022). It was proven in the brick industry, that $PM_{2.5}$ of 72.3 lg/m^3 (95% CI: 10.2, 134.3) carries 2.2 times greater odds of suffering from COPD in adults over 40 years old and 4.2 times (95% CI: 2.7, 6.8) greater in adults over 18 years old (Brooks et al., 2023).

Air pollutants in urban (non-industrial) areas can come from fumes from moving vehicles. Particulates found on roadways include Zn, Mn, and Pb. Zn comes from motor vehicle exhaust, tire, and brake wear, while Mn comes from anti-knock ingredients in gasoline and airborne dust (Ou et al., 2022). Studies in Portugal showed that the concentration of air pollutants to which urban residents were exposed significantly depends on the mode of transportation. The average concentration of $PM_{2.5}$ in vehicles (cars and buses) was lower than in the ambient air, suggesting that vehicle cabins may provide a protective effect (Martins et al., 2021). In the 21st century, particulate matter in outdoor air is dominated by primary carbonaceous matter from road traffic and secondary pollutants, namely ammonium salts and secondary organic carbon. Diesel engines produce particles primarily composed of carbon. As exhaust emissions cool in the exhaust manifold and associated piping, carbon particles agglomerate, forming a high-surface-area material into which unburned and partially burned gaseous products are adsorbed, as well as sulfur oxides and nitrogen oxides (NOx) formed during high-temperature combustion in the cylinder. Organic carbon particulates are also formed in the atmosphere through complex chemical pathways from organic compounds of emitted gases (Bessagnet et al., 2022).

In a study analyzing $PM_{2.5}$ patterns in Jakarta in 2016-2019, it was stated that the annual average $PM_{2.5}$ concentration ranged from 1.2 - 156.1 μg/m^3. $PM_{2.5}$ concentrations increased from night to morning and decreased from afternoon to evening. The increased number of motorized vehicles contributes highly to $PM_{2.5}$ concentrations in Jakarta (Hutauruk et al., 2020). Another study that analyzed $PM_{2.5}$ and PM_{10} at the Bundaran HI Monitoring Station in Central Jakarta in February-October 2021 stated that the highest daily distribution pattern of $PM_{2.5}$ was Sunday, while the highest daily distribution pattern of PM_{10} was Friday. For monthly distribution patterns, both were highest in July. The increasing concentrations of $PM_{2.5}$ and PM_{10} were related to the number of vehicles, congestion, and speed of vehicles passing through the road. Particulate matter on Jakarta's roads is mostly generated by gasoline and diesel as vehicle fuel (Perdana et al., 2023). Vehicle exhaust produces mostly black carbon particles and organic compounds, while non-exhaust emissions consist mostly of brake dust abrasion particles, tire dust, road surface abrasion particles, and suspended road surface dust (Harrison, 2020).

This study also examined spatiality through Moran's autocorrelation, which indicates the similarity of a geographic unit about its neighbors. A positive value of Moran's I indicate that the feature is surrounded by features with similar values. This feature is part of the cluster (Jaber et al., 2022). The results of this study are in line with the existing theory, that particulate concentrations have a positive autocorrelation and the distribution pattern is to form clusters. It can be seen that the areas in the yellow (medium) and green (low) pollutant zones are clustered with the areas to their left and right. This means that if the particulate concentration in one area is at a moderate level, the adjacent areas are also at a moderate level. This can be seen in the PM_{10} distribution map in Cakung, Pulogadung, Kelapa Gading, and Koja districts. Likewise, areas with particulate matter concentration levels in the red zone (high) can be seen on the PM_{10} distribution map that is clustered in Kelapa Gading district.

The results of this study were in line with research in South Korea that the annual average concentration index of $PM_{2.5}$ and PM_{10} is 0.37, which indicates a significant level of positive spatial autocorrelation. The level of spatial autocorrelation was higher in spring and winter, while low in summer. In all seasons, except summer, and annual average results, cluster types with generally the same shape were found between $PM_{2.5}$ and PM_{10} (Mun et al., 2022). The study in China also produced similar findings, that there was a positive spatial autocorrelation in $PM_{2.5}$ concentrations, and the global Moran's I values were all significantly positive. Cities with high annual average $PM_{2.5}$ levels were close to other cities with high $PM_{2.5}$ levels, the same applies to low annual average levels (Wang et al., 2022).

Conclusion

$PM_{2.5}$ concentration was a risk factor for ARI, while PM_{10} concentration was not a risk factor for ARI in Kelapa Gading, Koja, Tanjung Priok, Cilincing, Pulogadung, and Cakung districts. The distribution pattern of particulate matter concentration in Kelapa Gading, Koja, Tanjung Priok, Cilincing, Pulogadung, and Cakung districts is clustered, meaning that there is a similarity of index values in the surrounding areas.

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Conflicts of Interest

The authors have no conflicts of interest during the study and the writing of this article.

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