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Association between Sulfur-dioxide and Nitrogen-dioxide levels with Acute Respiratory Infections during Covid-19 Pandemic in Cilacap Regency

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Abstract
Introduction: Restrictions on human mobility and industrial activities during the COVID-19 pandemic temporarily improved air quality in many regions, including Indonesia. Cilacap Regency, an industrial area with high traffic density, provides a relevant setting to examine the relationship between air pollutants and respiratory health outcomes.
Methods: This ecological time-series study used secondary data from 2019–2022 obtained from the Cilacap Environmental Bureau and Health Office. The study analyzed trends in sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) concentrations and their association with Acute Respiratory Infection (ARI) incidence using Pearson correlation analysis.
Results: SO_2 and NO_2 concentrations declined during the mobility restriction period in 2020 and increased again in 2021–2022. Similarly, ARI cases decreased in 2020 and rose to 147,198 cases in 2022. Pearson correlation analysis showed no statistically significant association between pollutant levels and ARI incidence ($p = 0.458$).
Conclusion: The findings suggest that SO_2 and NO_2 concentrations were not significantly associated with ARI incidence during the study period. However, limited monitoring frequency and the absence of other key pollutants may have affected the results. Improved air quality monitoring and inclusion of additional environmental variables are recommended to better understand the relationship between air pollution and respiratory health.

Keywords: Acute Respiratory Infections (ARI), air quality, Sulfur dioxide, Nitrogen dioxide, COVID-19, air pollutant.

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Introduction

Air pollution is an important environmental factor affecting respiratory health. Lung function may be worsened, and the risk of Acute Respiratory Infections (ARI) may be elevated due to exposure to fine particles, toxic gases, and reactive chemical products in the air. This is a problem in parts of Indonesia that are rapidly industrializing. Cilacap Regency represents such a context because it is home to many factories, heavy traffic, and a large population. In Central Java, motor vehicle production in Cilacap in 2020 was the second-highest at 818,330 units. The continuing rise in vehicles would lead to fluctuations in SO_2 and NO_2 concentrations, reducing the local Air Quality Index from 82.79 (2018) to 80.09 (2021). The average vehicle growth since 2018 was 2.3% per annum.

The burden of respiratory disease in Cilacap is considerable and enduring. At the top right, ARI remains a dominant public health problem with 60,898 cases in 2022. Environmental influences such as industrial development, population growth, and mobility contribute to the intensification of potential pollutant exposures. Thus, it is essential to investigate whether there are consistent trends in air quality over a long period and the related burden of ARI to guide public health interventions.

The COVID-19 pandemic introduced a new dimension to the association between air pollution and respiratory outcomes, as the disease affects the respiratory system and can worsen the condition of lungs exposed to air pollutants. In the early phases of the pandemic, surveillance and other restrictive patterns of public life and industrial activity led to modifications in emissions patterns which were reported worldwide studies including from Wuhan[1] , Baghdad[2], Northwest US cities[3], the United States[4], the United Kingdom[5], four world cities[6], and Dhaka.[7] Data show that COVID-19 infection results in more severe and fatal cases following exposure to particulate matter at high concentrations. Concentrations of SO2, NO2, and respiratory symptoms were also interrelated, suggesting the need to continuously monitor pollutants both during and after the pandemic.

Many Indonesian studies that compared pre- and post-lockdown conditions failed to account for seasonal variation, making the results difficult to interpret. Comparisons between consecutive years for the same months provide better seasonal adjustment. To the best of our knowledge, there has been no previous research in Cilacap that combined an analysis of air quality over a year (2019–2022) with data on ARI incidence. Furthermore, focusing only on SO_2 and NO_2 levels limits the potential to examine the impact of other pollutants that may also be pertinent to the respiratory system. [7]

This study aimed to fill gaps by analysing and comparing SO_2 and NO_2 concentrations before, during, and after the pandemic, and by investigating their statistical association with ARI cases in Cilacap over the period 2019-2022. The results will contribute to evidence-based environmental epidemiology in Indonesia and to recommendations for the development of a regional air quality monitoring system, as well as for pollution control and respiratory disease prevention policies in the industrial area.[8]

One of the key contributions of the study includes a yearly air quality comparison to mitigate seasonal bias, which provides more robust estimates of the change in SO_2 and NO_2 concentrations; an assessment of weaknesses within the local monitoring system in Cilacap to facilitate the enhancement of pollutant coverage and quality of measurement; and the combination of the yearly air quality pattern with ARI data to derive insights on the linkage between environmental exposure and respiratory susceptibility during and post-pandemic.

Method

This study employed an observational analytical design using a retrospective ex post facto approach based on secondary data. The study is more specifically categorized as an ecological study, as it analyzes aggregated data on air quality indicators and Acute Respiratory

Infection (ARI) incidence at the population level in Cilacap Regency from 2019 to 2022. No experimental manipulation or intervention was conducted, and all variables had already occurred prior to analysis.[9]

Air quality monitoring was conducted at four representative sites (sites nos. 1, 5, 6, and 7) located in residential, transportation, office, and industrial areas. To reflect real community exposure, the data were adjusted for site location, traffic intensity, and other industrial sources of emissions. Monthly SO_2 and NO_2 levels were determined by manual active sampling with a 1-hour exposure time per sampling event, as specified in the Environmental Agency's guidelines. Standardization procedures ensured data integrity and enabled accurate comparisons across years [10].[10]

The choice of SO_2 and NO_2 as indicators is based on local monitoring practice, which considers only these two parameters on a routine basis. Both are combustion-related pollutants that are strongly associated with vehicle emissions, industrial processes, and the burning of fossil fuels. Other respiratory-related parameters, such as $PM_{2.5}$, PM_{10}, CO, and O_3, are not routinely monitored by Cilacap; therefore, analysis could be confined to the available parameters. However, the pandemic period can be analyzed for pollutant trends using available data.[11]

The monitoring activities were carried out in accordance with the technical guidance issued by the Ministry of Environment and Forest via Circular Letter Number S.318/PPKL-SET/REN.0/12/2020 concerning the Application of the Methodology to Calculate the Environmental Quality Index for the year 2020 – 2024. The pollutant concentrations were converted into index values, with the ambient air quality standards referring to the National Ambient Air Quality Standards (NAAQS) as regulated in Government Regulation No. 22 of 2021. The calculations of the index are:

The NO_2 index is given by

$IPNO_2 = (-0.2 \times (0.177 \times NO_2 \text{ concentration})) + 100$

The SO_2 index is given by

$IPSO_2 = (-0.2 \times (0.625 \times SO_2 \text{ concentration})) + 100$

These index values, expressed on a 0–100 scale, provide standardized representations of pollutant levels and facilitate interannual comparison. The Integrated Exposure Unit (IEU) was calculated using equal weighting between the two indices:

IEU = 50% SO_2 index + 50% NO_2 index

This methodological description ensures transparency in transforming concentration data into comparable indicators and supports the interpretation of the relationship between air quality and ARI incidence.[12]

Table 1. Air Quality Index (AQI)

Air Quality Index					
Very good			x	>	90
Good	70	<	x	≤	90
Enough	50	≤	x	≤	70
Less	30	≤	x	<	50
Very Less			x	<	30

Source: Environmental Agency of Cilacap Regency

Data analysis began with a descriptive assessment of ambient air quality trends, including temporal pattern characterization, central tendency and dispersion of observations, and detection of anomalous behaviour and seasonal variation in pollutant index values. This stage provided a quantitative perspective on year-to-year and pandemic-wide variations in SO_2 and NO_2 concentrations.

Subsequently, linear correlation analyses were conducted to evaluate temporal correlations with the dynamics during the COVID-19 phase. These were tests measuring the strength and direction of correlations between time-series pollutant indices and change indicators, such as community mobility, levels of industrial activity, and other observed environmental conditions. In practice, linear correlation coefficients (such as Pearson) can be used to quantify these relationships and test their significance.[13]

It is important to acknowledge that, in ecological and environmental epidemiology studies, the use of aggregated data and linear correlation methods may not always capture complex, non-linear relationships between pollutant

exposure and health outcomes. Previous methodological literature has highlighted that variations in exposure assessment, temporal resolution, and statistical modelling approaches can lead to heterogeneous and sometimes non-significant findings across studies.[14] Therefore, the selection of Pearson correlation in this study is intended as an initial exploratory approach rather than a definitive causal model, and its limitations in detecting subtle or lagged associations are recognized.[15]

The descriptive and correlational analyses together facilitated the detection of changes in SO_2 and NO_2 concentrations that were consistent with changes in social and economic activities during the pandemic. Descriptive results provided temporal context and baseline patterns, and correlational analysis examined whether fluctuations in pollutant indices statistically paralleled the implementation of mobility restriction policies, changes in industrial production, and other environmental changes. Overall, these approaches provided a more robust interpretation of pollutant dynamics over the study period, facilitating more informed speculation about the associations between air quality and changing environmental conditions during the COVID-19 pandemic.[16]

Result And Discussion

Table 2 shows an increasing trend in ARI cases among individuals aged 5 and older, with the exception of a decrease from 92,015 cases in 2019 to 65,235 cases in 2020. The number of ARI cases, both in adults and toddlers, varies annually, as data from the Cilacap Regency Health Office makes clear. In 2019, there were 92,015 ARI cases in people five years of age or older and 52,589 in children under five. The numbers for toddlers and those aged five and older decreased to 33,066 and 65,235, respectively, in 2020. Subsequently, the cases increased in 2021 and reached a peak in 2022, with a total of 147,198 cases (consisting of 40,413 toddlers and 106,785 individuals aged 5 and older).

From January 1 to December 3, 2022. This figure is consistent with the prediction that social disruption and altered patterns of interaction during the COVID-19 pandemic increased population susceptibility to respiratory Illness. Changing patterns of respiratory infections have been seen again, as disease incidence shifted during the COVID-19 pandemic due to lockdowns and social distancing, which slowed down pathogen circulation and the development of immunity.[17] The high rate of ARI highlights the importance of further study of environmental and behavioural determinants of transmission during pandemic and post-pandemic periods. Changes in air quality due to pandemic dynamics are related to a study by Setyowati et al. (2021), which suggests that changes in daily routine influence pollutant concentrations. Weather factors, such as rainfall and relative humidity, may prolong the survival of respiratory pathogens in the air, increasing the likelihood of transmission. Hence, climatic variability needs to be considered a key covariate when investigating ARI variation. Pollutant monitoring in Cilacap so far has been limited to SO_2 and NO_2. Ambient air quality measurements were taken at 46 monitoring sites (24 in the first semester and 22 in the second) in 2019. In 2020, logistical constraints due to the pandemic reduced the number of monitoring sites from 46 to 30, with consequences for data completeness and interpretation of air quality trends (Figure 1).

Analysis of Figure 2 suggests that the ambient air concentration of nitrogen dioxide (NO_2) was consistently lower than that of sulfur dioxide (SO_2), although the concentration of NO_2 was relatively high in 2019. The pre-pandemic period was a time of regular travel, business, and population movement, drawing increasing amounts of pollution from each of those vectors. The mobility restrictions instituted because of the pandemic led to decreases in both pollutants, resulting in a temporary improvement in air quality.

Emission-wise, SO_2 is generally considered a by-product of the combustion of sulfur-containing fuels in commercial and industrial boilers and in diesel engines.

At the same time, NO_2 is mainly emitted by gasoline-powered internal combustion engines. This implies that changes in SO_2 and NO_2 concentrations reflect changes in anthropogenic activity patterns and fuel types. Therefore, the decrease observed during the mobility restrictions and the subsequent increase following their relaxation are in line with the profiles of these emissions. These findings are consistent with the report by Y. Wang et al. (2020) and field studies in Chinese industrial areas, which showed about 50% lower NO_2 and approximately 30% less SO_2 during the early 2020 lockdown, as a result of curtailed manufacturing and automotive operations.[18] (Figure 2)

The interpretation of Figure 3 shows that transport was also a significant source of SO_2 and NO_2 levels in 2022. The concentrations were 9.116 µg / Nm³ for SO_2 and 10.823 µg / Nm³ for NO_2. These values do not exceed the limit stipulated in the Government Regulation No. 22 of 2021 regarding the Control of Air Pollution. The number of motorized vehicles in Cilacap reached 818,330 units in 2020 and has continued to increase annually since then. This situation reflects a firm reliance on private transport due to poor public transit development. In addition, the high inflow of traffic from neighbouring regions exacerbates the local emission load, and so vigilant monitoring is required to avoid a dramatic upsurge in pollutant exposure. Those emission profiles have immediate air-quality consequences and respiratory-health significance for the exposed population. In the public health point of view, contact with air pollutants can increase the risk of respiratory infections and consequent diseases. Rendana and Komariah (2021) reported a strong positive association between concentrations of SO_2, CO, and $PM_{2.5}$ and COVID-19 cases, suggesting that exposure to pollutants can amplify community susceptibility, particularly in areas with high levels of industrialization. The burden of Acute Respiratory Infection is also associated with air pollution, as particulate and gaseous pollutants can compromise respiratory defences and facilitate pathogen invasion. People with a recent history of febrile illness or ILI symptoms are also considered at higher risk of having COVID-19, as certain coronaviruses cause upper respiratory tract infections (Ministry of Home Affairs Team, 2021). These opinions are feverishly cited above in the mandates. Earlier studies have also suggested that SO_2 exposure is a risk factor for ARI.[19]

Figure 4 shows that the Air Pollutant Standard Index (APSI) in Cilacap Regency was relatively stable (around 80) from 2018 to 2021, with some degradation observed during the pandemic. Several stations reported results below 70, such as Kawunganten T-junction, Karangkandri PLTU north site, Jeruklegi, and Kroya landfill site. However, the overall AQI remained "Good" despite these fluctuations.[20]

Air quality monitoring in 2021 was conducted at 44 sites in crowded residential areas, areas influenced by transportation, industrial areas, and commercial and administrative areas, as shown in Figure 1. The monitoring focused on gaseous pollutants (SO_2 and NO_2), which are representative of emissions from industry and traffic. The lack of dust ($PM_{2.5}$ and PM_{10}), ozone (O_3), and carbon monoxide (CO) affects the quality of air analysis.

The scatter plot in Figure 2 presents the relationship between AQI values and the total number of ARI cases. From the figure, the data points appear to be widely dispersed, and the coefficient of determination (R^2 = 0.1896) is relatively low. This is consistent with the Pearson correlation result shown in Table 3 (p = 0.458), which indicates that the relationship is not statistically significant. Although in 2022 the number of ARI cases reached its highest value (147,198) along with a higher AQI (94.51), the overall pattern does not show a clear linear trend. This suggests that the variation in AQI is not strongly associated with changes in ARI cases during the study period.[21]

Based on Table 3, the Pearson correlation test indicates that there is no statistically significant relationship between SO_2 and NO_2 concentrations and the incidence of ARI during the 2019–2022 period (p = 0.458). Since the p-value exceeds the significance level of 0.05, the

null hypothesis cannot be rejected. This suggests that changes in ARI cases over time do not show a clear linear relationship with the measured pollutant concentrations. In other words, the variation in ARI incidence observed in this study does not appear to be consistently associated with the levels of ambient SO_2 and NO_2 recorded at the monitoring locations. Therefore, these pollutants cannot be considered strong independent predictors of ARI incidence in Cilacap Regency during the study period.

The lack of statistical significance observed in this study (p = 0.458) does not necessarily indicate the absence of an environmental impact on public health; rather, it primarily reflects the poor temporal resolution of the current monitoring protocol in Cilacap Regency. The manual active sampling, conducted only once per semester (bi-annually) for a duration of one hour, is fundamentally inadequate to capture the daily dynamics and transient spikes in pollutant concentrations associated with shifts in community mobility and industrial routines. This infrequent sampling induces a 'smoothing effect' on the dataset, where extreme values are averaged out, thereby drastically reducing the statistical power required to detect meaningful associations between ambient exposure and ARI incidence. Consequently, the observed non-significance is a methodological artifact rather than a definitive conclusion on the relationship between air quality and respiratory health in the region.

Theoretically, SO_2 and NO_2 remain significant determinants of chronic exposure that heighten respiratory vulnerability, SO_2 is recognized for inducing bronchoconstriction and hindering mucociliary clearance, while NO_2 stimulates epithelial cell inflammation and compromises innate immunological defence mechanisms. Established epidemiological literature maintains that ambient pollutant exposure is closely linked to respiratory infection risks when supported by high-resolution temporal data.[22] Recent findings from China further suggest that short-term NO_2 exposure can induce direct oxidative stress in respiratory epithelial cells, thereby increasing susceptibility to both viral and bacterial pathogens.[23]

The methodological constraints of this study, where monitoring data was collected only every six months, precluded the application of more sophisticated statistical techniques, such as time-series modelling, generalized additive models, or multivariable regression. These advanced methods are necessary to account for non-linearity, lag times, and cumulative exposure effects, which Pearson correlation cannot facilitate. Furthermore, the investigation was limited to SO_2 and NO_2 due to data availability. The absence of other critical pollutants (e.g., $PM_{2.5}$, PM_{10}, CO, and O_3) and local environmental variables (e.g., humidity and population density) acts as a significant confounding factor that may obscure the validity of the exposure assessment.[24]

In conclusion, these findings emphasize that the prevailing bi-annual manual sampling protocol is insufficient for a comprehensive public health risk assessment in an industrial corridor like Cilacap. Future research must prioritize a transition toward continuous, real-time automated monitoring systems. The availability of such high-fidelity data is vital for effectively adjusting for the complex interplay between pollutant exposure and respiratory health responses, ultimately providing a more precise empirical foundation for environmental health policy formulation.

Table 2. Number of ARI Cases among in Cilacap Regency, 2019–2022

No.	Year	ARI in Toddlers (0–5 Years)			ARI in Individuals Aged >5 Years		
		M	F	TOTAL	M	F	TOTAL
1.	2019	26,686	25,903	52,589	42,497	49,518	92,015
2.	2020	16,768	16,298	33,066	30,327	34,908	65,235
3.	2021	20,029	19,761	39,790	49,158	51,416	100,574
4.	2022	19,946	20,467	40,413	50,489	56,296	106,785

Source: Cilacap Regency Health Office

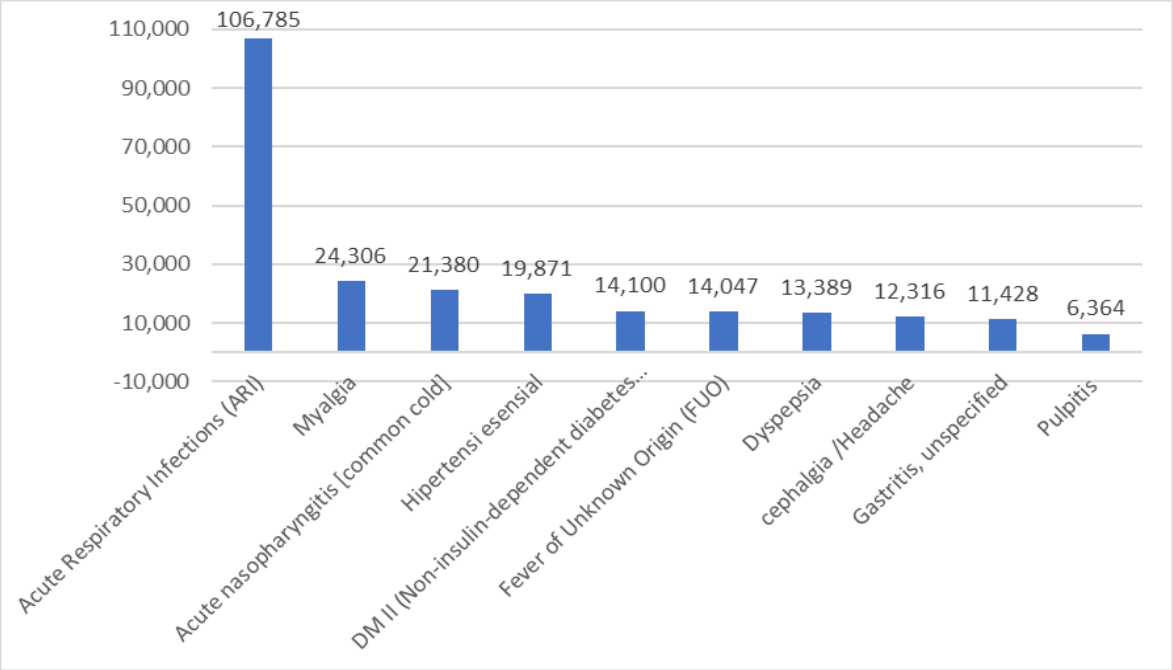

Figure 1. Top 10 Diseases (in Number of Cases) Reported at Health Centers in Cilacap Regency, 2022
Source: Cilacap Regency Health Office

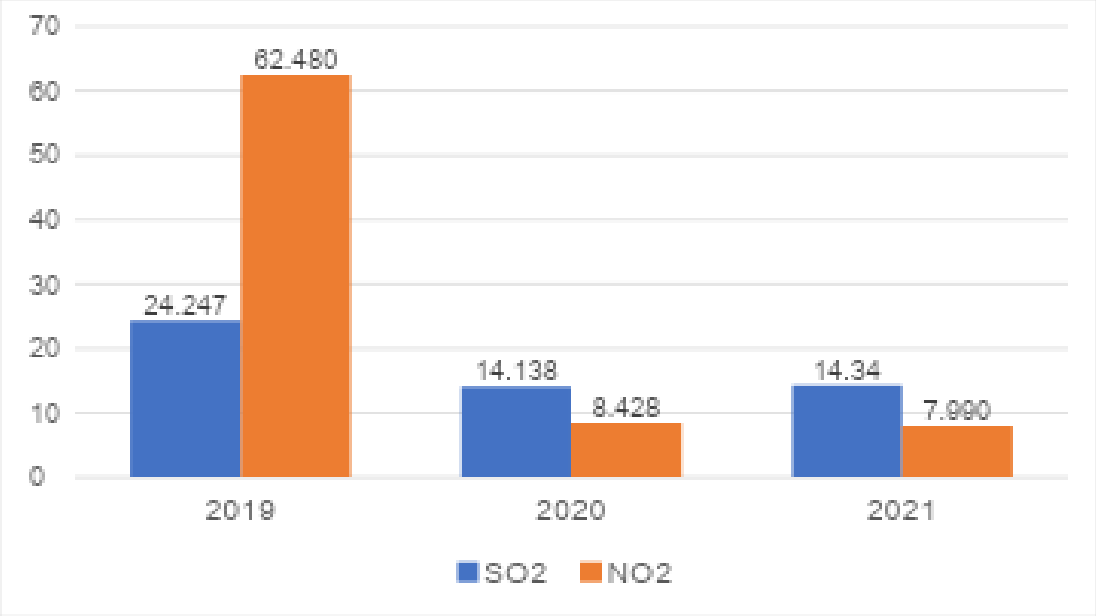

Figure 2. Sulfur Dioxide (SO_2) and Nitrogen Dioxide (NO_2) Concentration Levels in Cilacap Regency, 2019–2021 (µg/Nm³)
Note: The National Ambient Air Quality Standards (NAB) are 150 µg/Nm³ for 1-hour limits of SO_2 and 200 µg/Nm³ for 1-hour NO_2 (PP No. 22/2021)
Source: Environmental Agency of Cilacap Regency

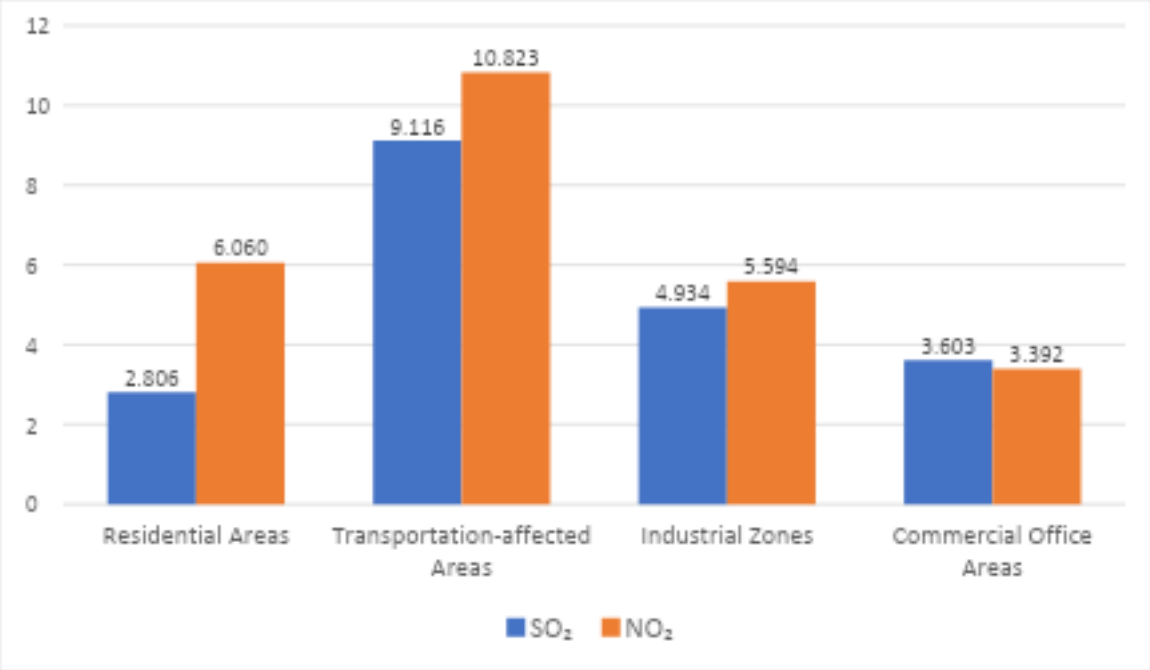

Figure 3. Sulfur Dioxide (SO_2) and Nitrogen Dioxide (NO_2) Concentration Levels by Monitoring Locations in Cilacap Regency, 2022 (µg/Nm³)
Note: The National Ambient Air Quality Standards (NAB) are 150 µg/Nm³ for 1-hour limits of SO_2 and 200 µg/Nm³ for 1-hour NO_2 (PP No. 22/2021)
Source: Environmental Agency of Cilacap Regency

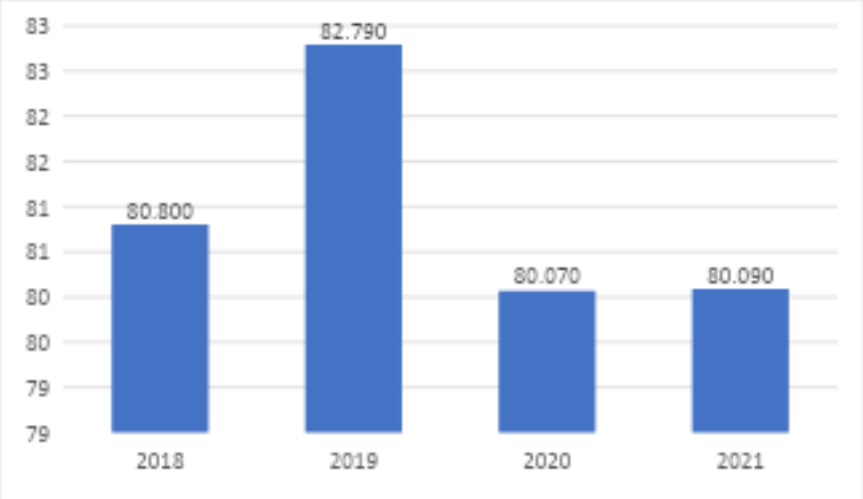

Figure 4. Air Quality Index (AQI) of Cilacap Regency, 2018–2021
Source: Environmental Agency of Cilacap Regency

Figure 1. Air Quality Monitoring Locations in Cilacap Regency, 2021
Source: Environmental Agency of Cilacap Regency

Table 3. Pearson Bivariate Correlation Analysis

		AQI 2019-2022
ARI 2019-2022	Pearson Correlation	0,542
	Sig (2-tailed)	0,458

Source: Analyzed Secondary Data

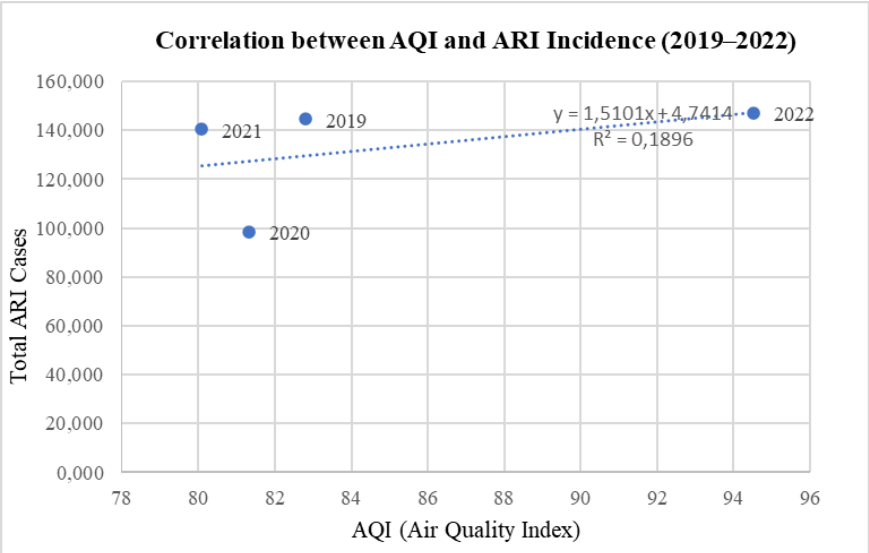

Figure 2. Scatter plot of Air Quality Index (AQI) and total ARI cases in Cilacap Regency (2019–2022)

Conclusions

The Air Quality Index (AQI) in Cilacap Regency from 2019 until 2021 was still within the solid indicator (sound level), and the routine measurement results of SO_2 and NO_2 in 2022 in the residential, office, traveling, and industrial areas were under the threshold of the limit. However, in this dataset, the concentration levels of SO_2 and NO_2 during the same period

showed no statistically significant association with ARI cases between 2019 and 2022. This lack of a positive association should not be interpreted as evidence that air quality has no bearing on ARI incidence, as it was infrequently conducted and the essential contaminants, including $PM_{2.5}$ and PM_{10}, were not part of regular monitoring. Therefore, results should be interpreted with caution, given the constraints of the available secondary data.

More studies are needed to build a fuller picture of the associations between air pollution and ARI. Further studies need to include additional control variables, such as temperature, humidity, individual health status, and population mobility. They should be strengthened by more frequent, higher-volume air quality monitoring. Better exposure assessment and richer covariate data are also needed to determine the mechanisms by which air quality affects respiratory outcomes and to guide protective actions against COVID-19 and other respiratory infections, especially in regions with high pollution levels.

Ethics approval

This study utilized secondary data from official government institutions and did not involve direct human participants or personal identifiable information. Therefore, ethical approval was not required.

Availability of data and materials

The datasets used and/or analyzed during the current study were obtained from the Cilacap Environmental Bureau and the Cilacap Health Office. The data are not publicly available but can be accessed from the corresponding author on reasonable request.

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