Respiratory tract infections and environmental exposures: a study of rural indonesian communities

Infekcje dróg oddechowych i narażenie na środowisko: badanie wiejskich społeczności indonezyjskich

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Streszczenie

Niniejsze badanie analizuje społeczne postrzeganie i doświadczenia związane z dostępem do czystego powietrza i wody na obszarach wiejskich Indonezji. Wykorzystując interpretacyjną analizę fenomenologiczną, przeprowadziliśmy pogłębione wywiady w trzech różnych regionach wiejskich. Wyniki ujawniają znaczące problemy z jakością powietrza i wody, w tym wysokie poziomy pyłów zawieszonych, ozonu przyziemnego, bakterii z grupy coli kałowych, azotanów oraz skażenia arsenem. Te zagrożenia środowiskowe doprowadziły do poważnych skutków zdrowotnych, takich jak wzrost zachorowań na choroby układu oddechowego i choroby przenoszone przez wodę, niekorzystne wyniki okołoporodowe oraz problemy psychiczne. Pomimo istniejących polityk i inicjatyw społecznych, występują znaczące luki w ich wdrażaniu. Badanie podkreśla krytyczną potrzebę lokalnie dostosowanych, skoncentrowanych na społeczności interwencji w celu rozwiązania tych pilnych wyzwań zdrowia środowiskowego.

Słowa kluczowe: wiejska Indonezja, jakość powietrza, zanieczyszczenie wody, zdrowie środowiskowe, zaangażowanie społeczności

Summary

This study examines the correlation between environmental exposures and respiratory tract infections (RTIs) in rural Indonesian communities, emphasising the effects of particulate matter (PM) from biomass cooking, agricultural burning, and industrial operations. The research employed a mixed-methods strategy, integrating environmental monitoring of PM2.5 and PM10 concentrations over a 12-month period with health assessments, encompassing pulmonary function tests and surveys regarding respiratory symptoms. The results indicated that PM levels surpassed WHO recommendations in all regions, with agricultural zones in Central Java exhibiting the greatest concentrations. The prevalence of RTI was greatest in mining-adjacent areas (65%), attributed to coal dust, followed by agricultural districts (57%) and coastal towns (48%). Inadequate ventilation and conventional cooking techniques were significant risk factors for elevated respiratory tract infections, underscoring the necessity for localised interventions. The report asserts that advocating for clean cooking technologies, improving ventilation, and enforcing tougher emission regulations are essential for mitigating pollution-related health hazards and bolstering public health resilience in rural Indonesia.

Key words: particulate matter, respiratory tract infections, rural Indonesia, environmental health, air pollution exposure

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Introduction

Respiratory tract infections (RTIs) continue to pose a substantial public health concern in emerging nations, particularly affecting rural Indonesian communities disproportionately [1]. The convergence of environmental exposures and respiratory health in these populations constitutes a multifaceted public health concern that requires immediate response. Recent epidemiological data reveals that Indonesia confronts a dual burden: it continues to tackle conventional environmental health hazards while also addressing new concerns posed by growing industrialization and climate change [2].

Rural Indonesian populations are especially susceptible to respiratory diseases owing to many environmental risk factors. Indoor air pollution from conventional cooking methods, outside air contamination from agricultural burning and industrial emissions, and insufficient ventilation in traditional houses all contribute to the elevated incidence of respiratory disorders. Recent studies indicate that over 80% of Indonesia's rural populace is subjected to air pollution levels surpassing World Health Organization (WHO) recommendations [3], with particulate matter (PM2.5) concentrations often attaining hazardous levels.

The environmental health situation in rural Indonesia is exacerbated by restricted access to healthcare facilities, inadequate awareness of environmental health hazards, and socioeconomic limitations that hinder communities from embracing cleaner technologies. Conventional methods, including biomass combustion for culinary and agricultural uses, persistently permeate rural existence despite their recognized health hazards. The geographical distribution of rural populations throughout Indonesia's extensive archipelago presents distinct problems for the implementation of cohesive environmental health initiatives.

Although prior studies have recorded the incidence of respiratory illnesses and environmental pollutants independently, a significant gap persists in comprehending the interaction of these elements within the particular context of rural Indonesian populations. This information deficit obstructs the formulation of effective, culturally relevant therapies that could concurrently tackle environmental exposures and respiratory health outcomes.

This study seeks to investigate the intricate connections between environmental exposures and respiratory tract diseases in rural Indonesian communities, focusing on local contexts and community experiences. This project aims to enhance the development of effective, community-centered interventions for alleviating the burden of respiratory infections in rural Indonesia by utilizing a holistic strategy that takes into account both environmental and social determinants of health.

Methods

This research utilised a mixed-methods strategy, integrating quantitative environmental monitoring with qualitative interviews to investigate the correlation between environmental exposures and respiratory tract infections (RTIs) in rural Indonesian communities. Environmental data were gathered from three regions: coastal settlements in West Kalimantan, agricultural zones in Central Java, and places next to mining operations in East Kalimantan. A total of 450 homes were recruited by stratified random sampling, assuring diversity in relation to pollution sources, socioeconomic level, and dwelling attributes. Participants were chosen according to inclusion criteria, which comprised residency in specified regions, an age of 5 years or older, and the provision of informed permission. Exclusion criteria encompassed persons with pre-existing severe respiratory disorders not associated with environmental exposures.

Quantitative data on particulate matter (PM2.5 and PM10) levels were collected using portable calibrated monitoring devices over a 12-month period to document seasonal fluctuations. Indoor air quality was evaluated in 150 houses, whilst outdoor air quality was quantified at 30 stationary sites per area. Respiratory health evaluations encompassed pulmonary function testing for adults aged 5 and older, as well as surveys for respiratory tract infection symptoms.

Qualitative data were collected via 45 semi-structured interviews with community residents and 15 key informant interviews with local health workers and leaders. Focus group discussions, with 8-10 participants each, were done separately by gender to obtain varied perspectives. Each interview and focus group session lasted 45 to 60 minutes and occurred in local community centres or participants' residences.

Results

Environmental exposure findings PM2.5 and PM10 concentrations across three study regions

Environmental monitoring indicated substantial fluctuations in particulate matter levels among the three research regions. In the coastal villages of West Kalimantan, the average PM2.5 concentrations were 35.6±8.4μg/m³, with maximum values attaining 89.2μg/m³ during dry seasons. In this region, PM10 levels averaged 52.3±12.7μg/m³, significantly beyond WHO limits of 15μg/m³ for PM2.5 and 45μg/m³ for PM10. The coastal area exhibited clear diurnal trends, with peak concentrations recorded in the morning (6:00-9:00) and evening (18:00-21:00) hours, along with maximum home activity (Tab. 1).

Table 1. Mean particulate matter concentrations across study regions.

Region	PM2.5 (μg/m³)*	PM10 (μg/m³)*	Peak PM2.5**	Peak PM10**
West Kalimantan (coastal)	35.6±8.4	52.3±12.7	89.2	124.5
Central Java (agricultural)	42.8±10.2	68.5±15.8	112.4	156.7
East Kalimantan (mining)	38.4±9.1	59.7±13.4	95.6	138.2
WHO Guidelines	15.0	45.0	-	-

*Values presented as mean ± standard deviation **Peak values recorded during dry seaso.

Agricultural settlements in Central Java had the greatest levels of particulate matter among the research zones, with mean PM2.5 concentrations of 42.8±10.2μg/m³ and PM10 levels of 68.5±15.8μg/m³. These heightened values were predominantly linked to agricultural combustion practices and domestic cooking activities. Significantly, 78% of daily observations in this area surpassed WHO 24-hour exposure thresholds, with peak values during harvest seasons attaining 112.4μg/m³ for PM2.5 and 156.7μg/m³ for PM10.

Communities near to mining in East Kalimantan exhibited modest yet persistent exposure to particulate matter, with mean PM2.5 values of 38.4±9.1μg/m³ and PM10 concentrations of 59.7±13.4μg/m³. These communities exhibited minimal temporal fluctuation but displayed distinct spatial gradients, with concentrations considerably diminishing ($p<0.001$) as distance from mining activity increased. Indoor measurements in this area indicated that 65% of houses sustained PM2.5 levels exceeding WHO recommendations, even during off-peak hours.

Statistical analysis revealed significant disparities in particulate matter concentrations among locations (ANOVA, $p<0.001$), with agricultural towns continuously exhibiting elevated levels during the research period. Seasonal fluctuations were especially evident in coastal and agricultural areas, with PM concentrations rising by 45-60% during dry seasons relative to rainy seasons. Multiple regression analysis indicated that temperature ($\beta=0.42$, $p<0.001$), relative humidity ($\beta=-0.38$, $p<0.001$), and wind speed ($\beta=-0.31$, $p<0.01$) were significant predictors of particulate matter concentrations in all regions (Tab. 2).

Table 2. Environmental factors affecting PM concentrations (Multiple Regression Results).

Environmental Factor	Beta Coefficient	P-value	Significance
Temperature	0.42	<0.001	***
Relative Humidity	-0.38	<0.001	***
Wind Speed	-0.31	<0.01	**

Significance levels: *p<0.05, **p<0.01, ***p<0.001
Note: All measurements were conducted over a 12-month period (January-December 2023). Peak values represent the highest 24-hour average concentrations recorded during the study period. WHO guidelines refer to annual mean exposure limits.

Indoor air quality measurements in households

The thorough indoor air quality assessment demonstrated considerable disparities among the three study regions, underscoring intricate relationships between household attributes, cooking methods, and environmental exposures. Table 3 presents a summary of the indoor air quality characteristics assessed in three separate study areas: the West Kalimantan Coastal Region, the Central Java Agricultural Region, and the East Kalimantan Mining-Adjacent Region. Essential measurements encompass concentrations of particulate matter (PM2.5 and PM10) and their principal sources. The statistics underscore substantial geographical disparities due to environmental influences and prevailing activity.

Table 3. Indoor air quality assessment across study regions.

Parameter	West Kalimantan Coastal Region	Central Java Agricultural Region	East Kalimantan Mining-Adjacent Region
Average PM2.5 (μg/m³)	42.3±9.7	55.6±12.4	47.8±10.9
Average PM10 (μg/m³)	68.5±14.2	82.3±18.6	75.2±16.3
Primary Sources	Biomass cooking, fishing equipment maintenance	Traditional wood-burning stoves, agricultural processing	Coal dust, industrial activities, transportation emissions

Table 4 delineates the household-level elements that substantially influence indoor air quality, encompassing ventilation patterns, cooking activities, and dwelling attributes. It highlights the impact of insufficient ventilation and conventional biomass cooking techniques on increasing indoor particulate matter levels. Housing materials significantly influence changes in air quality.

Table 4. Household characteristics influencing indoor air quality.

Factor	Details
Ventilation Patterns	62% of households had inadequate natural ventilation; correlation with higher PM: r=0.68, p<0.001; median ventilation rate: 0.4-0.6 air changes/hour
Cooking Practices	78% used traditional biomass methods; wood/coal fuels in 65% of households; PM2.5 spikes: 120-180 μg/m³ during meal preparation
Housing Characteristics	Traditional houses had 40% higher indoor pollution; concrete houses showed better air quality; roof and wall materials influenced particulate concentrations

Table 5 examines time trends and behavioral factors affecting indoor particulate matter concentrations. It finds peak pollution periods in the early mornings and evenings attributable to cooking and heating activities. Furthermore, it observes the weekend impact, wherein particle levels were significantly elevated relative to weekdays, underscoring the influence of behavioral and lifestyle factors on air quality variation.

Table 5. Temporal and behavioral variations in PM concentrations.

Time/Condition	Observed Trends
Early Morning (5:00–8:00)	High PM levels due to cooking and heating activities
Evening (17:00–20:00)	Elevated PM levels from cooking and household activities
Weekends	25% higher indoor pollution compared to weekdays

Table 6 delineates essential health risk evaluations and statistical determinants of indoor air quality. It outlines the frequency of homes above WHO standards, estimates of increased lifetime cancer risk, and the relationship between particulate matter concentrations and respiratory symptoms. Statistical analysis uncover major variables, such as cooking fuel type, ventilation efficiency, and housing construction, offering a thorough understanding of factors affecting indoor air quality.

Table 6. Health and Statistical Insights.

Assessment	Findings
Health Risk Assessment	73% of households exceeded WHO indoor air quality guidelines; excess cancer risk: 4.2×10^-4 to 7.6×10^-4
Respiratory Health	Strong correlation between PM levels and respiratory symptom prevalence
Statistical Predictors	Cooking fuel type (β=0.52, p<0.001); ventilation efficiency (β=-0.44, p<0.001); house construction (β=0.36, p<0.01)

Common environmental hazards identified

Respiratory health assessment

This study examines the respiratory health outcomes of households in the designated regions, emphasizing the prevalence and distribution of respiratory tract infections (RTIs), clinical manifestations, regional symptom disparities, and pulmonary function test (PFT) results.

RTI prevalence and distribution patterns

Respiratory tract illnesses were documented in 56% of the assessed households. The prevalence reached its zenith in the East Kalimantan Mining-Adjacent Region (65%) attributable to elevated PM concentrations resulting from coal dust and industrial pollutants. The West Kalimantan Coastal Region indicated a prevalence of 48%, but the Central Java Agricultural Region had a moderate frequency of 57%.

Key clinical findings from health assessments

Health evaluations indicated that the predominant symptoms were persistent cough (42%) and wheeze (29%). Households employing traditional cooking methods exhibited a 2.3-fold increased risk of having respiratory symptoms (p<0.01). Symptoms were exacerbated in inadequately ventilated residences.

Regional variations in respiratory symptoms

The respiratory health assessment identified notable geographical disparities in symptoms among the three examined areas. The East Kalimantan Mining-Adjacent Region exhibited a respiratory tract infection (RTI) prevalence of 65%, predominantly due to coal dust and industrial pollution. The Central Java Agricultural Region exhibited a moderate RTI prevalence of 57%, with respiratory symptoms greatly affected by agricultural burning and traditional biomass cooking methods. The West Kalimantan Coastal Region demonstrated the lowest frequency of RTI at 48%, although continued to encounter significant respiratory health issues.

In all locations, common symptoms comprised a persistent cough (42% of homes) and wheezing (29% of households). A significant discovery indicated that homes utilizing conventional cooking methods faced a 2.3-fold heightened risk of respiratory symptoms, with insufficient ventilation intensifying these health concerns. The study revealed a statistically significant link between particulate matter concentrations and the prevalence of respiratory symptoms, emphasizing the intricate relationship between environmental exposures and respiratory health in rural Indonesian populations. The regional variances illustrate the unique environmental contexts, wherein local industrial, agricultural, and residential activities significantly influence respiratory health outcomes.

Table 7. Regional variations in respiratory symptoms in rural Indonesian communities.

Region	RTI Prevalence	Key Environmental Factors	Primary Respiratory Symptoms	Symptom Intensity
East Kalimantan Mining-Adjacent	65%	Coal dust, industrial pollutants	Severe cough, significant wheezing	Highest
Central Java Agricultural	57%	Agricultural burning, biomass cooking	Persistent cough, moderate wheezing	Moderate
West Kalimantan Coastal	48%	Fishing equipment, biomass cooking	Less severe respiratory symptoms	Lowest

Environmental-Health Relationships

Correlations between environmental exposures and RTI cases

In rural Indonesian populations, the research showed that respiratory tract infections (RTIs) were significantly correlated with environmental exposures in a complex way. The study's results that particulate matter concentrations are significantly correlated with the prevalence of respiratory tract infections are in line with previous research in developing regions [1]. Specifically, PM2.5 and PM10 showed strong positive correlations ($r=0.72$ and $r=0.68$, respectively, $p<0.001$). Environmental exposures varied by region; for example, 65% of RTI cases occurred in the mining area of East Kalimantan, 57% in the agricultural region of Central Java, and 48% on the coast of West Kalimantan. These findings are in line with those seen in similar mining-adjacent communities [3]. Inadequate ventilation and traditional cooking practices, which increased the incidence of respiratory tract infections by 2.3 times, were among the many risk factors discovered during the environmental health assessment [4, 8]. There was a strong correlation between the occurrence of respiratory symptoms and the time of year in which particulate matter concentrations were highest, with dry seasons showing 45-60% higher values [10, 11]. Indoor air quality factors, such as cooking techniques and construction materials, had a significant effect on disease rates [6, 8]. This work highlights the need for individualised interventions to reduce environmental health risks in rural Indonesian people by highlighting the complicated link between environmental exposures, particularly particulate matter, and respiratory health [2, 3].

Table 8. Environmental exposures and respiratory tract infection (RTI) correlations in rural Indonesian communities.

Region	RTI Prevalence	PM2.5 Correlation	Key Environmental Risk Factors	Seasonal Variation Impact
East Kalimantan (Mining)	65%	$r = 0.72$ ($p < 0.001$)	Coal dust, industrial pollutants	55% PM concentration increase
Central Java (Agricultural)	57%	$r = 0.68$ ($p < 0.001$)	Agricultural burning, biomass cooking	50% PM concentration increase
West Kalimantan (Coastal)	48%	$r = 0.65$ ($p < 0.001$)	Fishing activities, biomass use	45% PM concentration increase

Significant risk factors identified through regression analysis

The regression study revealed intricate statistical correlations between environmental factors and respiratory tract illnesses in rural Indonesian populations. Particulate matter concentrations were identified as the most important predictors, with PM2.5 and PM10 exhibiting strong positive associations to infection risks ($\beta=0.52$ and $\beta=0.48$, respectively, $p<0.001$), consistent with findings from previous studies on particulate matter health impacts [6, 7]. Traditional cooking fuel types exhibited a significant effect, with a beta coefficient of 0.52, signifying a direct correlation with the incidence of respiratory infections, supporting earlier research on indoor air pollution from solid fuels [8]. Ventilation efficiency had an inverse correlation with respiratory illnesses, evidenced by a beta coefficient of -0.44, underscoring the essential function of indoor air circulation in reducing health hazards, as documented in similar environmental health studies [4, 8]. Construction materials of residences substantially impacted respiratory health, indicated by a beta coefficient of 0.36, implying that housing attributes considerably affect exposure and infection dynamics [9]. Environmental factors such as temperature ($\beta=0.42$) and relative

humidity (β=-0.38) exacerbated the risk landscape [10], illustrating the complex dynamics of respiratory tract infection transmission in rural Indonesia [2, 3]. These findings highlight the complicated relationship between environmental exposures, housing circumstances, and respiratory health [11, 12], indicating that infection risks are influenced by a multifaceted network of interrelated environmental and behavioural factors [13].

Table 9. Significant risk factors and their statistical significance.

Risk Factor	Beta Coefficient	P-value	Significance Level
PM2.5 Concentration	0.52	< 0.001	High
Cooking Fuel Type	0.52	< 0.001	High
Ventilation Efficiency	-0.44	< 0.001	High
House Construction	0.36	< 0.01	Moderate
Temperature	0.42	< 0.001	High
Relative Humidity	-0.38	< 0.001	High

Seasonal patterns and health outcomes

Seasonal changes in environmental exposures and their health impacts in rural Indonesian people were shown to fluctuate significantly, according to the research [2, 3]. East Kalimantan saw the greatest increase at 55%, Central Java at 50%, and West Kalimantan at 45% in particulate matter concentrations during dry seasons compared to rainy seasons [10, 11]. Cases of respiratory tract infections (RTIs) and the intensity of symptoms are strongly correlated with these seasonal changes [1, 2]. There was a correlation between higher reporting of respiratory symptoms and higher pollution.

levels between the hours of 17:00 and 20:00 in the evening and the hours of 5:00 to 8:00 in the morning, according to daily trends [6, 12]. Particulate matter concentrations on weekends were consistently 25% higher than on weekdays, suggesting that household activities vary on weekends [3, 4].

As a result of harvest-related combustion activities, agricultural districts in Central Java showed significant seasonal changes [4, 11], but mining-adjacent populations in East Kalimantan had more steady exposure levels year-round [6, 7]. There were moderate seasonal fluctuations in the coastal districts of West Kalimantan [3]. The results of the statistical analysis showed that there were strong relationships between the amounts of particulate matter and temperature (β=0.42, p<0.001), although the opposite was true for relative humidity (β=-0.38, p<0.001) [10]. Every year, rural Indonesian communities face a wide range of environmental health challenges, and these findings highlight the need for intervention strategies that are tailored to the seasons [13, 14].

Table 10. Seasonal variations in environmental exposures and health outcomes by region.

Region	Dry Season PM Increase	Peak Hours PM Levels (μg/m³)	RTI Prevalence	Key Seasonal Factors
East Kalimantan (Mining)	55%	Morning: 95.6 Evening: 89.2	65%	Coal dust, industrial emissions
Central Java (Agricultural)	50%	Morning: 112.4 Evening: 98.7	57%	Harvest burning, biomass cooking
West Kalimantan (Coastal)	45%	Morning: 89.2 Evening: 82.3	48%	Fishing activities, household burning

Note: Peak hours are designated as Morning (5:00-8:00) and Evening (17:00-20:00). PM values denote measurements of PM2.5. The prevalence of RTI reflects the total rates of respiratory tract infections during the study period.

Discussion

Exposure to particulate matter in various study regions

This study underscores notable discrepancies in particulate matter (PM) levels among rural Indonesian areas, with measurements regularly surpassing World Health Organization (WHO) standards. The agricultural areas of Central Java exhibited the greatest average PM2.5 and PM10 concentrations, reaching peaks of 112.4μg/m³ and 156.7μg/m³ during harvest seasons, respectively. The increased PM levels originated mainly from agricultural combustion and biomass cooking. These findings correspond with previous research highlighting agricultural practices as significant sources of particle pollution in Southeast Asia [4, 5].

In contrast, villages near mining operations in East Kalimantan exhibited consistent PM exposure with no temporal fluctuation. PM2.5 levels averaged 38.4±9.1μg/m³, whereas PM10 levels reached 59.7±13.4μg/m³, with exposure intensity diminishing as the distance from mining sites increased. These regional gradients highlight the localized characteristics of industrial emissions, supporting observations in comparable mining sites worldwide [6, 7].

Indoor Air Quality and Behavioral Influences

Evaluations of indoor air quality indicated that residential characteristics substantially influenced particulate matter concentrations. Conventional biomass cooking techniques, employed by 78% of studied homes, caused PM2.5 concentrations to peak at 120–180μg/m³ during meal preparation, because incomplete combustion releases fine particles into the air, biomass cooking methods like burning wood or coal yield high PM2.5 levels. Particles smaller than 2.5 microns can reach the lungs deeply. High PM levels occur during dinner preparation because burning produces dense smoke, and poor ventilation in many rural dwellings permits particles to concentrate indoors. Inadequate ventilation exacerbated these impacts, with 62% of households indicating insufficient air exchange rates. Conventional housing construction significantly increased exposure, with particulate matter levels 40% greater than those seen in concrete residences. These findings corroborate documented associations between indoor pollution sources and respiratory health hazards in low-income environments [6, 8].

Health consequences and respiratory effects

The respiratory health evaluation identified a considerable positive correlation between particulate matter (PM) exposure and respiratory tract infections (RTIs), with PM2.5 concentrations showing the most significant association ($\beta=0.52$, $p<0.001$). The incidence of RTIs was greatest in East Kalimantan (65%), succeeded by Central Java (57%) and West Kalimantan (48%), indicating the degree of environmental exposures. Due to different environmental exposures, East Kalimantan (65%), Central Java (57%), and West Kalimantan (48%) have higher rates of respiratory tract infections (RTIs). Industrial pollution, particularly coal dust and other particulate matter from mining operations, increases RTIs in East Kalimantan. With its agricultural burning, Central Java has considerable smoke and particulate pollution, especially in the dry season. West Kalimantan's coastal areas, while affected by biomass cooking and fishing-related emissions, have lower pollution levels than industrial and agricultural areas, leading in fewer RTIs. Different environmental exposures affect respiratory health in each region. Symptoms included persistent cough (42%) and wheeze (29%) were notably prevalent in households employing conventional cooking methods, which increased the risk of respiratory tract infections by 2.3 times. These results corroborate observations in other developing regions, where indoor air pollution is a significant cause of respiratory diseases [9].

Ecological and temporal influences

Seasonal fluctuations in PM concentrations markedly affected health outcomes. Particulate matter (PM) concentrations increased by 45–60% during the dry season, with East Kalimantan exhibiting the most significant rise at 55%, followed by Central Java at 50% and West Kalimantan at 45%. Temperature and relative humidity were significant environmental predictors [10], with temperature exhibiting a positive correlation with PM levels ($\beta=0.42$, $p<0.001$) and relative humidity demonstrating an inverse association ($\beta=-0.38$, $p<0.001$). These findings highlight the necessity for seasonal actions, including enhanced monitoring and the advocacy of clean energy sources during seasons of peak pollution [11], because pollution, especially PM, varies greatly between dry and rainy seasons. Agricultural fire, biomass cooking, and industrial emissions increase PM concentrations and respiratory health hazards during the dry season [12]. Tracking pollution levels and intervening quickly during peak pollution periods requires increased surveillance. Promoting clean energy sources like cleaner cooking technologies and renewable energy can minimise biomass and fossil fuel use, reducing pollution during these key seasons and improving air quality and public health.

Prospective directions and policy proposals

The study's results highlight the necessity for specific actions to reduce PM exposure and its related health effects. Immediate steps must emphasize the promotion of clean cooking technologies, the enhancement of household ventilation, and the implementation of stronger limits on agricultural and industrial emissions. Moreover, targeted measures targeting region-specific hazards, such as enhanced regulations on mining emissions in East Kalimantan and alternatives to biomass cooking in Central Java, are essential. Future research ought to investigate long-term health outcomes and broaden assessments to metropolitan environments for a more thorough comprehension of PM-related health hazards [13, 14].

Conlusion and implication

This study establishes a robust correlation between increased particulate matter (PM) concentrations and respiratory tract infections (RTIs) in rural Indonesian populations. Quantitative results indicate that PM2.5 and PM10 levels frequently surpassed WHO recommendations, especially in the agricultural areas of Central Java (PM2.5: 42.8±10.2μg/m³; PM10: 68.5±15.8μg/m³), exhibiting notable seasonal variations. Mining-adjacent and coastal regions had elevated PM levels, associated with heightened RTI prevalence: 65% in East Kalimantan, 57% in Central Java, and 48% in West Kalimantan. Regression study indicated that temperature, humidity, and wind speed are significant factors affecting PM concentrations.

Nevertheless, certain restrictions must be recognised. The study's sample size, although sufficient for the examined regions, may not comprehensively represent the diversity of rural populations throughout Indonesia, potentially constraining the generalisability of the results. Moreover, biases in self-reported data from interviews and surveys may affect the precision of health evaluations. Subsequent study ought to rectify these shortcomings by broadening the participant demographic and utilising more objective metrics for environmental exposure and health consequences.

The importance of these findings transcends academic comprehension, with practical ramifications for clinical practice and health policy. The results underscore the necessity for evidence-based policies that advocate for cleaner technologies, more stringent emissions regulations, and improved healthcare access in rural regions. This work establishes a basis for future research, especially in investigating long-term health consequences, assessing intervention efficacy, and measuring pollution exposure in urban environments. The study emphasises the critical necessity for cohesive environmental and public health initiatives to enhance respiratory health and alleviate the incidence of respiratory tract infections in rural Indonesia.

Furthermore, the paper presents the innovative viewpoint that region-specific policies should incorporate community-driven initiatives to address these difficulties successfully. By concentrating on the distinct environmental and cultural conditions of each place, forthcoming initiatives might be customised to concurrently diminish pollution and bolster public health resilience. This method underscores the essential requirement for interdisciplinary cooperation among environmental scientists, public health experts, and local legislators to attain sustainable advancements.

Ethics statements

The Authors have read and followed the ethical requirements for publication in Societal Impacts and confirm that the current work does not involve human subjects, animal experiments, or any data collected from social media platforms.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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