THE IMPACT OF THE COVID-19 PANDEMIC ON THE NUMBER OF ACUTE RESPIRATORY INFECTION CASES BASED ON AIR QUALITY PARAMETERS OF SULFUR DIOXIDE AND NITROGEN DIOXIDE IN CILACAP REGENCY

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Abstract

Restrictions on human movement and industrial operations during the COVID-19 pandemic led to a temporary improvement in air quality in many cities, including those in Indonesia. Cilacap Regency, an oil-industry area with significant traffic, is a suitable place to study associations between ambient pollutants and respiratory symptoms. The research employed a one-equivalent control group posttest-only design and used secondary data from 2019–2022 obtained from the Cilacap Environmental Bureau and the Cilacap Health Office to examine trends in air quality and link them to the incidence of Acute Respiratory Infection. Only SO_2 and NO_2 were analyzed, since these are the pollutants routinely monitored. Descriptive results indicate declines in SO_2 and NO_2 during SARS-CoV-2 mobility restrictions periods, and rises in 2021 and 2022. ARI cases decreased during the onerous restrictions in 2020 and increased again to 106,785 cases in 2022. Results of the Pearson correlation analysis revealed a non-statistically significant relationship between ARI incidence and SO_2 and NO_2 concentrations (p value = 0.458 from a two-tailed test). This null finding probably reflects the poor temporal resolution of exposure, as $PM_{2.5}$, PM_{10}, CO, and O_3 are other important pollutants that were absent. Taken together, this information implies that the present monitoring in Cilacap does not adequately capture exposure profiles that are necessary to perform robust analyses of epidemiological studies, and that increasing monitoring frequency, broadening pollutant panels, and considering the integration of environmental and behavioral confounders of health would enhance our understanding of the intricate relations between air pollution and respiratory and public health.

Keywords: Acute Respiratory Infections (ARI), air quality, SO_2, NO_2, COVID-19, Cilacap

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 is like that 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 is a dominant public health problem, with 60,898 ARI 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 initial pandemic phases, 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 (Sulaymon et al., 2021), Baghdad (Hasnain et al., 2021), Northwest US cities (Xiang et al., 2020), the United States (Jephcote et al., 2021), the United Kingdom (Travaglio et al., 2021a; Travaglio et al., 2021b), four world cities (Viteri et al., 2020), and Daka (Rahman et al., 2021). 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.

This study aims to fill gaps by analyzing 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.

One of the key contributions of the study include 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.

RESEARCH METHOD

This research used an ex post facto approach by reviewing secondary data from environmental and health surveillance reports obtained from the Environmental Agency of Cilacap Regency and the Cilacap District Health Office. This is an ex post facto study of whether pollutant quantifications and the registration of ARI cases were conducted before analysis. The study considered the yearly changes in SO_2 and NO_2 levels and ARI rates from 2019 to 2022.

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.

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.

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."Pollutant concentrations were converted into index values using the Air Pollution Index calculation equations as stated in the Decree of the State Minister for the Environment Number Kep-45/MENLH/10/1997. 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

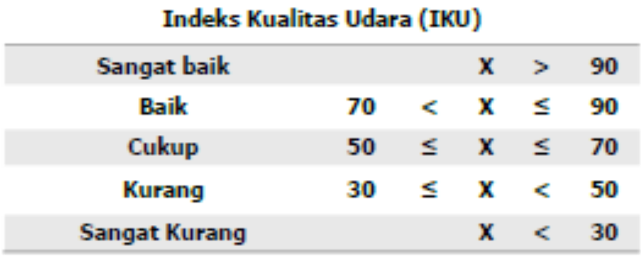
$IPSO_2 = (-0.2 \times (0.625 \times SO_2 \text{ concentration})) + 100$

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:

$IEU = 50\% \; SO_2 \text{ index} + 50\% \; NO_2 \text{ index}$

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.

Table 1. Index Air Quality (AQI)



Indeks Kualitas Udara (IKU)

Sangat baik			**X**	**>**	**90**
Baik	**70**	**<**	**X**	**≤**	**90**
Cukup	**50**	**≤**	**X**	**≤**	**70**
Kurang	**30**	**≤**	**X**	**<**	**50**
Sangat Kurang			**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 behavior 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.

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.

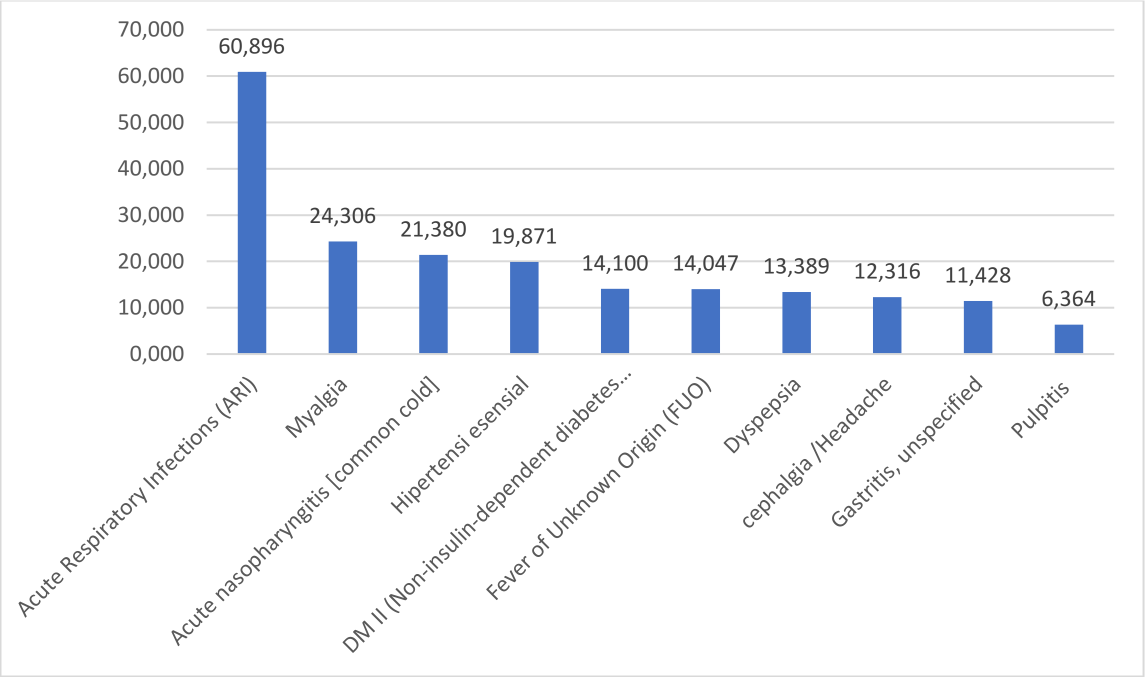
RESULT AND DISCUSSION

Table 2. Number of ARI Cases (in Number of Cases) Among Toddlers and Individuals Aged >5 Years 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: Secondary Data From the Cilacap Regency Health Office

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 newborns, 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, on the other hand, decreased by 33,066 and 65,235, respectively, in 2020 before increasing in 2021 and 2022.

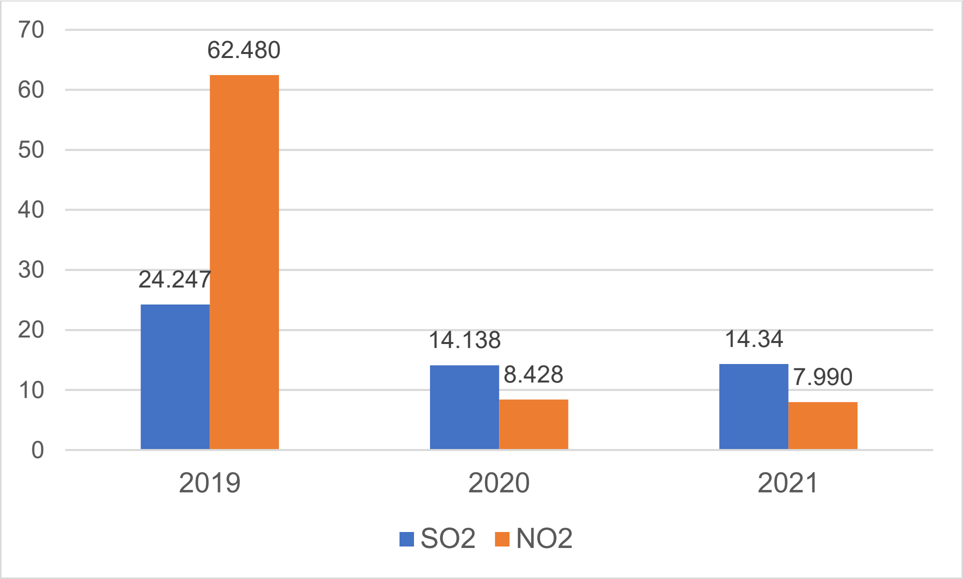


Graph 1. Top 10 Diseases (in Number of Cases) Reported at Health Centers in Cilacap Regency, 2022
Source: Secondary Data From the Cilacap Regency Health Office

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 (Medicine, 2024). 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.



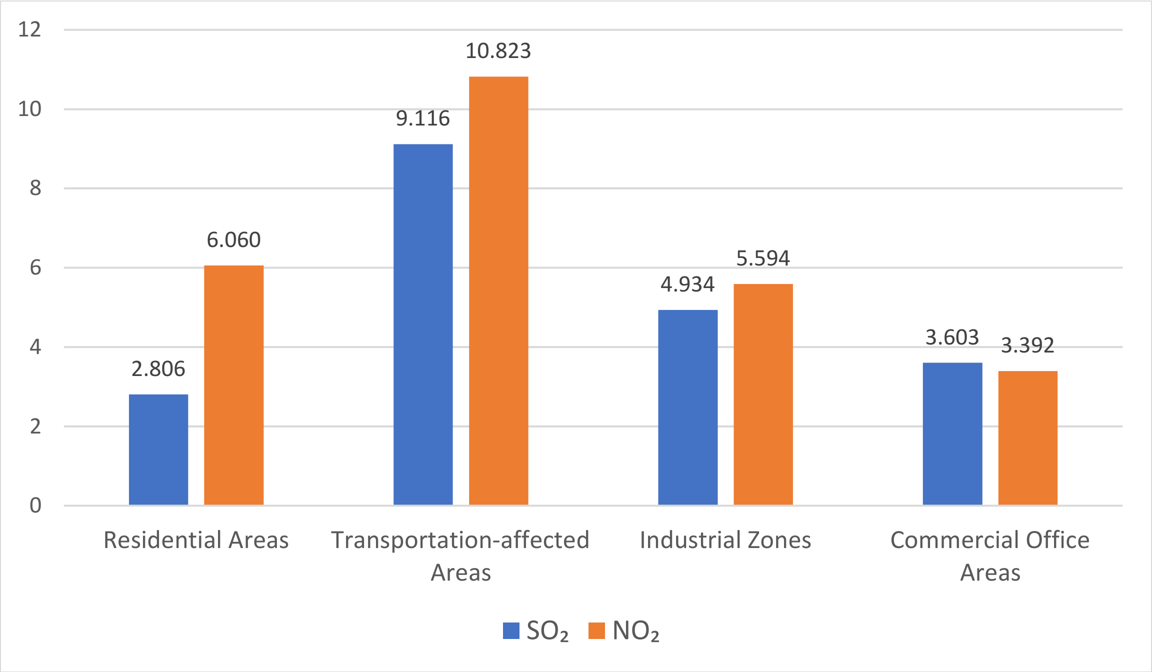
Graph 2. Sulfur Dioxide (SO_2) and Nitrogen Dioxide (NO_2) Concentration Levels in Cilacap Regency, 2019–2021 (µg/Nm³)

Note: The National Ambient Air Quality Standards (NAB) are 900 µg/Nm³ for 1-hour SO_2 and 400 µg/Nm³ for 1-hour NO_2 (PP No. 41/1999)

Source: Environmental Agency of Cilacap Regency

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.

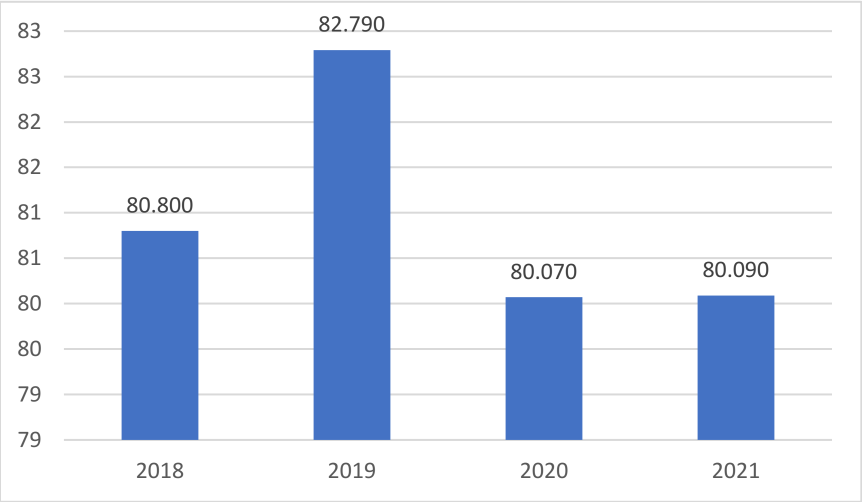


Graph 3. Sulfur Dioxide (SO_2) and Nitrogen Dioxide (NO_2) Concentration Levels by Monitoring Locations in Cilacap Regency, 2022 (µg/Nm^3)
Note: The National Ambient Air Quality Standards (NAB) are 900 µg/Nm^3 for 1-hour SO_2 and 400 µg/Nm^3 for 1-hour NO_2 (PP No. 41/1999)
Source: Environmental Agency of Cilacap Regency

The Interpretation of Graph 3 shows that transport was also a significant source of SO_2 and NO_2 levels in 2022. The concentrations were 9.116 µg / Nm^3 for SO_2 and 10.823 µg / Nm^3 for NO_2. These values do not exceed the limit stipulated in the Government Regulation No. 41 of 1999 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 neighboring 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.

From 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 (Rendana & Komariah, 2021).



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

Graph 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.

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

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 emission s 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.

Table 3. Analysis Correlation Pearson Bivariate

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

Source: Analyzed Secondary Data

According to Table 3, there is no significant association with equated concentrations of SO_2 and NO_2 during the same period for a two-tailed p value of 0.05 (the actual value is 0.458); hence, the number of cases of ARI from 2019 to 2022 was not significantly related to the concentration of SO_2 and NO_2 over time. This non-significance is mainly due to the infrequent sampling protocol: a one-hour manual active sampling procedure was used to measure these two gases once per semester; thus, this method cannot reflect daily, monthly, or seasonal variations in exposure. Occasionally, sampling like this "smooths out" the variability in pollutant concentrations that might otherwise be observed, thereby reducing the statistical power needed to detect meaningful associations with ARI rates.

SO_2 and NO_2 are plausible as chronic sources of exposure resulting in respiratory susceptibility. SO_2 causes bronchoconstriction and reduced mucociliary clearance; increases hyper-responsiveness of the airway leading to an increased risk of infection; and NO_2 induces epithelial cell inflammation and may inhibit macrophage function thus impairing innate immunological defence mechanisms at a local level. Pathophysiological changes associated with SO_2 and NO_2 can assist in explaining the increased risk of acute respiratory infection for individuals living in communities where these pollutants are continuously present despite the regulatory limits for short-term concentrations not being exceeded.

While the present correlation analysis was not statistically significant, past epidemiological studies have identified a positive correlation between exposure to both SO2 and NO2 and the development of respiratory disease. For example, one study performed in Indonesia using a multiple linear regression setup found that NO2 exposure had a strong correlation with ARI incidence, especially among children. SO2 was also found to have an effect on respiratory disease development in older adults, providing additional evidence of the physiological mechanism by which pollutants contribute to increased respiratory disease vulnerability (Rafmawan, 2026). Other studies of urban air quality have also found that when seasonal and temporal patterns are accounted for, NO2 and SO2 are important predictors of ARI incidence, indicating that deteriorating air quality is a significant contributor to the burden of respiratory diseases in communities (Suparta, 2020). Recent epidemiological data has also been reported in China, which shows that short-term NO2 exposure can cause direct injury to respiratory epithelial cells due to oxidative stress and can increase vulnerability to viral and bacterial infections, especially when combined with particulate matter (Cao et al., 2025). Airborne pathogens (e.g., SARS-CoV-2) can remain viable in aerosols for several hours; therefore, there is a risk of exposure for individuals who are already compromised due to pre-existing pulmonary diseases. Environmental health factors such as ventilation pattern, occupancy density, and duration of exposure have been shown to play an important role in the transmission of ARIs.

The amount of information available in the collected dataset was minimal and required that a statistical analysis method such as Pearson correlation be employed for methodologic reasons. Because Pearson correlation statistics do not determine whether exposure caused the outcome or the implications of cumulative or lagged exposure and/or non-linear relationships between air pollutant exposure and the health outcomes studied, they do not facilitate the identification of exposure-related temporal patterns or causal associations. Given that there was only one set of monitoring data collected every six months, more advanced statistical analysis techniques (multivariable regression, generalized additive and time-series models) cannot be applied to these data. This may limit the ability of these statistical analysis techniques to examine temporal trends and to make causal inferences using high-resolution exposure data.

This research study only investigated two air pollutants (SO_2 and NO_2) due to the limited monitoring data available from the Cilacap Regency of Indonesia. Other important air pollutants commonly evaluated in epidemiological studies (e.g., $PM_{2.5}$, PM_{10}, CO, and O_3) had no monitoring data available. Therefore, there were other significant sources of air pollution not being evaluated that could confound the results and affect the validity of the exposure assessment of the air pollutants measured in this study, and therefore, the association of air pollution levels and ARI.

Moreover, different local environmental variables (e.g., humidity, precipitation, temperature, population density and migration, and indoor air pollution) have not been evaluated, and may have confounded these results as well. As a result of using secondary observational data and for the fact that the values collected were subject to measurement error, we cannot infer that a causal relationship exists between the air pollutants measured and ARIs. Therefore, we advise that caution be exercised when interpreting these results. Future studies should utilize more frequent monitoring of air quality and include a greater number of pollutants and meteorological parameters than this study, as well as to include additional behavioral covariates and perform more advanced statistical analyses in order to effectively adjust for nonlinearity, lag time, and other complex relationships of exposure and response.

CONCLUSIONS

The Air Quality Index (AQI) in Cilacap Regency from 2019 until 2021 was still within the solid indicator (sound level) of between 80.07 and 82.79, 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, however, because it was infrequently conducted and because 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.

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