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Research article

Environmental impact analysis of air pollution resulting from narcotics destruction in South Sulawesi

Sudarianto[1,*], Sukri Palutturi[2] and Hasmin[3]

[1] Environmental Science Doctoral Study Program, Postgraduate School, Hasanuddin University, Makassar 90245, Indonesia
[2] Health Administration and Policy Department, Faculty of Public Health, Universitas Hasanuddin, Indonesia
[3] Graduate School, Hasanuddin University, Makassar 90245, Indonesia

* **Correspondence:** Email: sudarku@gmail.com; Tel: +6282343434368.

Abstract: The destruction of narcotics evidence through open burning has the potential to generate air pollutants that adversely affect environmental quality and human health. Although this method is widely used for evidence disposal, limited studies have evaluated the characteristics of pollutant emissions and their environmental impacts. This study aimed to analyze the effects of air pollution resulting from the open burning of narcotics evidence in South Sulawesi and to identify mitigation strategies based on an industrial ecology approach. A field experimental study with a spatial–temporal design was conducted by measuring five air pollutants (SO_2, NO_2, O_3, NH_3, and CO) using an Impinger Gas Sampler. Measurements were performed at three observation periods (before, during, and after burning) and three monitoring distances (0, 100, and 200 m). Differences in pollutant concentrations across observation periods were analyzed using the Friedman test, while simple linear regression was applied to evaluate the relationship between monitoring distance and pollutant concentrations. The Friedman test demonstrated significant differences in pollutant concentrations across observation periods ($P < 0.05$), with concentrations increasing markedly during burning and declining afterward, although remaining above baseline levels. Linear regression analysis revealed a strong negative relationship between distance and pollutant concentrations ($R^2 = 0.750 – 0.993$), indicating that pollutant levels decreased with increasing distance. Dispersion modeling estimated that O_3 and NO_2 could travel approximately 1384 and 1337 m, respectively, whereas NH_3 dispersed over approximately 412 m. These findings indicate that emissions from narcotics burning may affect both local and regional air quality. From an industrial ecology perspective, open burning is inconsistent with closed-

loop system principles because it releases unmanaged atmospheric emissions. Open burning of narcotics evidence significantly contributes to air pollution and may impact surrounding communities beyond the burning site. The adoption of environmentally sustainable destruction technologies, such as controlled incineration equipped with emission filtration systems, is recommended to reduce pollutant emissions and support environmentally responsible evidence disposal.

Keywords: air pollution; narcotics burning; environmental impact; pollutant dispersion; industrial ecology

1. Introduction

Drug abuse is not only an urgent public health issue but also has significant impacts on the physical environment. Activities associated with the production, distribution, and consumption of illicit drugs frequently contribute to ecosystem degradation through various mechanisms, including deforestation, water contamination, and soil toxification caused by the uncontrolled use of hazardous chemicals such as chemical fertilizers and pesticides [1]. These environmental impacts create multidimensional challenges involving complex interactions between public health, social conditions, and the physical environment, as highlighted by several academic studies and international reports [2].

Drug abuse has long been recognized as a global issue requiring serious attention from governments and international organizations. According to the United Nations Office on Drugs and Crime, approximately 296 million people worldwide used illicit drugs, and this number continues to increase annually [3]. Beyond its substantial social, health, and economic consequences, drug abuse also generates significant environmental impacts. In particular, the combustion of narcotic substances can release hazardous air pollutants into the atmosphere, including carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter ($PM_{2.5}$ and PM_{10}), and other toxic compounds [4]. Consequently, emissions generated during narcotics destruction may contribute to deteriorating air quality and increase risks to public health [5].

Air pollution generated from illegal drug burning has been shown to increase atmospheric concentrations of fine particulate matter ($PM_{2.5}$), posing serious risks not only to human health but also to overall air quality [6]. In urban environments, increased concentrations of air pollutants have also been associated with a higher frequency of emergency hospital visits related to substance use disorders [7].

Indonesia is one of the countries facing substantial challenges related to illicit drug trafficking and abuse. The National Narcotics Agency reported that the annual prevalence of drug abuse in Indonesia reached approximately 1.73% of the population aged 15–64 years, representing around 3.33 million users in 2023. As part of law enforcement activities, confiscated narcotics are routinely destroyed to prevent their redistribution into illegal markets [8]. However, these destruction processes are frequently conducted through open burning without adequate emission control systems, thereby creating additional environmental problems in the form of air pollution [9]. Large-scale burning of narcotics has the potential to release toxic emissions, increase the risk of respiratory diseases, and further deteriorate ambient air quality, particularly in areas surrounding the destruction sites [10].

The destruction of confiscated narcotics through combustion also poses significant risks to the physical environment. According to reports from the South Sulawesi Provincial National Narcotics Agency, the destruction of confiscated narcotics using an incinerator still generated hazardous emissions, as demonstrated by an incident in which an officer responsible for evidence destruction

experienced acute poisoning and remained unconscious for three days. These findings raise concerns regarding both occupational health and environmental safety during narcotics destruction activities [11].

The physical environmental impacts associated with drug abuse are closely linked to social environmental degradation. Communities with a high prevalence of drug abuse often experience increased crime rates, social disintegration, and stigmatization of affected individuals [12]. The interaction between physical environmental degradation and social deterioration creates a vicious cycle that reduces community well-being and quality of life, highlighting the need for more comprehensive and integrated intervention strategies [13].

Exposure to air pollutants has direct adverse effects on human health, particularly on the respiratory and cardiovascular systems [14]. Fine particulate matter ($PM_{2.5}$), due to its extremely small particle size, can penetrate deep into the pulmonary alveoli and enter the bloodstream, leading to chronic diseases such as asthma, bronchitis, and lung cancer [15].

In addition, air pollution resulting from combustion releases fine particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), and volatile organic compounds (VOCs), all of which contribute to the deterioration of local air quality. Previous studies have also demonstrated that the open burning of narcotics generates hazardous pollutants, including ozone (O_3) and nitrogen dioxide (NO_2), which may induce respiratory and cardiovascular disorders.

Several international studies have investigated the environmental impacts of illicit drug laboratories [16]. For example, research conducted in Australia reported that waste generated from methamphetamine production caused air and water contamination in residential environments surrounding clandestine laboratories [17]. However, similar studies remain limited in Indonesia, making this research particularly relevant for addressing the existing knowledge gap in South Sulawesi, one of the major narcotics distribution hubs in eastern Indonesia.

Based on an extensive review of the available literature, no previous study has specifically examined the environmental impacts of air pollution resulting from the destruction of confiscated narcotics [18]. Therefore, this study aimed to quantitatively measure the concentrations of gaseous air pollutants using an Impinger Gas Sampler during the destruction of confiscated narcotics in South Sulawesi. The findings are expected to enrich the scientific literature on the relationship between narcotics control activities and environmental protection, while also providing practical evidence to support the development of environmentally sustainable policies for the destruction of confiscated narcotics.

Although previous studies have extensively examined environmental contamination associated with illicit drug production and laboratory activities, little attention has been paid to the environmental consequences of narcotics destruction, particularly emissions generated during the official destruction of confiscated narcotics. To the best of our knowledge, no published study has quantitatively evaluated gaseous air pollutants emitted during narcotics destruction under actual operational conditions [19]. Consequently, scientific evidence regarding the magnitude of pollutant emissions, their spatial dispersion, and the associated environmental risks remains unavailable. This lack of evidence represents a critical knowledge gap because the destruction of confiscated narcotics is routinely conducted as part of law enforcement activities, yet its potential environmental impacts have not been adequately incorporated into environmental management or public health policies. Without reliable emission data, it is difficult to assess environmental exposure risks, establish evidence-based regulatory standards, or develop environmentally sustainable destruction technologies [20].

Therefore, this study was conducted to quantitatively measure the concentrations of gaseous air pollutants generated during the official destruction of confiscated narcotics using open burning under

actual operational conditions in South Sulawesi, Indonesia. Beyond reporting pollutant concentrations, this study integrates spatial–temporal monitoring, statistical analysis, and theoretical dispersion modeling to characterize the environmental behavior of combustion emissions. This approach provides a new scientific framework for evaluating emissions from law-enforcement activities, expands the application of environmental monitoring to forensic and public policy contexts, and contributes to environmental science by providing the first field-based evidence of pollutant dispersion associated with narcotics destruction. The findings are expected to support the development of evidence-based environmental regulations, environmentally sustainable destruction technologies, and risk assessment strategies for protecting both ecosystems and public health.

2. Materials and methods

2.1. Type and design of research

This study employed a field-based quantitative research design with a spatial-temporal approach to assess variations in ambient gaseous pollutant concentrations associated with narcotics destruction activities. The study evaluated five gaseous pollutants: sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), ammonia (NH_3), and carbon monoxide (CO). The spatial and temporal sampling procedures were conducted at predetermined distances and observation periods as described below. Air quality measurements were conducted at three monitoring distances, namely 0 (burning source), 100, and 200 m from the combustion source. This design enabled the assessment of temporal changes in pollutant concentrations as well as the spatial dispersion of pollutants generated during the burning process.

2.2. Research location and time

This study was conducted at the BNN Provinsi Sulawesi Selatan (National Narcotics Agency of South Sulawesi Province), located at Jl. Manunggal No. 22, Maccini Sombala, Tamalate District, Makassar City, South Sulawesi, Indonesia 90224. The location was selected because the South Sulawesi Provincial National Narcotics Agency is an authorized government institution responsible for implementing the prevention, eradication, rehabilitation, and control of narcotics-related activities in South Sulawesi. The site was also selected as the research location because narcotics destruction activities were conducted at this facility, providing an appropriate field setting for assessing changes in ambient gaseous pollutant concentrations associated with the destruction process.

Air sampling was conducted at three predetermined distances from the narcotics destruction point: 0 m, representing the immediate source area; 100 m, representing the intermediate exposure area; and 200 m, representing the farther surrounding area. These distances were established to evaluate the spatial variation of gaseous pollutants generated during the narcotics destruction process.

The study was conducted from June to December 2025. Air samples were collected during scheduled narcotics destruction activities and were categorized into three observation periods: before, during, and after the destruction process. The "before" period represented measurements taken before the destruction activity, the "during" period represented measurements taken while the destruction process was occurring, and the "after" period represented measurements taken after the destruction process had been completed.

2.3. Research instruments, materials, and analytical methods

The instruments and materials used in this study were selected according to the analytical requirements of each gaseous pollutant and the applicable Indonesian National Standards (SNI). The main field instruments included an Impinger Gas Sampler, flow meter, stopwatch, GPS, thermometer, hygrometer, and anemometer. Laboratory analyses were performed using a UV–Visible spectrophotometer for SO_2, NO_2, O_3, and NH_3, while CO was measured directly using a non-dispersive infrared (NDIR) carbon monoxide analyzer.

For the Impinger-based measurements, pollutant-specific absorbing solutions were used to collect the target gases. Analytical reagents included tetrachloromercurate (TCM) absorbing solution and pararosaniline reagents for SO_2 determination; Griess–Saltzman reagent for NO_2 determination; neutral buffered potassium iodide (NBKI) solution for O_3 determination; and sulfuric acid absorbing solution, phenol, and sodium hypochlorite reagents for NH_3 determination. Appropriate standard solutions were used for calibration according to the respective analytical procedures. Reagent-grade chemicals and mineral-free/deionized water were used for solution preparation.

The determination of SO_2, NO_2, O_3, and NH_3 was performed using the respective analytical procedures specified in SNI 19-7119.7-2017 for ambient air quality measurement. CO was determined using the NDIR method according to SNI 7119.10:2011. Sample preparation, measurement, and calculation of pollutant concentrations followed the applicable SNI procedures.

2.4. Air sampling procedure

Air sampling was conducted during official narcotics destruction activities in South Sulawesi from June to December 2025. The sampling design incorporated three spatial locations and three temporal observation periods. Spatial sampling locations were established at the destruction point (0 m), 100 m from the destruction point, and 200 m from the destruction point. At each distance, measurements were conducted during three periods: before, during, and after the narcotics destruction process.

SO_2, NO_2, O_3, and NH_3 were collected using an Impinger Gas Sampler containing the appropriate absorbing solution for each pollutant. The instrument was positioned at the predetermined sampling distance, and ambient air was drawn through the corresponding absorbing solution. The sampling flow rate, sampling duration, volume of absorbing solution, and sample treatment followed the procedures specified in the applicable SNI methods. After sampling, the absorbing solutions were labeled according to the sampling location and observation period and were subsequently analyzed in the laboratory using the corresponding analytical methods.

CO was not collected using the Impinger system. Instead, CO concentrations were measured directly at each sampling location and observation period using an NDIR-based CO analyzer in accordance with SNI 7119.10:2011. Instrument zero and calibration checks were performed using the appropriate reference gases before measurements.

At each spatial location, meteorological conditions, including air temperature, relative humidity, wind speed, and wind direction, were recorded as supporting information during sampling. GPS was used to document the sampling locations and their distances from the destruction point.

The prevailing wind conditions during sampling were recorded to support the interpretation of pollutant dispersion. Meteorological conditions were considered in interpreting the measured pollutant concentrations, particularly O_3, because its formation can be influenced by atmospheric and photochemical conditions.

The narcotics destruction process was conducted according to the operational procedures of the

authorized institution. The study focused on measuring ambient gaseous pollutant concentrations generated during the destruction process under the actual field conditions. Specific combustion parameters, such as combustion temperature, oxygen concentration, and residence time, were not directly measured and were therefore not included in the quantitative analysis.

The laboratory procedures for air pollutant analysis consisted of a series of steps, including air sample collection, sample transfer, chemical analysis, instrumental measurement, and data recording and validation. Quality control procedures, including instrument calibration and the use of appropriate blanks or standards, were implemented in accordance with the applicable analytical procedures. The overall workflow of the laboratory procedures for air pollutant analysis is presented in Figure 1. The combination of three distances (0, 100, and 200 m) and three observation periods (before, during, and after destruction) resulted in nine spatiotemporal sampling combinations for each pollutant at each sampling event. The same sampling framework was applied to all five target pollutants to facilitate comparisons of pollutant concentrations across monitoring distances and observation periods.

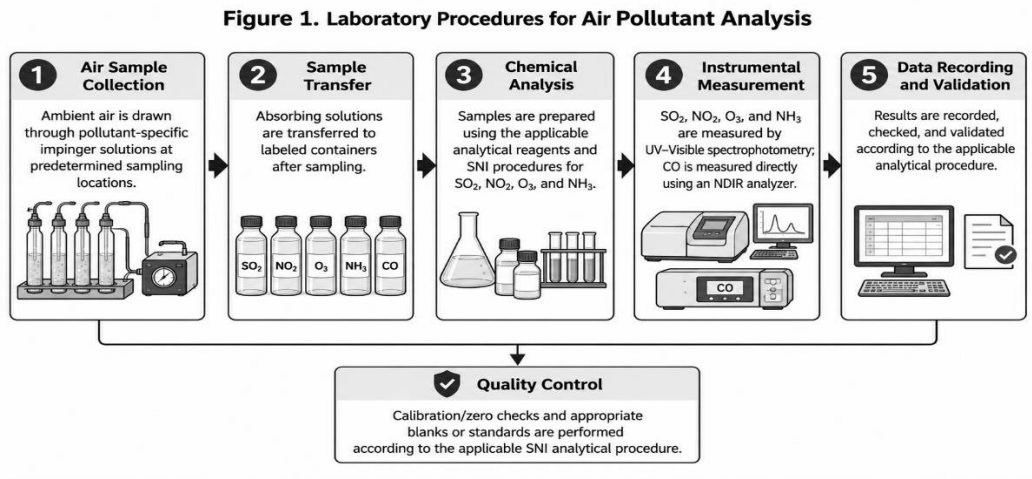


Figure 1. Laboratory procedures for air pollutant analysis.

2.5. Data processing and analysis

The collected data were coded, verified, and entered into an electronic database before statistical analysis. Descriptive statistics were used to summarize the concentrations of gaseous air pollutants according to observation period and monitoring distance. Differences in pollutant concentrations among the three observation periods were analyzed using the Friedman test, a nonparametric statistical method suitable for repeated measurements obtained from related samples. Statistical significance was established at $P < 0.05$.

To evaluate the influence of monitoring distance on pollutant concentrations, simple linear regression analysis was performed using the equation:

$$Y = a + bX$$

where Y represents the pollutant concentration, and X represents the monitoring distance from the burning source. The coefficient of determination (R^2) was calculated to estimate the proportion of variation in pollutant concentrations explained by monitoring distance. A p-value of < 0.05 was considered statistically significant. The study protocol was conducted with authorization from the relevant authorities responsible for narcotics destruction activities. All air sampling procedures were

performed without interfering with the operational process of evidence destruction and complied with applicable occupational safety and environmental monitoring procedures.

3. Results

The study was conducted from June to December 2025 at an official narcotics destruction site in South Sulawesi, Indonesia. Ambient air quality was monitored before, during, and after the destruction of confiscated narcotics using open burning. Air samples were collected at three monitoring distances (0, 100, and 200 m from the burning source) to evaluate temporal changes and the spatial dispersion of gaseous pollutants. Five air quality parameters were analyzed, including sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), ammonia (NH_3), and carbon monoxide (CO).

Table 1 shows that all measured pollutants increased substantially during the combustion process. Sulfur dioxide increased from 8.76 μg/m ^{3} before burning to 14.46 μg/m ^{3} during burning, while nitrogen dioxide increased from 7.27 to 24.79 μg/m ^{3}, representing the largest relative increase among the gaseous pollutants. Ozone concentrations also increased markedly from 21.88 μg/m ^{3} before combustion to 68.06 μg/m ^{3} during combustion before decreasing after burning. Similarly, ammonia concentrations increased from 0.0168 to 0.3488 ppm, whereas carbon monoxide increased from 5 ppm before burning to 45 ppm during combustion and remained elevated at 35 ppm after the burning process. The SO_2, NO_2, and O_3 concentrations measured during the sampling periods were below their respective 1-h ambient air quality standards. For NH_3, a direct comparison with the Indonesian national ambient air quality standard could not be made because NH_3 is not included among the ambient air quality parameters regulated under Appendix VII of Government Regulation No. 22 of 2021. The measured concentrations in this study represent concentrations during the respective sampling periods and should therefore not automatically be interpreted as 24-h average concentrations.

Table 1. Ambient air pollutant concentrations at the burning source (0 m) before, during, and after narcotics destruction.

Parameter	Unit	Before	During	After	Air quality standard (averaging period)
SO_2	μg/m ^{3}	8.755	14.457	12.085	150 μg/m ^{3}(1 h)
NO_2	μg/m ^{3}	7.267	24.786	17.676	200 μg/m ^{3}(1 h)
O_3	μg/m ^{3}	21.875	68.060	38.083	150 μg/m ^{3}(1 h)
NH_3	ppm	0.0168	0.3488	0.0498	Not specified
CO	ppm	5	45	35	Applicable standard according to the relevant averaging period

Table 2 demonstrates that elevated pollutant concentrations were still detected at a distance of 100 m from the combustion source. All pollutants followed the same temporal pattern observed at the source location, with peak concentrations occurring during burning followed by partial declines after combustion. The measured SO_2, NO_2, and O_3 concentrations remained below their respective 1-h ambient air quality standards. NH_3 concentrations increased substantially during the destruction process; however, direct comparison with the Indonesian national ambient air quality standard was not possible because no ambient air quality standard for NH_3 is specified in Appendix VII of Government Regulation No. 22 of 2021. As with the measurements at 0 m, the observed concentrations represent the respective sampling periods and should not be interpreted as 24-h average concentrations. Although pollutant concentrations generally decreased compared with measurements at the burning

source, the results indicate that combustion emissions continued to affect air quality within at least a 100-m radius.

Table 3 indicates that pollutant concentrations gradually decreased with increasing distance from the burning source. Nevertheless, all monitored pollutants remained higher during combustion than before burning. The measured SO_2, NO_2, and O_3 concentrations remained below their respective 1-h ambient air quality standards. NH_3 concentrations increased during combustion, but they could not be directly compared with an Indonesian national ambient air quality standard because NH_3 is not regulated as an ambient air quality parameter under Appendix VII of Government Regulation No. 22 of 2021. The concentrations reported in Table 3 represent the respective sampling periods rather than 24-h average concentrations. These findings indicate that gaseous pollutants generated during narcotics destruction were dispersed beyond the immediate combustion area and remained detectable at least 200 m from the emission source.

Table 2. Ambient air pollutant concentrations at 100 m from the burning source.

Parameter	Unit	Before	During	After	Air quality standard (averaging period)
SO_2	μg/m ^{3}	9.019	14.457	13.653	150 μg/m ^{3}(1 h)
NO_2	μg/m ^{3}	7.289	24.754	18.653	200 μg/m ^{3}(1 h)
O_3	μg/m ^{3}	23.589	62.425	31.553	150 μg/m ^{3}(1 h)
NH_3	ppm	0.0107	0.2852	0.0929	Not specified
CO	ppm	5	40	35	Applicable standard according to the relevant averaging period

Table 3. Ambient air pollutant concentrations at 200 m from the burning source.

Parameter	Unit	Before	During	After	Air quality standard (averaging period)
SO_2	μg/m ^{3}	8.622	11.761	10.724	150 μg/m ^{3}(1 h)
NO_2	μg/m ^{3}	7.187	20.982	16.835	200 μg/m ^{3}(1 h)
O_3	μg/m ^{3}	22.694	58.257	27.668	150 μg/m ^{3}(1 h)
NH_3	ppm	0.0156	0.1759	0.0464	Not specified
CO	ppm	6	32	28	Applicable standard according to the relevant averaging period

Figure 2 illustrates the temporal and spatial variations in ambient air pollutant concentrations measured at three monitoring distances (0, 100, and 200 m) before, during, and after narcotics destruction by open burning. All pollutants exhibited a consistent temporal pattern, with concentrations increasing markedly during combustion and decreasing after burning, although post-combustion levels generally remained higher than baseline values. Sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) increased during the burning process but remained below the Indonesian ambient air quality standards for the applicable 1-h averaging period at all monitoring distances. In contrast, NH_3 concentrations increased substantially during combustion, but no direct comparison with a national ambient air quality standard was made because NH_3 is not included in Appendix VII of Government Regulation No. 22 of 2021. The CO concentrations also increased during and after combustion; however, interpretation relative to the regulatory standard requires consideration of the applicable averaging period and unit conversion. A gradual reduction in pollutant concentrations with increasing distance from the combustion source was observed for all parameters, reflecting the atmospheric

dispersion and dilution of gaseous emissions. Nevertheless, the persistence of elevated NH_3 and CO concentrations at distances up to 200 m suggests that open burning during narcotics destruction may adversely affect ambient air quality beyond the immediate combustion area and potentially expose nearby communities to harmful air pollutants.

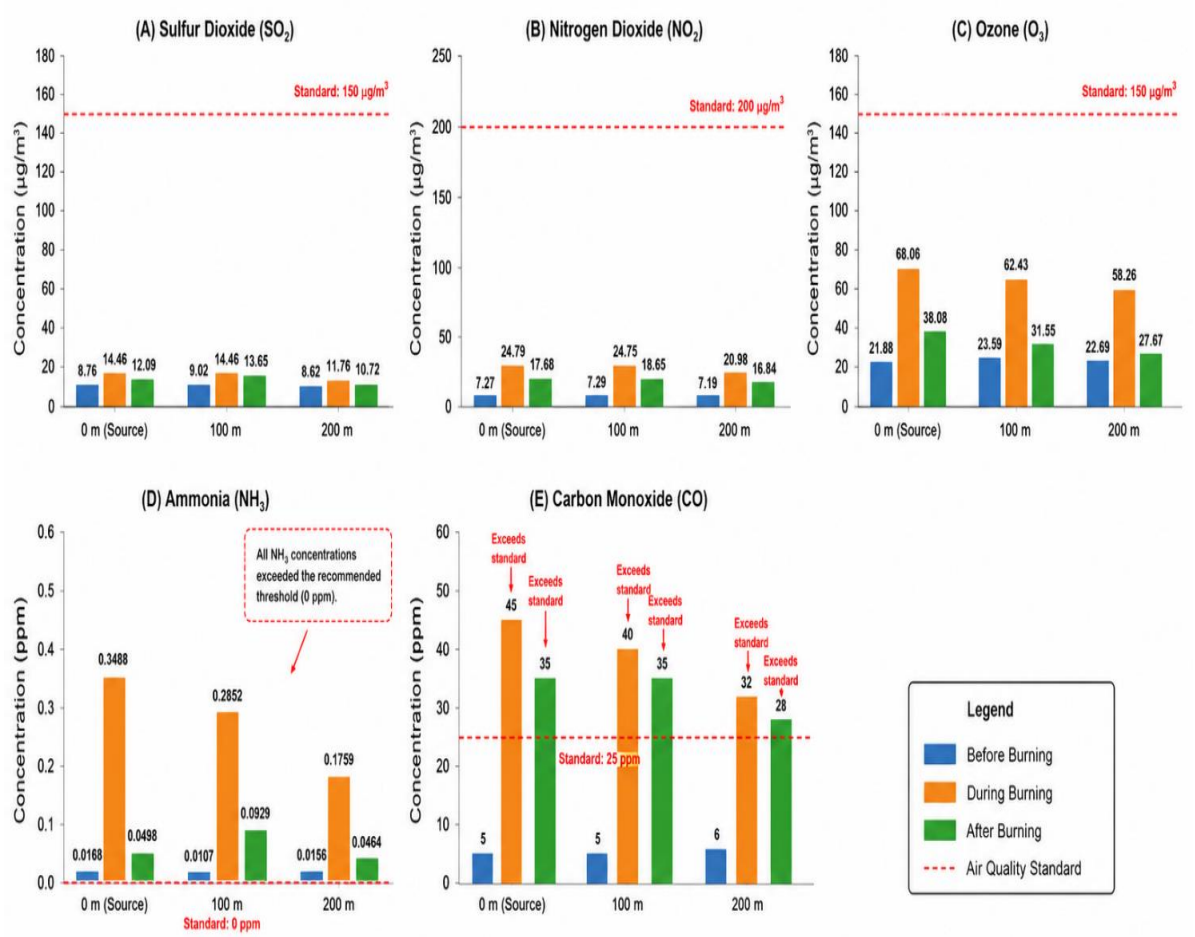


Figure 2. Temporal and spatial variations in ambient air pollutant concentrations during narcotics destruction by open burning.

Table 4 shows that the Friedman test revealed statistically significant temporal differences in the concentrations of all measured pollutants across the three observation periods ($P < 0.05$), indicating that pollutant levels increased significantly during combustion and decreased after burning, although post-combustion concentrations remained above baseline levels. Linear regression analysis demonstrated a consistent negative relationship between monitoring distance and pollutant concentration, as indicated by the negative regression coefficients for all pollutants. Ozone ($R^2 = 0.993$), carbon monoxide ($R^2 = 0.983$), and ammonia ($R^2 = 0.977$) exhibited the strongest relationships with monitoring distance, suggesting that distance explained more than 97% of the observed variability in their concentrations. Sulfur dioxide ($R^2 = 0.750$) and nitrogen dioxide ($R^2 = 0.760$) also showed substantial distance-dependent reductions. Based on the regression models, the estimated theoretical dispersion distances indicated that ozone (1,384 m), nitrogen dioxide (1,337 m), and sulfur dioxide (1,106 m) could potentially remain detectable over distances exceeding 1 km from the combustion source, whereas carbon monoxide (700 m) and ammonia (412 m) were projected to disperse over relatively

shorter distances. These findings suggest that emissions generated during narcotics destruction by open burning may affect ambient air quality beyond the immediate vicinity of the combustion site.

Table 4. Statistical analysis and estimated dispersion distances of ambient air pollutants during open burning of narcotics.

Parameter	Friedman test χ^2	p-value	Regression equation	R^2	Estimated dispersion distance (m)
SO_2	6.00	0.0498	$SO_2 = 14.91 - 0.0135X$	0.750	1106
NO_2	6.00	0.0498	$NO_2 = 25.41 - 0.0190X$	0.760	1337
O_3	6.00	0.0498	$O_3 = 67.82 - 0.0490X$	0.993	1384
NH_3	6.00	0.0498	$NH_3 = 0.356 - 0.000864X$	0.977	412
CO	6.00	0.0498	$CO = 45.50 - 0.0650X$	0.983	700

4. Discussion

This study provides quantitative evidence that official destruction of confiscated narcotics through open burning can temporarily alter ambient air quality. The findings demonstrated that the combustion process significantly altered ambient air quality, as indicated by substantial increases in sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), ammonia (NH_3), and carbon monoxide (CO). Across all monitoring locations, pollutant concentrations consistently increased during combustion and declined after burning; however, post-combustion concentrations remained higher than baseline levels. Statistical analysis using the Friedman test confirmed significant temporal differences among the three observation periods ($P < 0.05$), indicating that open burning had a measurable impact on ambient air quality.

The "before" measurements in this study provide a site-specific baseline representing ambient conditions immediately before the destruction activity. However, these values should not be interpreted as the usual or long-term background concentrations of the surrounding area because the study did not include continuous or repeated ambient air monitoring under non-destruction conditions. Therefore, the observed increases during combustion are more appropriately interpreted as short-term changes associated with the destruction event. Official comparison values are available through the Indonesian national ambient air quality standards specified in Appendix VII of Government Regulation No. 22 of 2021. The regulation specifies different averaging periods depending on the pollutant: SO_2 and NO_2 have standards for 1-h, 24-h, and annual averaging periods, whereas CO and O_3 have standards for 1-h and 8-h averaging periods. NH_3 is not included as an ambient air quality parameter in Appendix VII; therefore, the NH_3 concentrations measured in this study cannot be directly classified as exceeding an Indonesian national ambient air quality standard.

Although SO_2, NO_2, and O_3 remained below the Indonesian National Ambient Air Quality Standards for the applicable averaging period used for comparison, their concentrations increased markedly during combustion. For NH_3, the substantial increase during combustion is considered an observed emission-related change rather than an exceedance of a national ambient air quality standard because no national ambient standard for NH_3 is specified in Appendix VII of Government Regulation No. 22 of 2021. Similarly, interpretation of CO concentrations in relation to the regulatory standard should consider the applicable averaging period and the measurement unit. The concentrations obtained in this study represent the respective sampling periods and should not automatically be

interpreted as 24-h average concentrations. These findings indicate that narcotics combustion generated both primary pollutants directly released from combustion and potential secondary pollutants formed through atmospheric reactions. The simultaneous increase in NO_2 and O_3 may be associated with photochemical processes involving nitrogen oxides and other reactive compounds under suitable atmospheric conditions [21]. The persistence of elevated pollutant concentrations after combustion further suggests that pollutant dispersion and atmospheric dilution require considerable time before ambient conditions return to baseline.

Among the measured pollutants, CO and NH_3 deserve particular attention because both showed substantial increases during the destruction process. However, the NH_3 concentrations should not be described as exceeding a national ambient air quality standard because no such standard is specified in Appendix VII of Government Regulation No. 22 of 2021. Elevated CO concentrations may indicate incomplete combustion resulting from insufficient oxygen supply during open burning [22]. Carbon monoxide readily binds with hemoglobin to form carboxyhemoglobin, thereby reducing oxygen transport to body tissues and increasing the risk of acute toxic effects among exposed individuals [23]. Likewise, NH_3 concentrations increased sharply during combustion, suggesting the thermal decomposition of nitrogen-containing compounds within the destroyed narcotics and associated chemical materials [24]. Ammonia is recognized as a respiratory irritant capable of inducing eye irritation, airway inflammation, and adverse respiratory symptoms following acute exposure. Therefore, the observed increases in CO and NH_3 support the need for appropriate occupational exposure controls during destruction activities, particularly for personnel located close to the combustion source [25].

The spatial analysis revealed a clear decline in pollutant concentrations with increasing distance from the combustion source. Measurements obtained at 100 and 200 m consistently showed lower concentrations than those recorded directly at the burning site, indicating that atmospheric dispersion effectively diluted emitted pollutants. Nevertheless, pollutant concentrations at both distances remained substantially higher than baseline conditions, demonstrating that emissions continued to influence ambient air quality beyond the immediate combustion area. This observation is consistent with Gaussian plume theory, which explains that pollutant concentrations decrease progressively because of atmospheric diffusion, advection, and turbulent mixing. However, dilution does not occur instantaneously, allowing pollutants to remain detectable over considerable distances following emission [26].

Regression analysis further confirmed a strong inverse relationship between distance and pollutant concentrations. High coefficients of determination were observed for all measured pollutants, particularly O_3 ($R^2 = 0.993$), CO ($R^2 = 0.983$), and NH_3 ($R^2 = 0.977$), indicating that distance explained most of the observed variability in pollutant concentrations. These findings are consistent with previous atmospheric dispersion studies reporting that pollutant concentrations decrease predictably as distance from emission sources increases. Nevertheless, the persistence of detectable pollutant concentrations at 200 m indicates that atmospheric dilution alone is insufficient to eliminate exposure immediately after combustion.

An important contribution of this study is the estimation of theoretical pollutant dispersion distances based on regression models. O_3 exhibited the longest estimated dispersion distance (approximately 1.38 km), followed by NO_2 (1.34 km), SO_2 (1.11 km), CO (700 m), and NH_3 (412 m). These distances should be interpreted as theoretical estimates derived from the observed distance–concentration relationships rather than as actual plume travel distances. The actual transport and dispersion of pollutants are strongly influenced by wind speed, wind direction, atmospheric stability, temperature, humidity, and other meteorological conditions. Because complete wind speed and wind direction data were not

available for incorporation into the dispersion analysis, the estimated distances cannot be used to define the actual geographic extent of pollutant dispersion. The results therefore indicate a potential dispersion pattern rather than a definitive exposure radius. The longer predicted transport distance of O_3 is scientifically plausible because ozone is a secondary pollutant that can be formed through photochemical reactions involving nitrogen oxides and other reactive compounds [27]. However, the absence of complete meteorological data limits the extent to which this mechanism and the predicted O_3 transport distance can be confirmed under the specific field conditions of this study.

The findings should also be interpreted in relation to the absence of long-term background monitoring at the study site. The "before" concentrations provide useful short-term baseline information for the destruction event, but they cannot be considered representative of the normal annual or seasonal air quality of the surrounding area [28]. Future studies should therefore include repeated measurements on non-destruction days and, where possible, use data from the nearest official ambient air quality monitoring station as an external reference. This approach would allow the contribution of narcotics destruction to be distinguished more clearly from routine urban background pollution [29].

From a scientific perspective, this study contributes to environmental science in several important ways. First, it demonstrates that official narcotics destruction by open burning can produce measurable short-term changes in ambient gaseous pollutant concentrations. Second, by combining spatial–temporal monitoring with regression-based dispersion modeling, this study introduces a practical approach for evaluating pollutant transport from non-industrial combustion sources under real operational conditions. Third, the estimated relationships between distance and pollutant concentration provide preliminary information that can support environmental exposure assessment and the design of future monitoring strategies, although they should not be interpreted as definitive dispersion distances in the absence of meteorological modeling. These findings extend current knowledge beyond conventional studies of industrial and biomass combustion by identifying law-enforcement activities as an additional potential environmental emission source that should be considered in future environmental monitoring and air quality management frameworks.

Compared with previous studies, this research fills an important knowledge gap regarding environmental pollution associated with official narcotics destruction [30]. Earlier investigations have primarily focused on contamination originating from clandestine drug laboratories and illegal methamphetamine production, demonstrating contamination of soil, indoor environments, and wastewater [31]. Studies evaluating emissions generated during official destruction activities remain extremely limited. Consequently, this study extends current knowledge by demonstrating that government-authorized destruction activities themselves constitute an identifiable source of atmospheric pollution [32]. The results therefore broaden the environmental perspective of narcotics control by highlighting that destruction practices intended to protect public health may simultaneously generate secondary environmental risks when performed through uncontrolled open burning.

From the perspective of industrial ecology, the present findings demonstrate that narcotics destruction should be recognized as a special category of hazardous waste management rather than merely a law-enforcement procedure. The study therefore expands the application of industrial ecology principles to evidence destruction activities by demonstrating that emission control, material containment, and environmental monitoring should become integral components of sustainable narcotics disposal systems. This perspective broadens the scope of industrial ecology from conventional industrial processes to government operational activities that generate environmental emissions [33]. Such an approach is inconsistent with the principles of sustainable waste management, which emphasize pollution prevention and emission minimization throughout the waste management

cycle [34]. From a mitigation perspective, open burning should be minimized or replaced with a controlled destruction system that provides better control of combustion conditions and gaseous emissions. Where technically and legally feasible, high-temperature incineration equipped with appropriate air-pollution control systems, such as gas scrubbing and particulate control, should be considered. Destruction activities should be conducted in designated areas with restricted access and appropriate exclusion zones, while personnel should use suitable respiratory and personal protective equipment. Environmental monitoring should be integrated into the destruction protocol, including measurements before, during, and after destruction, together with meteorological monitoring of wind speed and direction. Destruction should preferably be postponed under meteorological conditions that could increase pollutant accumulation or transport toward nearby populated areas. These measures would help reduce environmental emissions and occupational exposure while supporting safer and more sustainable narcotics destruction practices [35]. In addition, destruction activities should be conducted in designated areas with restricted access, appropriate worker exclusion zones, and suitable respiratory and other personal protective equipment. Continuous or real-time monitoring of key pollutants, particularly CO, together with meteorological monitoring of wind speed and direction, would provide an additional basis for determining safe operational conditions. Destruction activities should also be avoided or postponed under meteorological conditions that may increase exposure to nearby workers or communities, where operationally feasible.

Environmental monitoring should form an integral part of the destruction protocol. Before each destruction event, baseline measurements should be obtained; during destruction, real-time or short-interval monitoring should be conducted; and post-destruction monitoring should continue until pollutant concentrations approach pre-event conditions. Establishing a standardized environmental monitoring protocol would provide evidence for determining appropriate exclusion zones and identifying conditions under which destruction activities should be temporarily suspended.

The findings also have important implications for occupational and public health. Elevated concentrations of CO and NH_3 observed during destruction activities indicate that law enforcement personnel conducting combustion operations may experience short-term exposure to hazardous gases, particularly when appropriate respiratory protection and exclusion zones are not implemented [36]. However, the present study did not directly assess individual exposure or health outcomes; therefore, these findings indicate potential exposure rather than demonstrated health effects. The theoretical regression estimates also suggest that several pollutants may remain detectable with increasing distance, but these estimates should not be interpreted as confirmed community exposure distances because meteorological conditions were not incorporated into the model. Accordingly, environmental risk assessment should become an integral component of narcotics destruction procedures, including routine air quality monitoring, establishment of evidence-based safety zones, meteorological monitoring, worker protection, and adoption of cleaner destruction technologies to minimize environmental emissions.

Several limitations should be acknowledged when interpreting these findings. Measurements were conducted during a single narcotics destruction event at one official destruction site, limiting the generalizability of the results to other locations and destruction scenarios. Monitoring was restricted to three observation periods and three sampling distances. Complete wind speed and wind direction data were not systematically measured during the sampling periods; therefore, a wind-rose analysis could not be performed. Consequently, the regression-derived dispersion distances represent theoretical estimates and should not be interpreted as actual plume trajectories or definitive exposure boundaries. Comprehensive meteorological parameters, including atmospheric stability, temperature, and relative humidity, were also not systematically recorded, limiting the assessment of their influence

on pollutant dispersion and ozone formation. Furthermore, analytical method validation parameters, including selectivity, sensitivity, linearity, limit of detection (LOD), and limit of quantification (LOQ), were not comprehensively evaluated in this study. Only gaseous pollutants were measured, whereas particulate matter ($PM_{2.5}$ and PM_{10}), volatile organic compounds, polycyclic aromatic hydrocarbons, dioxins, furans, and heavy metals were not evaluated despite their potential importance during combustion processes. Detailed combustion parameters, including oxygen concentration, combustion temperature, residence time, and the type or amount of additional fuel used during narcotics destruction, were not measured; therefore, their specific contribution to pollutant formation could not be quantitatively assessed. In addition, long-term background air-quality monitoring outside the destruction event was not conducted. Finally, this study assessed environmental exposure without evaluating biological exposure or health outcomes among workers and surrounding communities. Future research should therefore include repeated observations during multiple destruction events, concurrent meteorological measurements, comprehensive analytical method validation, non-destruction background monitoring, detailed characterization of combustion conditions, and broader pollutant monitoring. Advanced dispersion modeling incorporating wind speed, wind direction, atmospheric stability, and other meteorological parameters should also be applied to obtain more reliable estimates of pollutant transport and potential exposure areas.

5. Conclusions

This study demonstrates that the open burning of confiscated narcotics significantly affects ambient air quality by increasing the concentrations of SO_2, NO_2, O_3, NH_3, and CO. Friedman test results ($P < 0.05$) confirmed significant temporal differences in pollutant concentrations before, during, and after combustion, with peak concentrations occurring during the burning process. Although SO_2, NO_2, and O_3 remained below the Indonesian ambient air quality standards, NH_3 and CO exceeded the permissible limits, indicating potential environmental and public health risks. Regression analysis showed a strong negative relationship between distance and pollutant concentrations ($R^2 = 0.75 – 0.993$), confirming that atmospheric dispersion reduces pollutant levels with increasing distance; however, several pollutants, particularly O_3 and NO_2, were estimated to disperse beyond 1 km from the emission source. Beyond demonstrating the environmental impacts of open burning during narcotics destruction, this study provides an important scientific contribution to environmental science by establishing the first field-based evidence of pollutant generation and atmospheric dispersion associated with official narcotics destruction activities. The integration of spatial–temporal monitoring with dispersion modeling offers a novel framework for evaluating environmental emissions from law-enforcement operations and can be adapted to other non-industrial combustion activities. These findings provide scientific support for the development of evidence-based environmental regulations, air quality management strategies, and sustainable hazardous waste destruction technologies, thereby strengthening the integration of environmental protection into narcotics control policies.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare that they have no conflicts of interest.

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