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Air Quality and Its Effects on Acute Respiratory Infections Among Children Under Five in Jambi City: A Generalized Additive Model Approach

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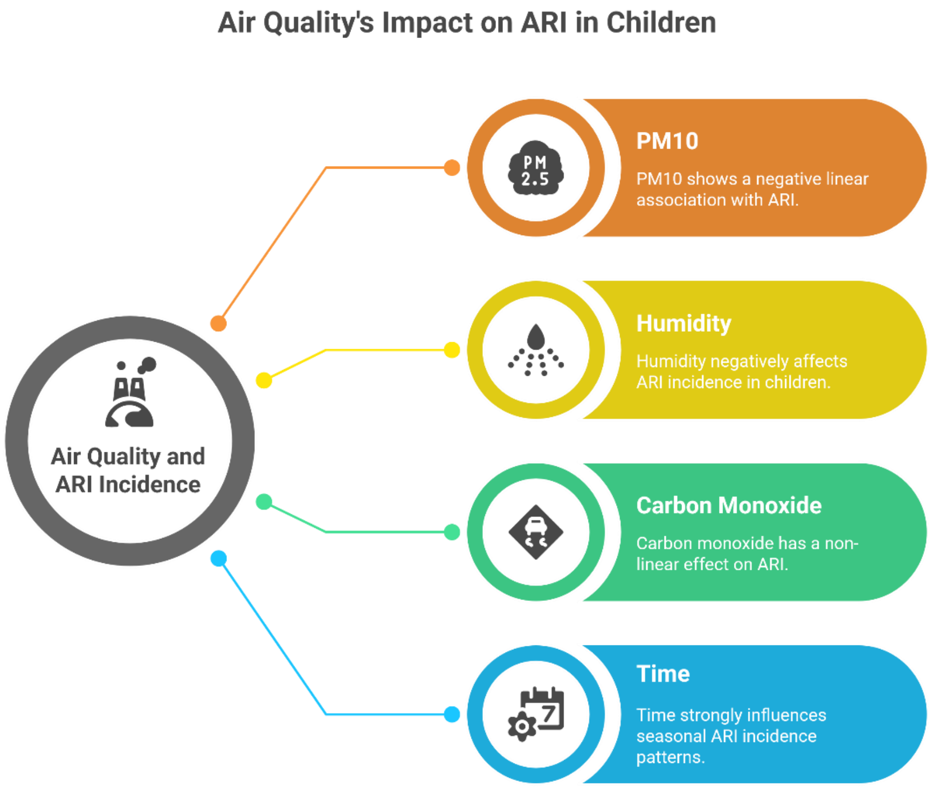
ABSTRACT

Acute Respiratory Infections (ARI) are the leading cause of morbidity and mortality among children under five and a common reason for health service visits. The World Health Organization (WHO) recognizes air pollution as the greatest environmental threat to human health, including ARI risk. In Jambi City, the prevalence of ARI among children under five remains high, while air quality is of concern due to motor vehicle emissions, open waste burning, and forest fires. Air quality can have direct and indirect effects on ARI incidence. Previous studies in Jambi have analyzed ARI using individual-level data; research on broader patterns, trends, and air quality influence remains limited. This study aims to analyze the influence of air quality on ARI incidence in children under five in Jambi City. The study was a time series using monthly data on ARI prevalence, PM10, SO2, CO, O3, temperature, humidity, and rainfall. The results showed ARI cases were high at the beginning and end of each year, fluctuating from 2021 to 2023 with a marked increase in 2023. The final GAM model indicated a significant negative linear association for PM10 (p=0.04) and humidity (p=0.03). Carbon monoxide (CO) demonstrated a significant non-linear effect (edf=4.01, p=0.0005). Time (month), representing seasonal and long-term trends, showed the strongest non-linear association (edf=7.9, p=0.0001), reflecting seasonal variation in ARI incidence. Efforts are needed to raise awareness about ambient air quality, particularly PM10 and CO, so that parents remain vigilant outdoors with children. These findings highlight the importance of interventions, including emission control and education, to reduce ARI risk in under-five children.

Key Messages:

- The prevalence of ARI among children under five in Jambi City demonstrated a fluctuating yet upward trend from 2021 to 2023. Higher ARI rates were observed at the beginning and end of the year, indicating potential seasonal patterns.
- Time (monthly) emerged as the dominant predictor of ARI prevalence among children under five in Jambi City, while carbon monixide (CO) and relative humidity also shown significant non-linear associations. Interestingly, PM10 demonstrated a linear but negative relationship with ARI prevalence.

GRAPHICAL ABSTRACT



INTRODUCTION

Acute Respiratory Infections (ARI) remain a health problem(1), both globally (2,3), and in Indonesia (4), including in the city of Jambi. ARI is also one of the 10 most common diseases in healthcare facilities (5). The prevalence of ARI in the city of Jambi is known to be 7.38% based on health worker diagnoses and 9.31% based on health worker diagnoses and/or symptoms experienced (6). Data from the Jambi City Health Department shows that the prevalence of ARI cases among infants in 2021 was 16.68%; in 2022, it was 16.63%, and there was an increase in 2023 to 33.2%. According to the 2020 Indonesia Profile, the incidence of pneumonia among infants was 15.7% in 2020 and 10.14% in 2021 (7,8). The epidemiological data demonstrate the considerable burden of ARI emong toddlers and its potential adverse health impacts.

Acute Respiratory Infections (ARI) has a negative impact on children's health, particularly affecting lung function, such as increased resistance and decreased forced expiratory flow and volume in toddlers (9). ARI in toddlers can recur if risk factors remain or no intervention is taken. This condition can affect the bronchoalveolar and pulmonary blood vessel development, as well as the lower respiratory system (10,11). In addition, ARI in infants is also known to cause death in infants(3).

The Simpul theory explains that disease outbreaks, including ARI, can occur due to several influencing nodes(12). Five interacting nodes can cause ARI, one of which is node 5, namely the supra-system variable. Suprasystem variables that can influence ARI outbreaks in toddlers are air quality and climate. The WHO also states that pollution or air quality has been recognized as the greatest environmental threat to human health, including the risk of ARI occurrence (13). Several studies have shown a correlation between SO2, CO, NO, and PM with ARI occurrence (14–18). Air pollutants such as Particulate Matter (PM) and gaseous pollutants like sulfur dioxide (SO2), nitrogen dioxide (NO2), and carbon dioxide (CO2) can cause respiratory issues in humans, thereby increasing the risk of ARI cases (14,19). Air quality data from IQAir in Jambi City over the past month (March 12 to April 11, 2024) showed that, based on PM 2.5 and the Air Quality Index (AQI) indicators, the overall air quality was mostly in the moderate category (yellow), with several days falling into the unhealthy for sensitive groups category

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(orange). (20). In Jambi City, air pollution is primarily driven by motor vehicle emissions and household activities such as open waste burning. In addition, Jambi Province is classified as an area at risk of forest and land fires, which often lead to transboundary haze episodes and further worsen air quality, including in Jambi City (21).

Acute Respiratory Infections (ARI) remain a major public health concern and are among the leading causes of mortality in children, potentially influenced by air quality conditions, particularly in urban areas such as Jambi City. Several studies based on individual-level data have been conducted previously (22–25), including in Jambi City (26–28). In addition, several studies on ARI among children under five have also employed spatial analysis (29–31). However, research that systematically examines temporal trends and environmental determinants of ARI, especially the role of air quality, remains limited. In particular, evidence from Jambi City is scarce. This study, therefore, aimed to examine the patterns and trends of ARI prevalence and to analyze the impact of air quality and climatic factors on ARI incidence among children under five in Jambi City.

METHODS

This study was design as a time-series analysis conducted in Jambi City, Indonesia. The variables included cases of Acute Respiratory Infections (ARI) among children under five, air quality indicators (PM_{10}, SO_2, CO, and O_3), and climate parameters (rainfall, humidity, and temperature). ARI cases were idetified based on ICD-10 codes J00, J01-J06, J09-18, J20, J21, and J22, covering both upper and lower respiratory tract infections, including pneumonia. The ARI variable was calculated as a prevalence rate by dividing the monthly number of cases by the number of children under five multiplied by a constant (1000). Data on ARI were obtained from the Jambi City Health Department, based on reports from primary health centers (Puskesmas); air quality data from the Jambi City Environmental Agency (Dinas Lingkungan Hidup Kota Jambi), collected at a single fixed monitoring station; and climate data from BMKG Jambi Provincial Office, collected at a single fixed station. The data covered the period from 2021 to 2023, with the unit of analysis being months.

Analyses included descriptive statistics, correlation analysis, and Generalized Additive Modeling (GAM). Variable selection in the GAM was based on p-values and QIC (Quasi-lokelihood under the Independence model Criterion). Variables were eliminated sequentially, starting from the highest p-value, while comparing the QIC of the reduce model. A lower QIC indicated better model prefomance. The Generalized Additive Model (GAM) was fitted using the mgcv package in R. The prevalence of ARI was modeled with a Gamma error distribution and a log link function, since the variable was strictly positive and right-skewed. The smoothing parameters were selected automatically by generalized cross-validation. Several assumption tests and diagnostic checks were performed in this study. Normality was assessed using the Kolmogorov-Smirnov test, multicollinearity among predictors was examined with Variance Inflation Factor (all VIF < 5), and residuals of the GAM model were analyzed for model fit and smoothing adequacy (all k-index p-values > 0.05). Residual autocorrelation was evaluated using ACF/PACF plots and the Durbin-Watson test (DW = 2.39), indicating no significant autocorrelation. All data were processed using R programming and Microsoft Excel. The R packages used were readxl, dplyr, ggplot2, lubridate, patchwork, GGally, car, and mgcv.

Code of Health Ethics

This study received an ethical exemption certificate from the Jambi Health Polytechnic, Ministry of Health of the Republic of Indonesia, with the reference number LB.02.06/2/946/2024.

RESULTS

Table 1 shows that the average prevalence of Acute Respiratory Infections (ARI) among children under five in 2021 was 13.9 per 1,000 children, with the lowest prevalence recorded at 8.32 per 1,000 and the highest at 25.9 per 1,000. In 2022, the average ARI prevalence was also 13.9 per 1,000 children, with a minimum of 8.22 and a maximum of 23.2 per 1,000 children. However, in 2023, there was a noticeable

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increase in ARI prevalence, with the average rising to 27.7 per 1,000 children. During this period, the lowest recorded prevalence was 19.9 per 1,000 while the highest reached 34.7 per 1,000.

Table 1. Distribution of ARI Prevalence Among Children Under Five in Jambi City, 2021-2023

Year	Mean	Median	Min-Max	SD
2021	13.9	13.6	8.32 – 25.9	4.61
2022	13.9	13.7	8.22 – 23.2	3.94
2023	27.7	26.9	20.6 – 34.7	3.76

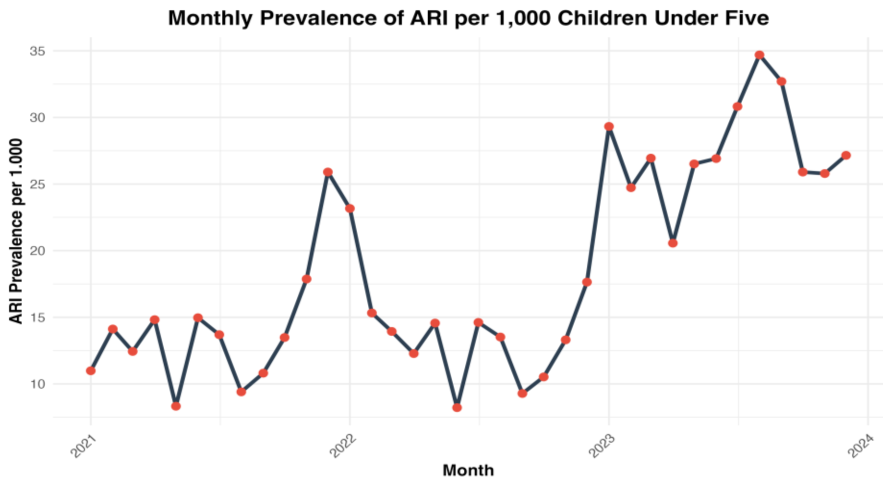

Figure 1. Trend in the Prevalence of Acute Respiratory Infections (ARI) per 1,000 Children Under Five in Jambi City, 2021-2023

Figure 1 illustrates the prevalence of ARI among children under five per 1,000 population from 2021 to 2023. The trend shows a fluctuating pattern; however, a general increase in ARI prevalence is observed over the three years. Several significant spikes occured, particularly at the end odf 2021, the of 2022, and mid-2023. The highest peak was recorded in August 2023, with a prevalence of 34.7 per 1,000 children under five.

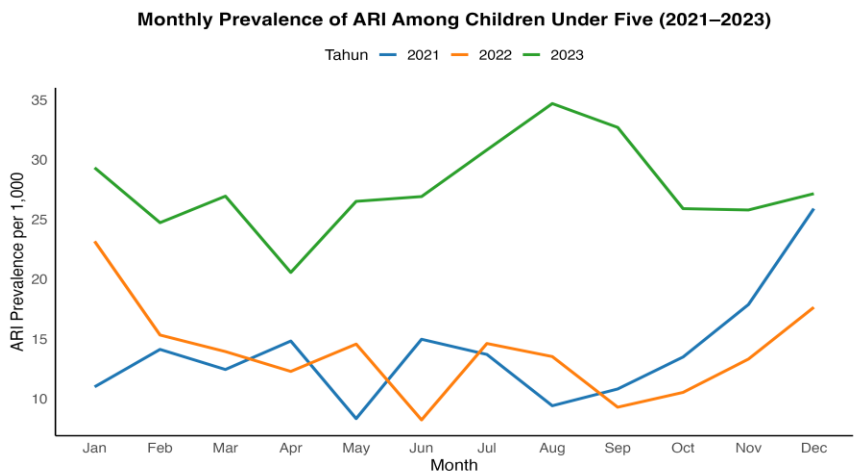

Figure 2. Yearly Comparison of Acute Respiratory Infection (ARI) Prevalence per 1,000 Children Under Five

Figure 2 compares the monthly prevalence of ARI in children under five years of age by year from 2021 to 2023. The prevalence of ARI in children under five years of age in 2023 appears to be higher than in 2021 and 2022. Figure 2 also shows that the prevalence of ARI in children under five tends to be high at the

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beginning and end of the year. The pattern indicates the possibility of a seasonal pattern of ARI incidence in children under five in the city of Jambi.

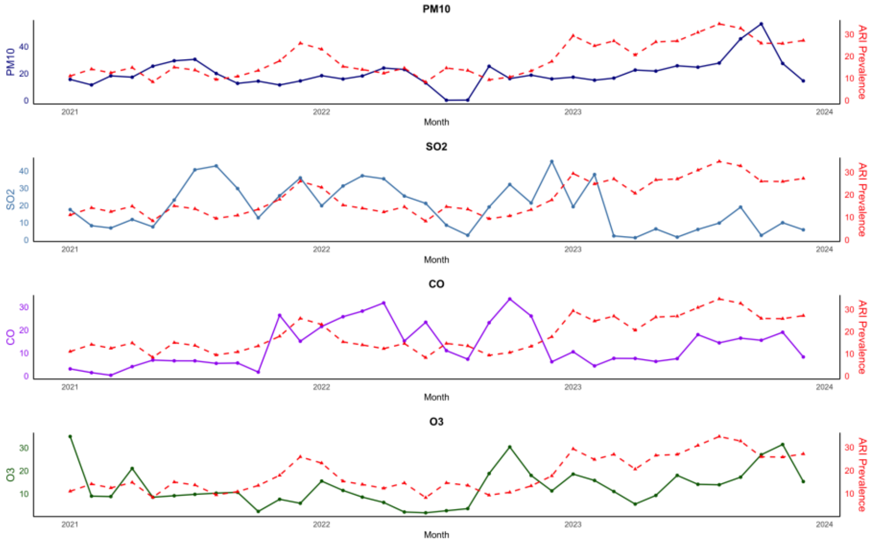

Figure 3. Monthly Ambient Air Quality Trends (PM_{10}, SO_2, CO, and O_3) in Jambi City, 2021-2023

Figure 3 shows that PM_{10} levels in Jambi City fluctuated from 2021 to 2023, with a noticeable increase observed in October 2023. SO_2 concentration also exhibited fluctutions throughtout the same period. CO levels showed a fluctuating pattern as well, with a clear upward trend. A significant rise was observed from late 2021 to late 2022, followed by another increase in mid-2023. O_3 levels in Jambi City similarly fluctuated and demonstrated an upward trend, particularly at the end of 2022 and again at the end of 2023.

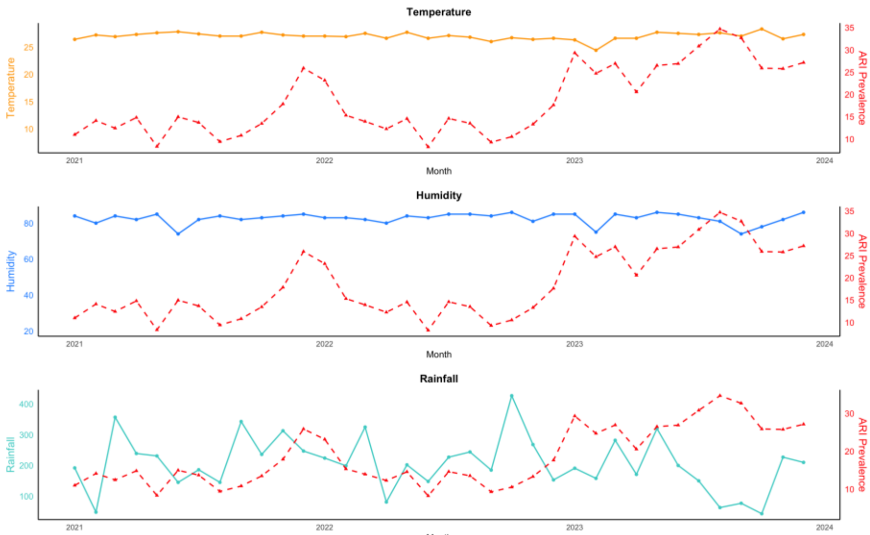

Figure 4. Monthly Temperature, Humidity, and Rainfall Trends in Jambi City, 2021-2023

Figure 4 shows that the temperature in Jambi City, based on the month, shows fluctuations but tends to be stable every month from 2021 to 2023. Humidity in Jambi City also shows fluctuations but tends to be stable every month, while rainfall appears to be more volatile every month from 2021 to 2023.

Correlation between Air Quality and Climate with the Prevalence of ARI in Toddlers in Jambi City

A correlation analysis was conducted to determine the correlation between each air quality parameter (PM_{10}, SO_2, CO, NO_2, and O_3) and the prevalence of ISPA in infants. Since air quality data and ISPA prevalence were normally distributed, a Pearson correlation test was performed. Table 2 shows the results of the correlation analysis.

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Table 2. Correlation Analysis of Independent Variables With the Prevalence of Acute Respiratory Infections (ARI)

No.	Variable	n	*p*	r
1	PM_{10}	36	0,027	0,367
2	SO_2	36	0,048	-0,331
3	CO	36	0,769	-0,051
4	O_3	36	0,205	0,216
5	Temperature	36	0,748	0,055
6	Rainfall	36	0,098	-0,279
7	Humidity	36	0,332	-0,166

The correlation analysis identified PM_{10} and SO_2 as the obly air-quality variables significantly associated with ARI prevalence. PM_{10} exhibited a statistically demonstrable positive correlation with ARI prevalence (r=0.367), indicating that higher ambient concentrations of PM_{10} are accompanied by increased ARI prevalence in Jambi City. In contrast, SO_2 showed a statistically demonstrable negative correlation with ARI prevalence (r=-0.331). Meanwhile, CO, O_3, temperature, rainfall, and humidity did not show statistically significant correlations with ARI prevalence.

Inter-Variable Correlation

Figure 5 presents the results of the correlation analysis among variables, which indicate that there are no strong correlations between any pair of variables (r<0.7). Subsequently, a multicollinearity test was conducted using teh Variance Inflation Factor (VIF). The VIF values for each independent variable were as follows: PM_{10} = 2.71, CO = 1.18, SO_2 = 1.29, O3 = 1.58, temperature = 1.71, rainfall = 1.62, and humidity = 1.8. Based on these results, no multicollinearity was detected among the independent variables, thus allowing for further analysis using the Generalized Additive Model (GAM).

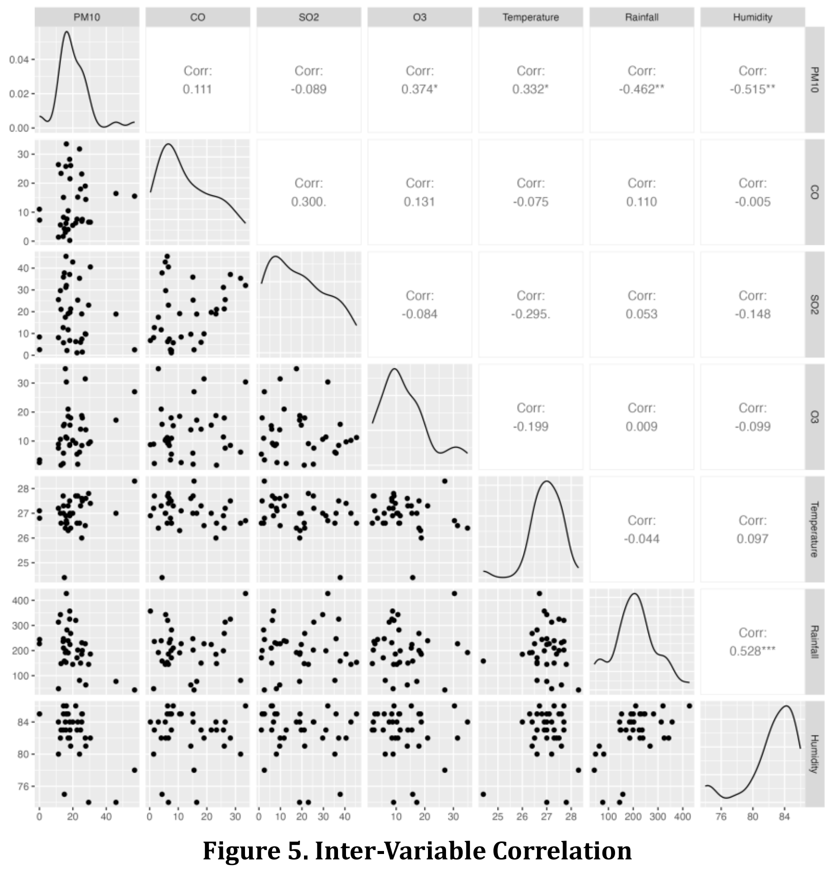

Figure 5. Inter-Variable Correlation

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Analysis of the Effect of Air Quality on ARI Prevalence in Children Under Five

The Generalized Additive Model (GAM) was used to examine the effect of air quality on the prevalence of ARI among children under five. The initial specification of the Generalized Additive Model is as follows:

Table 3. Initial Generalized Additive Model

Variabel	edf	Ref.df	F	*P*
Intercept	1			
PM_{10}	1	1	5,94	0,02
CO	4,2	5,03	3,42	0,03
SO_2	1	1	0,25	0,62
O_3	1,46	1,73	0,26	0,74
Rainfall	1	1	0,03	0,85
Temperature	1	1	1,98	0,17
Humidity	1	1	6,32	0,02
Time (Month)	7	7,95	10.41	0,001

Subsequently, model selection was performed by considering the Quasi-likelihood under the Independence Model Criterion (QIC). The final model, determined based on the lowest QIC values, is presented in Table 4.

Table 4. Final Generalized Additive Model

Variable	edf	Ref.df	F	*p*
Intercept				
PM_{10}	1	1	4,77	0,04
CO	4,01	4,89	4,72	0,005
Humidity	1	1	5,12	0,03
Time (Month)	7,9	8,67	14,99	0,001

Table 4 shows the final Generalized Additive Model (GAM) results. The analysis identified four variables that significantly influence the prevalence of ARI among children under five in Jambi City, namely PM_{10}, carbon monoxide (CO), relative humidity, and time (month). PM_{10} concentration has a significant linear relationship with the prevalence of ARI in toddlers (F=4.77, *p*=0.04). CO concentration has a non-linear and complex relationship with the prevalence of ISPA (F=4.01, *p*=0.005). Air humidity also has a significant linear effect on the prevalence of ISPA (F=5.12, *p*=0.03). The time variable (January 2022 to December 2023) showed the most dominant influence on the prevalence of ARI (F=14.99, *p*=0.001). The time variable showed a non-linear and complex pattern, possibly reflecting seasonal trends or other time-related influences.

DISCUSSION

The result of this study indicates that the prevalence of Acute Respiratory Infections (ARI) among children under five exhibited a fluctuating pattern but showed an overall increasing trend from 2021 to 2023. In 2023, ARI prevalence was notably higher compared to 2021 and 2022. The relatively lower prevalence observed in 2021 and 2022 may have been influenced by the COVID-19 pandemic, which likely affected healthcare-seeking behavior and reduced the number of visits to health facilities. As shown in figure 2, the prevalence trends in 2021 and 2022 were relatively similar, while a significant increase was observed in 2023, following the decline in COVID-19 cases and the official declaration of the end of the pandemic. Additionally, during mid-2023, forest and land fires occurred in Jambi Province, which also contributed to the rise in ARI prevalence during that period. The study further revealed that ARI prevalence among children under five tended to be higher at the beginning and end of each year, suggesting a possible seasonal pattern of ARI occurrence in Jambi City. Moreover, the findings demonstrated that the time variable (from January 2021 to December 2023) was the most dominant factor influencing ARI prevalence in children under five.

Acute Respiratory Infections (ARI) can be classified as a seasonal disease, with incidence typically increasing during the rainy or colder season (32,33). The distribution pattern of ARI prevalence observed

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in this study aligns with the trends reported in previous studies conducted in Indonesia (33–36). This seasonal pattern is associated with changes in environmental, host, and agent-related factors during tha rainy or cold seasons. These environmental conditions, both indoors and outdoors, can influence the efficiency of viral transmission, thereby contributing to be a higher number of ARI cases during colder or wetter periods (32). In addition, low temperatures and high humidity may impair the respiratory tract's defense mechanisms, making individuals more susceptible to respiratory infections (32,37). Several ARI-causing agents, particularly viruses such as the influenza virus, human coronavirus (HcoV), and human respiratory syncytial virus (RSV), tend to more prevalent during the rainy or cold seasons (32). Thus, the higher ARI prevalence at the beginning and end of the year in Jambi is most likely related to rainy season or climatic conditions, consistent with the seasonal nature of ARI.

This study also found that PM_{10} has a statistically significant and linear association with the prevalence of ARI among children under five, with an estimated degree of freedom (edf) of 1 and a *p*-value of 0.04. However, the observed relationship in this study was negative, indicating that an increase in PM_{10} levels was followed by a decrease in ARI prevalence among children under five. This finding contrasts with several previous studies that reported a positive association between PM_{10} levels and ARI incidence. For instance, a study of concentration and the incidence of pneumonia among children under five (r=0.875, p=0.000) (38). Similarly, a study conducted in Brazil in 2014 reported a significant association between PM_{10} exposure and respiratory problems, both on the day of exposure (RR=1.15; 95%CI: 1.09 to 1.20) and with a six-day lag (RR=1.05; 95%CI: 1.01-1.10) (39). Another study across 184 cities in India, conducted from 2011 to 2015, also showed consistent results, indicating that increased PM_{10} levels were associated with a higher risk of ARI in children under five (40). The discrepancy between this study's findings and previous research may be explained by several factors, particularly the impact of the COVID-19 pandemic from 2020 to 2022. During the pandemic, government policies related to social restrictions and changes in public behavior affected the incidence of ARI, including among young children. Additionally, the seasonality of ARI could have further influenced the observed patterns. Moreover, this study relied on city-level aggregate data, which may introduce ecological fallacy, as such data do not fully capture individual-level exposure.

Particulate matter (PM) is one of the most significant contributors to public health impacts, including acute respiratory infections (ARI). PM_{10} particles are approximately one-seventh the diameter of a human hair (41). PM refers to a complex mixture of suspended solid and liquid particles in the air with diameters less than 2.5 micrometers ($PM_{2.5}$) or less than 10 micrometers (PM_{10}) (42). The largest particles, known as coarse particles (with diameters between 2.5 μm and 10 μm), mainly consist of pollen, sea spray, and windblown dust from erosion, agricultural lands, roads, and mining operations. PM can also originate from the combustion of fuel or cooking activities, traffic and transportation, industrial processes, power plants, construction sites, waste burning, and forest and land fires, among others. Furthermore, PM is the most widely used indicator for assessing the health impacts of air pollution exposure(13).

Particulate Matter (PM) can affect ARI both directly and indirectly. Directly, PM can damage the respiratory tract and disrupt respiratory epithelial cells, leading to oxidative stress and inflammation, which can impair the airway epithelium's ability to clear pathogens and pollutants (42). PM is capable of penetrating deep into the lungs and entering the bloodstream (13). Indirectly, PM can affect children's immune function, particularly because their immune systems are still developing. This condition may weaken the immune response to respiratory infections (42). Even short-term exposure to PM_{10} has been shown to contribute to respiratory problems in children, particularly pneumonia (43). This study also supports such findings, as the impact of PM_{10} was assessed based on monthly concentrations in relation to ARI prevalence. Statistical analysis revealed no significant association, indicating that PM_{10} exposure had no immediate effect on ARI prevalence. Thus, PM_{10} exposure in this context appears to exert a short-term effect on the increase in ARI cases. The World Health Organization (WHO) has established ambient air quality guidelines for PM_{10}, setting a safe limit of 10 $\mu g/m^3$ for annual mean concentrations and 20 $\mu g/m^3$ for 24-hour mean concentrations (13).

Although PM_{10} showed a significant negative linear association with ARI in this study, it remains more prominent than CO, SO_2, and O_3. This is because PM is often used as a primary indicator for assessing

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the health impacts of air pollution exposure. PM particles can penetrate deep into the lungs and even enter the bloodstream, triggering various health effects, particularly on the respiratory system. Both short-term and long-term exposure to PM has been associated with increased morbidity and mortality from respiratory diseases, while long-term exposure is also linked to lung cancer (44).

The study found that carbon monoxide (CO) concentration had a statistically significant non-linear association with the prevalence of Acute Respiratory Infections (ARI) among children under five in Jambi City during the period 2021 to 2023 (p=0.005; edf – 4.014). The smoothed effect plot showed a curved pattern, indicating that ARI prevalence increased with rising CO concentrations up to a certain point, after which it began to decline at higher concentrations. Specifically, low to moderate CO concentrations (5-15 $\mu g/m^3$) were associated with an increase in ARI prevalence. However, at higher concentrations (>18 $\mu g/m^3$), the effect on ARI prevalence appeared to decrease. This inverse relationship at high pollution levels may be explained by behavior adaptations, where the public tends to reduce outdoor activities, including those involving children, when air pollution is particularly severe.

Carbon monoxide (CO) is a colorless and odorless gas primarily emitted from motor vehicles and open waste burning. Although CO does not directly cause ARI in children, it can diffuse through lung tissue and enter the bloodstream, impairing the body's ability to transport oxygen to cells. This oxygen deprivation can lead to cellular and tissue damage, potentially contributing to respiratory problems (13). A time-series study conducted in China in 2021 reported consistent findings, indicating that CO exposure was associated with an increased risk of hospitalization due to various respiratory diseases, including asthma, chronic obstructive pulmonary disease (COPD), lower respiratory tract infections, and pneumonia (45). Similarly, a study conducted in Kendari City, Southeast Sulawesi, in 2024 also found a significant association between CO levels and the incidence of ARI in children under five, even after controlling for other air pollutants such as $PM_{2.5}$, PM_{10}, SO_2, and NO_2 (45).

Jambi City, as the capital of Jambi Province, functions as the administrative center as well as a hub for various socio-economic activities. Consequently, the city's air quality is influenced by multiple sources, including emissions from motorized vehicles, open waste burning, and industrial activities. Furthermore, transboundary air pollution originating from forest and land fires also contributes to the degradation of air quality. Although such fires may not occur within the administrative boundaries of Jambi City, their adverse impacts are nonetheless experienced by the local population (46,47).

This study also found that relative humidity had a statistically significant and linear relationship with the prevalence of ARI among children under five, with an estimated degree of freedom (edf) of 1 and a p-value of 0.03. Interestingly, the association was negative, indicating that higher levels of humidity can accelerate the deposition of airborne pollutant particles, thereby reducing pollutant concentrations that contribute to higher ARI rates. This result is consistent with a 2022 study from Thailand, which demonstrated that increased relative humidity contributed to lower concentrations of $PM_{2.5}$ and PM_{10} (48).

High humidity levels can help maintain the integrity of the respiratory mucosa and reduce the concentration of airborne pollutants, thereby lowering the risk of Acute Respiratory Infections (ARI). Conversely, low humidity may increase the risk of ARI, as it can lead to dryness of the respiratory mucosa and impair ciliary function, making individuals more susceptible to viral infections. Additionally, both low and high humidity levels may prolong the survival of ARI-causing pathogens in the environment, thereby increasing the risk of infection and transmission (49). These findings are consistent with a study conducted in China, which demonstrated that humidity significantly affects outpatient visits for respiratory diseases. Specifically, when relative humidity was below 32%, each 1% decrease was associated with a 6% increase in respiratory disease cases (50). This result also aligns with a systematic review showing that humidity influences respiratory health, particularly among children. Humidity levels can affect biological or chemical components in the air, potentially triggering adverse effects on allergic respiratory diseases (51).

This study has several limitations. First, it used aggregated data, which may introduce ecological bias. Second, air quality measurements (PM_{10}, CO, SO_2, O_3) and climate data (temperature, humidity, rainfall) were collected from a single monitoring point for the entire city of Jambi, which may limit spatial representativeness. Third, the study period was limited to three years due to data availability. Despite these limitations, the findings provide valuable preliminary evidence on air quality and its impact on acute

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respiratory infections, particularly in children under five, and can serve as a basis for preventive measures and public health policies. Future research with multiple monitoring sites and longer study periods is recommended to further strengthen and generalize the findings.

CONCLUSION

The findings of this study indicate that the incidence of Acute Respiratory Infections (ARI) among children under five in Jambi City fluctuated from 2021 to 2023, with a noticeable increase observed particularly in 2023. The study identified several key factors influencing ARI prevalence in this population, namely time (month), PM10, carbon monoxide (CO), and relative humidity. The final GAM model revealed negative linear associations for PM10 and humidity. Carbon monoxide (CO) exhibited a significant non-linear effect, while time (month), reflecting seasonality, emerged as a significant predictor of ARI incidence. These findings highlight the urgent need for targeted interventions and preventive measures to reduce the burden of ARI in young children, especially in relation to air pollution. Specific actions include emission control and educational programs to raise parental awareness about air pollution. Public awareness campaigns regarding ambient air quality are essential to ensure that parents remain vigilant about pollution levels, particularly when taking their young children outdoors

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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