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Determination of the Effects of Exposure to Emissions from Chemical Industry on Health, Environment and Regulation

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Abstract: Rapid industrial growth in various regions of Indonesia has contributed significantly to the national economy. Pollution of air, water, and soil has become a critical concern when industrial activities are not managed in accordance with sustainability principles. This study aims to analyze the impact of emission exposure and operational activities of the chemical industry on public health, environmental conditions, and compliance with environmental regulations. A mixed-method approach was applied, combining quantitative and qualitative analyses. Quantitative data were obtained through air quality measurements and analyzed using linear regression and correlation techniques, while qualitative data explored regulatory compliance in greater depth. The findings reveal a positive correlation between increased emission exposure and higher incidences of respiratory disorders within the community. Environmental degradation was also evident, particularly in declining air quality and damage to surrounding vegetation. Although industrial practices generally comply with local environmental regulations, cases of Acute Respiratory Infections continue to rise. This indicates that regulatory compliance alone is insufficient to mitigate health risks. Therefore, stricter emission monitoring, improved transparency in environmental reporting, and enhanced community involvement are essential to support more sustainable and responsive industrial policies.

Keywords: Environmental pollution; Industrial emissions; Mixed Method; Public Health

Introduction

Rapid industrial growth in various regions has become an important part of socio-economic development (Ostro et al., 2024). One example is the existence of Chemical Industry which has made a real contribution in opening up employment opportunities and encouraging infrastructure disposal in the surrounding area. However, behind these positive impacts there are consequences that cannot be ignored, namely the risk of exposure to emissions that can endanger public health and damage the environment (Ofremu et al., 2025).

For residents living around industrial areas, clean air, clear water, and a healthy environment are not just basic rights, but daily needs that determine their quality of life (Zhao et al., 2024). When the air they breathe every day contains hazardous substances such as carbon monoxide (CO), sulfur dioxide (CO2), nitrogen oxides (NOx), and fine particles (PM), the risk of anxiety disorders, heart disease, and decreased immunity also increases significantly (Alves et al., 2025). Various studies including WHO (2021) have shown the serious impact of industrial pollution on human health, especially for vulnerable groups such as children and the elderly (Bruyneel et al., 2025).

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In addition to the impact on humans, the physical environment such as air, land and water are also under pressure due to industrial activities that are not environmentally friendly (Vojtisek-Lom et al., 2025). Pollutants from emissions can disrupt soil fertility, pollute water sources, and even disrupt local ecosystems. If this continues without proper control, there will be a real threat to environmental sustainability and natural carrying capacity in the future (Rincon et al., 2025).

In Indonesia, regulations have been established that regulate emission limits and industrial responsibilities in protecting the environment, such as Law No. 32 of 2009 and various derivative technical regulations (Ehman et al., 2025). However, in reality, the implementation of these regulations is often not optimal. Violations are still found, both due to weak supervision and low industry awareness in implementing sustainability principles (Paramati et al., 2025).

Based on the results of the environmental monitoring evaluation of Chemical Industry in 2021 conducted by the Environment Department, chimney emissions from units 9101 and 9201 are still below the established quality standard threshold (Chemical Industry, 2021). The main parameters such as particulates, SO2 and NO2recorded within the safe range, with the highest values still far below the maximum allowable limit. Emission opacity was also consistently below 20%, indicating good combustion quality (Chemical Industry, 2021). In addition, the exhaust gas flow velocity and O2 content2demonstrates stable and efficient operational performance (Chong et al., 2025). This finding reflects the Company's commitment to air pollution control and is an important foothold in efforts to continuously improve environmental performance and regulatory compliance (Roy et al., 2024).

Seeing this reality, this research is important to do. Not only to measure the extent to which emissions from Chemical industry have an impact on health and the environment, but also to assess whether the Company's operational practices are in accordance with standard regulations (Li et al., 2023). Because, efforts to improve environmental quality and public health are not enough with policies on paper, they need strong data and a comprehensive approach (Wu et al., 2024).

However, previous studies have focused on only one aspect, such as health or environmental aspects, without linking both to regulatory compliance as a whole (Iungman et al., 2024). In fact, these three aspects are interrelated and must be seen as a whole. Therefore, this study carries a mixed methods approach in order to be able to answer the complexity of the problem holistically (Manqele et al. 2024).

This research is important to conduct because the rapid growth of the chemical industry not only contributes to economic development but also poses serious risks to environmental quality and public health, particularly in areas located near industrial zones. Although, administratively, industries have complied with government-established emission standards, empirical findings indicate a continued increase in respiratory disorders such as Acute Respiratory Infections (ARI) among surrounding communities. This suggests a gap between regulatory compliance and actual impacts in the field (Etuman et al., 2024). Therefore, this study is crucial to comprehensively examine the relationship between emission exposure, environmental conditions, and public health using both quantitative and qualitative approaches. Furthermore, this research serves as a scientific basis for evaluating the effectiveness of existing environmental policies and provides strategic recommendations for governments and industries to improve emission management in a more sustainable manner while prioritizing public health protection (S. Liu et al., 2024). The novelty of this study lies in the integration of emission dispersion modeling, statistical analysis, and regulatory evaluation within a single comprehensive framework, enabling a more holistic assessment of industrial impacts compared to previous studies that tend to focus on only one aspect.

Method

Research Approach

This research used mix method approach. Quantitative approaches were used to measure and analyze emissions data, air quality and impacts on public health, while qualitative approaches were used to understand the regulatory context and industry compliance with environmental policies (K. Zheng et al., 2025).

Location and Research Objects

The research was conducted around a chemical company's industrial area, focusing on an area potentially directly impacted by industrial emissions, namely the Ciwandan sub district in Cilegon City. This area was chosen because it is located within a close radius of large-scale industrial activity, thus posing a high risk of air pollution and its impact on public health. Furthermore, the Ciwandan sub district reflects the dynamics between industrial and residential environments, making it a relevant location for examining the relationship between industrial emissions, environmental conditions, and community well-being holistically.

Data Collection Techniques

Quantitative data includes: air quality measurements and public health data. Qualitative data includes in-depth interviews and document studies. Document analysis and qualitative techniques were used to gain a deeper understanding of the relationship between air quality and public health. Document analysis involved reviewing the content of reports, regulations, and policies through a process of identifying, coding, and extracting key themes. Meanwhile, qualitative data analysis from in-depth interviews involved transcribing, coding, grouping themes, and interpreting the meanings emerging from community perceptions and experiences. The results of these two techniques were then linked to quantitative data such as air quality measurements and health statistics (ARI, asthma, etc.) to provide a more meaningful and relevant overview to support evidence-based policy formulation (Broster et al., 2025).

Data Analysis Techniques

Quantitative analysis includes correlation analysis and linear regression using SPSS and ALOHA. Qualitative analysis includes thematic analysis (Hatef et al., 2025).

Result and Discussion

Emission Exposure and Environmental Quality

Chemical Industry is located in the strategic industrial area of Cilegon City, Banten, an area known as the heart of the national chemical industry. Its proximity to the Port, distribution lines, and energy infrastructure makes this factory an important center in the inorganic chemical supply chain in Indonesia. To support the air pollution control system, the plant is equipped with seven units of chimneys (scrubbers), namely SC-60, SC-47, SC-59, SC-2047, SC-2059, SC-3815, and SC-3823. Each scrubber functions to handle specific emissions based on the type of reactor or industrial process stage connected.

The main sources of emissions come from various inorganic chemical production processes, including acid-base neutralization, fluoride compound synthesis and reactions of reactive gases such as ammonia and chlorine. These processes produce gas residues that must be strictly controlled because they contain hazardous substances such as NH_3, NO_2, HCL and H_2S.

Table 1. Estimated Pollutant Exposure from 7 Chimneys of PT. Chemical Industry

Code	Substance	Contingency (mg/m^3)	Flow Rate (m^3/s)	Mass Rate of Substance (kg/s)	Duration (Minutes)	Amount of Substance Entered (Gram)	Danger Zone (m)	Level ERPG
SC-60	NH3	0.2	0.805410	1.61x10-7	30	0.290	60	ERPG-1
SC-60	HF	0.4	0.805410	3.22x10-7	30	0.580	80	ERPG-1
SC-60	NO2	10	0.805410	8.05x10-6	30	14.490	120	ERPG-2
SC-47	NH3	0.1	1.335285	1.34X10-7	30	0.241	60	ERPG-1
SC-47	Cl2	0.3	1.335285	4.01X10-7	30	0.722	60	ERPG-1
SC-47	HCl	0.7	1.335285	9.35X10-7	30	1.683	80	ERPG-1
SC-59	NH3	0.1	1.031667	1.03X10-7	30	0.185	60	ERPG-1
SC-59	NO2	2.0	1.031667	2.06X10-6	30	3.708	120	ERPG-2
SC-2047	HCl	0.9	1.510144	1.36X10-6	30	2.448	80	ERPG-1
SC-2047	HF	0.6	1.510144	9.06X10-7	30	1.631	80	ERPG-1
SC-2047	H2S	0.2	1.510144	3.02X10-7	30	0.544	60	ERPG-1
SC-3823	HF	1.0	0.534821	5.35X10-7	30	0.963	80	ERPG-1
SC-2059	NH3	0.2	1.123456	1.20X10-7	30	0.216	60	ERPG-1
SC-2059	HF	0.3	1.123456	3.10X10-7	30	0.558	80	ERPG-1
SC2059	NO2	2.0	1.123456	1.00X10-6	30	1.800	120	ERPG-2
SC-3815	HCl	0.7	1.223456	1.10X10-6	30	1.980	80	ERPG-1
SC-3815	Cl2	0.3	1.223456	3.00X10-7	30	0.540	60	ERPG-1
SC-3815	HF	1.0	1.223456	4.50X10-7	30	0.810	80	ERPG-1

To find out the extent of this emission exposure, ALOHA software is used to check each chimney and its emission exposure distance. The methodological parameters used in the ALOHA simulation include: wind speed, atmospheric stability, air temperature, humidity and wind direction. The list of chemicals simulated from PT.XYZ is: NH_3, HF, NO_2, CL_2, HCL and H_2S. The nature of each substance (toxic, corrosive and irritative). ERGP level used. The following are the results of the analysis of PT. Chemical Industry on Health's emission exposure through ALOHA.

Based on Table 1, it shows that each chimney at Chemical Industryhas a variation in flow paths and contingencies, which results in the mass rate of the intermediate substance is 1.03×10^{-7} up to 8.05×10^{-6}kg/s. assuming a release duration of 30 minutes (equivalent to 1800 seconds), the amount of substance entering the atmosphere ranges from 0.18 grams to 14.49 grams. The substance with the highest emission mass is $NO_2$from the SC-60 chimney, which is 14.49 grams, while the lowest emission is $NH_3$from SC-59 of 0.185 grams.

Based on the Emergency Response Planning Guidelines (ERGP) parameters, the substance NO_2 categorized in ERGP-2 with a danger zone reaching 120 meters, indicating the potential for serious health impacts on individuals exposed for a short period of time. Meanwhile, other substances such as HF, HCl, NH_3, Cl_2, and H_2S is classified as ERGP-1, with a danger zone between 60 and 80 meters, which still has the potential to cause mild to moderate irritation or disturbance, especially in vulnerable groups.

Overall, although the number of substances released seems small, the existence of multiple chimneys and simultaneous exposure to various substances increases the cumulative risk to human health and the environment around the industrial area. Therefore, strengthening the scrubber system, implementing real-time emission monitoring, and evaluating compliance with national emission quality standards need to be a priority in industrial environmental management policies.

Impact on the Environment

The results of the environmental monitoring evaluation at Chemical industry present data on emission measurements and several scrubbers (air pollution control devices) at various production unit points, namely SC-60, SC-47, SC-59, SC-2047, SC-2059, SC-3815 and SC-3823 for semester 1 and semester 2 of 2024, respectively. This evaluation covers 18 applicable environmental standards.

In general, the evaluation results show that all parameters are below the specified standard quality threshold, all measurement points show results between 0.09 and 0.3 mg/m^3. Likewise for parameters chlorine, mercury, lead, arsenic, antimony and cadmium all of which showed results lower than the threshold value, this indicates that the content of this hazardous material is very low or insignificant (Fang et al., 2025).

Temperature parameters vary from 31^{0}C to 57^{0}C this indicates the operating conditions of each*scrubber*. Particulates, one of the important parameters of air pollution, were also recorded far below the threshold of 350 mg/m^3. Sulfur dioxide and nitrogen dioxideas the main pollutant gas is also within safe limits indicating the performance of an effective emission control system (Altaee et al., 2025). The opacity or level of smoke concentration is <20% far below the limit, this indicates that the emissions are clear and not dense (Gu et al., 2024). Overall, the results of this evaluation illustrate that the company's scrubber emission control system is functioning well and effectively (Wang et al., 2025).

Table 2. Environmental Monitoring Evaluation Results Report

Measured parameters	unit	Quality standards	2024													
			Scrubber Emission													
			SC-60		SC-47		SC-59		SC-2047		SC-2059		SC-3815		SC-3823	
			SMT 1	SMT 2	SMT 1	SMT 2	SMT 1	SMT 2	SMT 1	SMT 2	SMT 1	SMT 2	SMT 1	SMT 2	SMT 1	SMT 2
Temperature	˚C	-	34	31	49	57	32	43	42	47	34	32	35	43	40	33
NH_3	mg/m3	0.5	0.09	0.2	0.2	0.2	0.2	0.3	0.09	0.2	0.09	0.2	0.09	0.2	0.1	0.3
Cl_2	mg/m3	10	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
HCl	mg/m3	5	1	0.7	2	1	0.9	1	0.7	0.4	0.3	0.4	0.1	0.5	0.3	0.7
HF	mg/m3	10	0.4	0.5	0.2	1	0.3	1	0.3	0.6	0.2	0.6	0.2	1	0.2	1
NO_2	mg/m3	1000	10	<1	<1	<1	<1	<1	<1	<1	6	4	<1	<1	<1	<1
Opposites	%	35	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Particle	mg/m3	350	7	16	10	5	6	7	2	20	4	13	4	9	12	6
SO_2	mg/m3	800	380	40	<1	<1	<1	<1	40	14	23	17	<1	<1	<1	<1
Zn	mg/m3	50	0.05	0.02	0.04	0.02	0.04	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.05	0.02
H_2S	mg/m3	35	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Pb	mg/m3	12	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.02	<0.01
Hg	mg/m3	5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	mg/m3	8	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0,01	<0.01	<0.01
Sb	mg/m3	8	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cd	mg/m3	8	<0.01	<0.009	<0.01	<0.009	<0.01	<0.009	<0.01	<0.009	<0.01	<0.009	<0.01	<0.009	<0.01	<0.009
Velocity	m/detik	-	11.35	9.47	7.5	8.19	5.7	8.04	13.11	9.54	11.88	7.33	6.6	7.71	7	7.23
O_2	%	-	20.7	20.8	20.2	20.1	20.5	20.9	20.5	19.8	20.7	21	20.5	20.9	20.9	20.7

Impact on Public Health

Based on the results of the ALOHA simulation which shows the existence of a danger zone up to 120 meters from the emission source point, it provides an important indication that people who live or do activities within that radius have the potential to be exposed to toxic gases. Exposure to substances such as nitrogen dioxide, hydrogen fluoride, ammonia and chlorine is known in various medical literature to have accurate and chronic impacts on the respiratory system, eyes, skin and nervous system.

For example, NO_2 which has the highest concentration and danger zone in the simulation results, has been scientifically linked to bronchitis, decreased lung function, and increased risk of asthma, especially in children and the elderly. Likewise, other substances can cause respiratory tract irritation, although included in ERPG-1, it still risks causing eye irritation, throat and mild respiratory disorders, which if it occurs in the long term can worsen the health conditions of individuals who already have comorbidities. This is in line with the findings in the field related to health cases that occurred in the Chemical Industry industrial area which is explained through table 3.

Table 3. Impact of Emissions on Public Health

Location	Total population	Case ISPA %	Information
kepuh	12.500	720 (5.8%)	Close the cemical industry area
Gerem	10.200	610 (6.0%)	Often affected by wind from the chimney
Warnasari	9.500	540 (5.7%)	Near the base metal factory area
Pabean	7.800	430 (5.5%)	Densely populated location and port activity
Ciwandan	13.300	790 (5.9%)	Industrial concentration area
Lebak Denok	8.600	480 (5.6%)	Adjacent to the cement factory area
Total	61.900	3.570 (5.8%)	

Table 3 explains that the impact of industrial emission exposure on public health continues to occur, even though the results of the 2024 environmental monitoring evaluation around the industrial area of Chemical industry have all emission parameters below the standard quality threshold, but several points show values approaching the normal limit, especially for SO compounds.2NH3. However, the results of the ALOHA analysis show that several Chemical industry chimneys release hazardous substances that have health impacts on the surrounding community, especially vulnerable groups such as children, the elderly and people with respiratory diseases. Long-term exposure to these hazardous gases can trigger disorders such as ARI, Chronic Cough and even worsen the heart (Patel et al., 2023).

The fact that the danger zone based on the ALOHA simulation reaches 120m from the chimney indicates that under certain wind conditions or leakage incidents, these gases have the potential to be carried towards residential areas, especially if there is no adequate buffer zone or natural or artificial barrier.

Table 4. Correlations Test

Correlations		Substance con_mg_m3	Wide exp_m2	Duration exp_jam	Total popul	Case ISPA	Percent ISPA
Substance Concentration mg_m3	Pearson Correlation	1	.989**	.998**	.780*	.945**	.903**
	Sig. (2-tailed)		.000	.000	.022	.000	.002
	N	8	8	8	8	8	8
Wide expouse_m2	Pearson Correlation	.989**	1	.994**	.778*	.942**	.893**
	Sig. (2-tailed)	.000		.000	.023	.000	.003
	N	8	8	8	8	8	8
Duration of expouse_hour	Pearson Correlation	.998**	.994**	1	.770*	.946**	.911**
	Sig. (2-tailed)	.000	.000		.026	.000	.002
	N	8	8	8	8	8	8
Total Population	Pearson Correlation	.780*	.778*	.770*	1	.861**	.624
	Sig. (2-tailed)	.022	.023	.026		.006	.099
	N	8	8	8	8	8	8
case_ISPA	Pearson Correlation	.945**	.942**	.946**	.861**	1	.933**
	Sig. (2-tailed)	.000	.000	.000	.006		.001
	N	8	8	8	8	8	8
Percentation_ISPA	Pearson Correlation	.903**	.893**	.911**	.624	.933**	1
	Sig. (2-tailed)	.002	.003	.002	.099	.001	
	N	8	8	8	8	8	8

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

This is also confirmed through analysis using SPSS to find out several things. Hazardous substances to their impact on Public Health. Which is explained through Table 4 total population, Duration of expouse/hour, wide expouse_m^2, substance concentration_mg_m^3.

The results of the person correlation analysis show a very strong and significant relationship between the ALOHA simulation result variables and the impact on Public Health, especially in cases of acute respiratory infections (ARI) (K. Zheng et al., 2025). The concentration of hazardous substances in the air has a very high correlation with the duration of exposure ($r = 0.998$, $p < 0.01$) and the area exposed ($r = 0.989$, $p < 0.01$). This indicates that the higher the levels of toxic substances released into the air, the area and duration of exposure also tend to increase, creating a wider and longer potential hazard for the surrounding community (Alibekov et al., 2025).

Overall, these results provide strong empirical evidence that the ALOHA simulation variables, especially the concentration of substances and duration of exposure, are important indicators that significantly collaborate with the increase in Public Health risks in areas around the Industrial Area. These findings emphasize the importance of air quality monitoring and mitigation of hazardous substance exposure as part of Public Health protection strategies. Next is the ANOVA test in Table 5.

Table 5. ANOVA Test

ANOVA[a]						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	245961.692	4	61490.423	14.578	.026[b]
	Residual	12654.308	3	4218.103		
	Total	258616.000	7			

a. Dependent Variable: ISPA cases

b. Predictors: (Constant), total population, Duration of expouse/hour, wide expouse_m2, substance concentration_mg_m3

Based on the results of the ANOVA analysis, it shows that the regression model involving four predictors, namely the concentration of hazardous substances, area of exposure, duration of exposure and population has a significant effect on ARI cases. A significance value of less than 0.05 indicates that simultaneously, these variables are able to explain the variations that occur in ARI cases meaningfully. Thus, exposure to pollutants measured through the ALOHA simulation result variable by population factor has a significant contribution to the increase in respiratory disorders in the affected areas (Odiete, 2024).

Table 6. Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.975[a]	.951	.886	64.947

a. Predictors: (Constant), total population, Duration of expouse/hour, wide expouse_m2, substance concentration_mg_m3

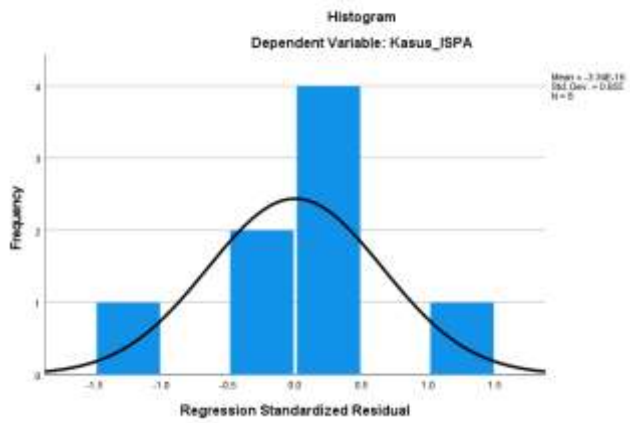

Figure 1. Residual

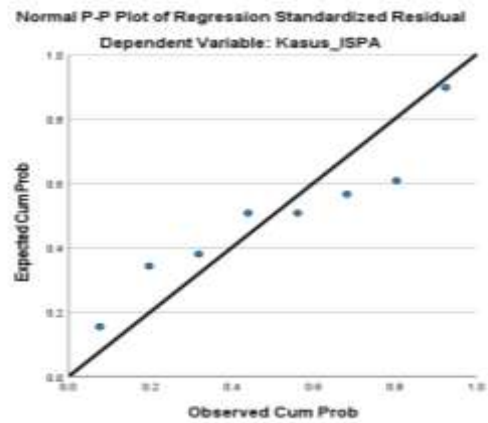

Figure 2. Regress

The histogram results show that the residual distribution pattern forms a systematic bell-like curve, with a peak in the middle and a gradual decrease on both sides. This indicates that the largest residual is normal, which means that the normality assumption has been met. This distribution is important because in regression analysis. The conformity of the histogram shape with the normal distribution supports the validity of the regression model used to predict the number of ARI cases based on the ALOHA assumption result variables.

Government Regulations

Regulation of the Minister of Industry and Trade of the Republic of Indonesia No. 13/MPP/Per/1/1995

Related to the results of the analysis of the impact of exposure to hazardous substances on Public Health, especially the increase in ARI, this finding has a very relevant relationship with the regulation of the Minister of Industry and Trade of the Republic of Indonesia No. 13 / MPP / 1995 concerning the control of industrial air emissions through the installation of air pollution control devices (Scrubber). The histogram results in the regression model show a normal residual distribution, indicating that the prediction model of ARI cases due to exposure to hazardous substances from factory chimneys is valid and statistically reliable (Paiva et al., 2024).

These findings are reinforced by in-depth interviews with several residents of Ciwandan Village, who reported frequent respiratory problems such as chronic coughing, shortness of breath, and a burning sensation in the nose and throat, particularly when the industrial chimneys are actively emitting thick smoke. One informant even noted that "children around here often cough, especially when the wind blows from the factory." These complaints are consistent with the increase in acute respiratory infections (ARI) cases recorded in public health data.

This reinforces the urgency of implementing the Ministerial Regulation. With statistical evidence that the concentration of substances and duration of exposure are strongly associated with increased respiratory disorders in the community, failure to implement scrubbers effectively can be considered a violation of the principle of health protection (Fellini et al., 2024).

It can be concluded that the valid statistical regression results support the need for optimal implementation of technical regulations such as scrubbers. In the context of Chemical industry, this provides scientific evidence that the effectiveness of scrubbers is not only a legal obligation, but also a social and public health responsibility, as emphasized in Permenperindag No.13 of 1995 (H. Zheng et al., 2024).

Decree of the Minister of State for the Environment No. 13 of 1995 Attachment VB Regarding Emission Quality Standards for Stationary Sources

In an effort to ensure environmental quality and public health, the Indonesian government through the Decree of the Minister of State for the Environment No. 13 of 1995 Attachment VB has set emission quality standards for stationary sources, which specifically regulate the maximum limits of air pollutants that may be emitted from industrial chimneys. These quality standards serve as a legal benchmark to ensure that industrial emissions do not have a negative impact on the environment and public health (Suprijanto et al., 2025).

According to the environmental evaluation report from 2021-2024, this Chemical Industry Company has every scrubber that meets the established quality standards. Administratively, it can be seen that various hazardous substances produced from the industrial process at this Chemical Company are still below the quality standard threshold. This explains that the emission control system such as scrubbers is working properly (Pappin et al., 2024).

However, the findings of the regression model in this study show something different regardless of technical compliance, empirical data shows a significant correlation between the duration and concentration of exposure with an increase in ARI in the surrounding community. One of the concerns is the NO_2 substance from the SC-60 chimney which although it does not exceed the threshold limit, has an incoming substance amount of 14.49 grams in 30 minutes, and a danger zone of 120 meters which is categorized at the ERPG-2 level, meaning it has the potential to cause moderate to severe health effects if inhaled for one hour.

Thus, there is an urgent need to review the effectiveness of the regulatory approach that only relies on technical thresholds, without considering the accumulation of long-term risks. Furthermore, the results of this evaluation encourage the industry not to only rely on control systems such as scrubbers as a form of legal obligation, but as part of a social commitment to maintaining air quality and Public Health.

Government Regulation No. 66 of 2014 Concerning Environmental Health

In an effort to maintain public health from the risk of air pollution, government regulation No. 66 of 2014 concerning environmental health is a very important legal basis. This regulation explicitly states that any implementation of activities that have the potential to cause health problems due to changes or environmental pollution must be supervised and controlled by industry and government. In the context of Chemical industry as one of the chemical industries operating in the Ciwandan industrial area, Cilegon, it has a direct responsibility to ensure that air emissions from its production process do not exceed the threshold that can endanger the surrounding community.

In general, Chemical industry has implemented industries in accordance with laws and regulations by routinely conducting environmental evaluations and government supervision in accordance with regulatory standards.

Regulation of the Minister of Health (Permenkes) No. 1077/Menkes/Per/V/2011

Regulation of the Minister of Health (Permenkes) No. 1077/Menkes/Per/V/2011 concerning Guidelines for Indoor Air Health provides quantitative limits for various types of air pollutants that have an impact on health. Although the focus of this regulation is on indoor spaces, the threshold values set, such as ammonia which is limited to 0.2 ppm, are an important reference for industrial emission control efforts, including around residential areas. If the ALOHA results show that the concentration of substances from Chemical industry's chimney approaches or exceeds the safe limit, then this condition can be categorized as a potential threat to public health, especially related to respiratory diseases such as ARI (Y. Liu et al., 2025).

Based on the results of the ALOHA simulation and statistical analysis that have been carried out, it can be concluded that the concentration of hazardous substances in the air, such as ammonia, shows a value that is close to the safe threshold according to Permenkes no. 1077/Menkes/Per/V/2011, which is 0.2 ppm. This is an indicator that emissions from industrial chimneys have a risk level to public health.

The results of regression and statistical correlation show that the concentration of substances, the area of exposure, and the duration of exposure have a very significant and strong relationship to ARI in the area around the industry. This finding is supported by the R square value of 0.951, which means that the ALOHA simulation result variable explains 95.1% of the variation in the number of ARI cases.

Based on PP no. 66 of 2014 concerning environmental health, every industry is required to ensure that its impact does not cause health problems to the community, however, with the discovery of a strong correlation between industrial emissions and increased ISPA, this is an indication that air pollution control has not been running optimally, and Chemical industry has not fully complied with the principles of the regulation.

Conclusion

Although data shows that all emissions from chemical companies are below the established quality standard threshold, this does not fully guarantee that emission controls have been effective in protecting public health. Results of the ALOHA model analysis and SPSS regression indicate a significant relationship between emission exposure and the increase in ARI (acute respiratory infection) cases in the surrounding area, indicating the continued potential for environmental health risks. These findings emphasize that compliance with technical standards alone is insufficient, especially without an evaluation of actual impacts on the ground. Therefore, corrective actions are needed in the form of comprehensive environmental audits, optimization of the performance of air pollution control equipment such as scrubbers, and ongoing monitoring to ensure that industrial activities do not violate the community's right to a clean and healthy environment.

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Author Contributions

Conceptualization, Priscaningtyan; methodology, Priscaningtyan and Widya Ernayati; software, Priscaningtyan; validation, Widya Ernayati and Robby Zidny; formal analysis, Priscaningtyan; investigation, Priscaningtyan; resources, Widya Ernayati; data curation, Priscaningtyan; writing original draft preparation, Priscaningtyan; writing review and editing, Widya Ernayati and Robby Zidny.

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Conflicts of Interest

The authors declare no conflict of interest.

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