

Environmental Health Risk Assessment (EHRA) Of Carbon Monoxide (CO) Exposure Among Fuel Station Operators At Gas Stations In Kota Baru District In 2026

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Abstract

This study aims to analyze environmental health risks caused by carbon monoxide (CO) exposure among gas station operators in Kota Baru District, Jambi City, in 2026 using the Environmental Health Risk Assessment (EHRA) method with a quantitative descriptive approach. The research was conducted from January to February 2026 and involved 61 respondents from five gas stations: SPBU 24.361.70, 24.361.51, 24.361.04, 24.361.13, and 24.361.58. Data collection was carried out through direct measurement of CO concentration using the AS8700A CO meter, wind speed measurement using an anemometer, temperature and humidity measurement using a thermohygrometer, and structured interviews regarding exposure characteristics. The results revealed that two locations showed unsafe risk levels under realtime conditions, namely SPBU 24.361.04 with a Risk Quotient (RQ) value of 1.187 and SPBU 24.361.51 with an RQ value of 1.073, both exceeding the safe threshold ($RQ > 1$). The highest CO concentration was recorded at SPBU 24.361.51, reaching 11.9443 mg/m³. The most dominant health complaints experienced by respondents were fatigue (54.1%) and dizziness (34.4%). Nevertheless, the 30-year lifetime risk projection indicated that all study locations remained within the safe category, with RQ values below 1.

Keywords: EHRA, Carbon Monoxide, Risk Quotient, Gas Station Operators, CO Exposure.

INTRODUCTION

Toxicants are toxic chemical substances that can disrupt the biological functions of the human body through environmental or occupational exposure. Toxicants refer to exogenous chemical compounds with toxic properties that can cause cellular damage through mechanisms such as binding to hemoglobin or inhibiting mitochondrial respiration. Examples include gases such as carbon monoxide (CO) originating from vehicle emissions, which are undetectable by human senses because they are odorless, colorless, and non-irritating to the mucosa. Carbon monoxide (CO) is classified as a systemic toxicant and an asphyxiant, meaning that it adversely affects the respiratory system.

Carbon monoxide (CO) is one of the major air pollutants produced by the incomplete combustion of fossil fuels, particularly from motor vehicles. CO is odorless and highly toxic, and inhalation over a certain period may lead to various serious health disorders. In acute conditions, CO exposure may cause mild symptoms such as headaches, dizziness, fatigue, nausea, and shortness of breath, while severe exposure may result in cardiovascular disorders, heart attacks, and death due to systemic hypoxia. Under chronic exposure conditions, CO increases the risk of hypertension (an increase in systolic blood pressure of up to 15 mmHg), coronary heart disease, stroke, chronic obstructive pulmonary disease (COPD), bronchitis, and respiratory disorders among workers. Carbon monoxide enters the body primarily through inhalation. The gas is inhaled through the nose or mouth, passes through the alveoli into the blood plasma, then enters red blood cells and binds with hemoglobin to form carboxyhemoglobin (COHb). This process occurs more rapidly than elimination because of the high concentration gradient and the extensive gas exchange surface area in the lungs. The primary target organs of carbon monoxide are the brain and the heart. Exposure to CO reduces the blood's oxygen-carrying capacity because CO competes with oxygen for binding sites on hemoglobin within red blood cells. Carbon monoxide is classified as a non-carcinogenic substance because it does not directly induce cancer but instead causes acute toxic effects such as respiratory impairment and hypoxia.

Global data indicate that in the United States, more than 40,000 cases of CO toxicity result in emergency department visits annually, with approximately 14,000 cases requiring hospitalization.

Among these cases, 10% experience partial recovery, 23–47% develop delayed neurological sequelae, and 2% result in death. Furthermore, data from the American Association of Poison Control Centers (AAPCC) in 2023 recorded 13,681 single-exposure CO poisoning cases, including 352 intentional cases, 372 severe outcomes, and 46 deaths. In Indonesia, national epidemiological data regarding carbon monoxide poisoning remain limited; however, CO poisoning incidents are diverse and potentially fatal. For example, in 2025, at least two CO poisoning incidents resulted in fatalities, including the fire at the Terra Drone shophouse in Kemayoran, Central Jakarta, which caused the deaths of 22 individuals. The Police Medical Service Bureau (Rodokpol) of the National Police Medical and Health Center (Pusdokkes Polri) stated that inhalation of carbon monoxide was the primary cause of death among the victims of the Terra Drone building fire.

In Jambi Province, research conducted by Nadilah in 2024 at the Simpang Rimbo intersection revealed that the highest CO concentration reached 279,424.4 $\mu\text{g}/\text{Nm}^3$ during the afternoon due to heavy traffic congestion, exceeding the permissible threshold and reflecting conditions similar to those found at heavily trafficked gas stations. In the same year, a CO poisoning incident occurred in Dusun Limbur Baru SP 5, Limbur Lubuk Mengkuang District, Bungo Regency, Jambi Province. A family of four suffered carbon monoxide poisoning while inside a Xenia vehicle. The victims were suspected to have died from inhaling CO gas originating from vehicle exhaust fumes trapped inside the car because the exhaust pipe was submerged in water.

According to data from the World Health Organization (WHO) presented in the official WHO Global Air Quality Guidelines document, the recommended concentration limits for carbon monoxide exposure to minimize health risks are as follows: the maximum CO concentration for short-term exposure (8 working hours) is approximately 10 mg/m^3 (equivalent to 9 ppm); for long-term exposure (24 hours), WHO recommends maintaining CO levels below 4 mg/m^3 . For a 15-minute exposure period, the maximum concentration is 115 mg/m^3 (approximately 100 ppm); for 30 minutes, the time-weighted average exposure limit is 55 mg/m^3 (50 ppm); and for 1 hour, the recommended exposure limit is 29 mg/m^3 (25 ppm). Furthermore, every 5 liters of gasoline can generate approximately 1–1.5 kg of carbon monoxide under conditions of incomplete combustion.

According to data from the Indonesian Central Statistics Agency (Badan Pusat Statistik/BPS), the number of motor vehicles in Indonesia increased significantly from 2021 to 2023, rising from 2,441,636 units in 2021 to 2,726,756 units in 2023. In Jambi Province, the number of motor vehicles in Jambi City fluctuated between 2019 and 2024. In 2019, the number of registered vehicles reached 960,222 units, increasing to 1,005,473 units in 2020. However, in 2021 the number declined sharply to 179,522 units, before increasing again to 779,749 units in 2022. Subsequently, the number decreased to 740,206 units in 2023 and further declined to 586,694 units in 2024. The growing number of motor vehicles contributes to the production of carbon monoxide (CO) emissions, and excessive CO concentrations may poison the human body and lead to various health problems.

Air pollution caused by carbon monoxide is largely generated by motorized transportation activities, which continue to increase in line with the growth in vehicle numbers. In gas station (SPBU) environments, CO concentrations may rise substantially due to the large number of vehicles keeping their engines running while refueling. This condition places fuel station operators at risk of direct and repeated exposure to CO throughout their working hours. Carbon monoxide disrupts oxygen transport in the blood because its affinity for hemoglobin is approximately 140–300 times greater than that of oxygen, thereby reducing the blood's capacity to deliver oxygen to body tissues.

Data from the World Health Organization (WHO) indicate that exposure to CO concentrations exceeding established threshold limits may cause health complaints such as dizziness, headaches, nausea, shortness of breath, and damage to the cardiovascular, hematological, and respiratory systems. Chronic effects resulting from repeated long-term CO exposure have also been documented, particularly among individuals continuously exposed over extended periods. Gas station operators, who work directly in environments with elevated CO concentrations, are therefore considered a vulnerable occupational group susceptible to these adverse health effects.

According to Government Regulation No. 41 of 1999, the permissible threshold limit for CO concentration in workplace air is 10,000 $\mu\text{g}/\text{Nm}^3$. Furthermore, the Minister of Manpower Regulation (Peraturan Menteri Ketenagakerjaan) No. 05 of 2018 establishes an occupational exposure limit of up to 28,630 $\mu\text{g}/\text{Nm}^3$.

At gas stations, fuel attendants are routinely exposed to various air pollutants that may endanger their health. These pollutants include PbCl, PbCO₃ particles, 2PbO, nitrogen dioxide (NO₂), hydrocarbons, and carbon monoxide gas. Such pollutants originate from vehicle emissions during the refueling process as well as from the fuel itself, which releases multiple hazardous compounds into the surrounding environment.

Based on preliminary observations and data obtained from the Directorate General of Oil and Gas (Migas ESDM) as well as district mapping through the official Kotajambisatu website, a total of 25 gas stations were identified within Jambi City. Their distribution varies considerably across districts, including Kota Baru (5 gas stations), Telanaipura (3), Jelutung (2), South Jambi (2), Pasar Jambi (1), East Jambi (2), Alam Barajo (3), Danau Sipin (2), and Paal Merah (3).

This study selected Kota Baru District, Jambi City, as the research location because available data indicate that this district serves as the primary center of fuel distribution, as reflected by the highest concentration of gas stations, totaling five branches with 69 fuel station operators identified during preliminary observations. This high concentration not only facilitates data accessibility but also provides a strong and relevant comparative basis for the study.

Preliminary observational data from the five gas station branches reveal diverse and complex workforce structures within the sector. Significant demographic variations were identified, ranging from the near-total dominance of male workers at the Pal 7 gas station (21 males to 2 females) to the more comprehensive job composition at Talang Gulo, which includes operators, office boys (OB), security personnel, and supervisors. Additionally, the workforce age distribution was largely concentrated within the productive age range of 20–40 years, indicating differences in work dynamics among gas station branches.

A study conducted by Asri Cita in gas stations located in Telanaipura District, Jambi City, reported varying CO gas concentrations across four gas stations, namely 7.5124 mg/m^3 at SPBU 24.361.02, 9.2989 mg/m^3 at SPBU 24.361.03, 9.3218 mg/m^3 at SPBU 24.361.35, and 8.2683 mg/m^3 at SPBU 24.361.41. Based on the environmental health risk assessment conducted in 2022, the Risk Quotient (RQ) values for all fuel operators at these locations were below 1 ($\text{RQ} < 1$). This indicates that no significant health risks associated with carbon monoxide exposure in ambient air were projected for the next 30 years.

In contrast, research conducted by Tiara Agustina at SPBU A identified significant issues related to carbon monoxide concentration levels. The average measured CO concentration during the daytime shift was 37.5 mg/m^3 , while the nighttime shift recorded an average of 31 mg/m^3 . Both values exceeded the safety limits established under SNI 19-7119.6-2005 and Government Regulation No. 41 of 1999, which specify a maximum permissible limit of 29 mg/m^3 . Furthermore, the Risk Quotient (RQ) calculations demonstrated that operators were at risk of adverse health effects because the RQ values exceeded 1 under lifetime exposure scenarios of 20 and 30 years. Specifically, the RQ values were 1.00 for 20-year daytime exposure, 1.355 for 30-year daytime exposure, and 1.121 for 30-year nighttime exposure.

Based on the study conducted by Diah Indriyani, three major factors were found to significantly influence the pulmonary function of gas station operators, namely gender ($p=0.035$), length of employment ($p=0.017$), and smoking habits ($p=0.023$). Furthermore, Linda's²² study involved 23 gas station operators grouped according to their years of service. The first group consisted of seven respondents with a working period of less than three years, while the second group included sixteen respondents with a working period of more than three years. The findings revealed a significant difference in abnormal hemoglobin levels between the two groups. In the group with less than three years of employment, only one respondent exhibited abnormal hemoglobin levels, whereas in the group with more than three years of employment, twelve respondents showed abnormal hemoglobin

levels. Statistical analysis using the Chi-square test yielded a p-value of 0.019. Since the value was lower than 0.05 ($p < 0.05$), the null hypothesis (H_0) was rejected and the alternative hypothesis (H_a) was accepted, indicating that duration of employment significantly affected hemoglobin levels among gas station operators in Jombang.

Similarly, Silmi's study reported that eight out of ten respondents (80%) had normal hemoglobin levels, while only two gas station operators (20%) demonstrated abnormal hemoglobin levels. Several contributing factors were identified, including duration of employment, respondent age, and compliance with the use of Personal Protective Equipment (PPE) during work activities.

The Environmental Health Risk Assessment (Analisis Risiko Kesehatan Lingkungan / ARKL) method can be applied in this study to evaluate the health impacts of air pollution exposure. This method serves as a systematic framework to estimate the level of carbon monoxide (CO) exposure as well as the associated health risks experienced by fuel station operators throughout their occupational period. The ARKL process is structured through several essential stages, including hazard identification, hazard characterization, exposure assessment, dose-response assessment, and risk characterization. Furthermore, if the risk characterization indicates unsafe conditions, the process proceeds to risk management and risk communication. The ultimate objective is to formulate and implement preventive and control measures specifically designed to address and mitigate occupational health risks.

Based on the background and issues discussed above, this study was conducted under the title: Environmental Health Risk Assessment (EHRA) of Carbon Monoxide (CO) Exposure among Fuel Station Operators at Gas Stations in Kota Baru District, 2025.

RESEARCH METHODS

This study employed a quantitative descriptive design using the Environmental Health Risk Assessment (EHRA) approach to measure the level of risk associated with carbon monoxide (CO) exposure among gas station operators in the Kota Baru District in 2026. The research was conducted from January to February 2026, involving a population of 69 gas station operators, all of whom were included as research samples. Data collection was carried out through direct measurement of CO concentration using the AS8700A *CO meter*, wind speed measurement using an *anemometer*, and temperature and humidity measurement using a *thermohygrometer*, as well as direct measurement of respondents' body weight. Exposure-related data, including exposure time, frequency, and duration, were obtained through interviews using structured questionnaires. Air sampling was conducted at three main points, namely the station entrance area, the operator area, and the station exit area, in accordance with the Indonesian National Standard (SNI) 19-7119.9-2005. The research data consisted of both primary and secondary data, which were subsequently processed through the stages of *editing*, *scoring*, *coding*, *tabulating*, *data entry*, and *cleaning* before being analyzed to determine the level of health risk caused by CO exposure in the gas station work environment.

RESULTS AND DISCUSSION

Hazard Identification

Carbon Monoxide (CO) Concentration

The identification of exposure risk was conducted through measurements of Carbon Monoxide (CO) concentrations in ambient air at five gas stations located in Kota Baru District, Jambi City, namely SPBU 24.361.70, 24.361.51, 24.361.04, 24.361.13, and 24.361.58. Data collection was carried out periodically during the morning, afternoon, and evening periods, with a measurement duration of one hour at each of the three designated sampling points using an AS8700A type CO Meter.

Table 1. Carbon Monoxide (CO) concentration at gas stations 24,361.70

Measurement Location	CO Concentration (ppm)			Average Concentration (ppm)
	Point 1 (Entrance)	Point 2 (Pertalite Area)	Point 3 (Exit)	
Morning (07:00–10:00)	6,08	8,5	6,25	6,9
Afternoon (12:00–15:00)	7,25	6,83	6,91	6,9
Evening (15:00–18:00)	6,83	8,66	9,5	8,33
Average Concentration (ppm)	6,72	7,9	7,5	

Based on observations conducted at SPBU 24.361.70, the accumulation of carbon monoxide (CO) gas demonstrated varying distributions across monitoring points. The peak concentration of 9.5 ppm was detected in the exit area (Point 3) during the afternoon period, while the minimum concentration of 6.08 ppm was recorded at the entrance area (Point 1) during morning measurements. Overall, the afternoon period represented the time with the highest pollutant load, with an average concentration of 8.33 ppm. In terms of monitoring locations, the Pertalite filling area exhibited the most significant level of CO pollution, with an average concentration reaching 7.9 ppm.

Table 2. Carbon Monoxide (CO) Concentration at Gas Stations 24,361.51

Measurement Location	CO Concentration (ppm)			Average Concentration (ppm)
	Point 1 (Entrance)	Point 2 (Pertalite Area)	Point 3 (Exit)	
Morning (07:00–10:00)	11,58	10,3	6,91	9,59
Afternoon (12:00–15:00)	7,91	12,5	8,75	9,72
Evening (15:00–18:00)	10,5	10,25	15,25	12
Average Concentration (ppm)	9,99	11,01	10,3	

Based on the research data, there was a considerable fluctuation in CO concentration at the gas station. The peak concentration was detected at the exit area (Point 3) during the afternoon measurement, reaching 15.25 ppm, while the lowest concentration was also recorded at the exit area (Point 3) during the morning period, at 6.91 ppm. On average, Point 2 (the Pertalite dispensing area) was identified as the most affected location by CO pollution, with a mean concentration of 11.01 ppm. In terms of time variation, the highest average CO concentration occurred in the afternoon period, reaching 12 ppm.

Table 3. Carbon Monoxide (CO) Concentration at SPBU 24.361.04

Measurement Location	CO Concentration (ppm)			Average Concentration (ppm)
	Point 1 (Entrance)	Point 2 (Pertalite Area)	Point 3 (Exit)	
Morning (07:00–10:00)	10,75	9,41	5	8,38
Afternoon (12:00–15:00)	7,08	11,25	6,66	8,33
Evening (15:00–18:00)	8,83	11,3	11,41	10,51
Average Concentration (ppm)	8,88	10,65	7,69	

The distribution of CO gas pollutants in the SPBU area showed a maximum concentration of 11.41 ppm, recorded at the exit gate (Point 3) during the afternoon period. In contrast, the lowest CO concentration was detected at the same location (Point 3) in the morning, with a value of 5 ppm. From a spatial perspective, the central area of the SPBU (Point 2) represented the zone with the highest average contamination level, reaching 10.65 ppm. Meanwhile, the afternoon period recorded the most significant average pollutant concentration compared to other time intervals, with a value of 10.51 ppm.

Table 4. Carbon Monoxide (CO) Concentration at SPBU 24.361.13

Measurement Location	CO Concentration (ppm)			Average Concentration (ppm)
	Point 1 (Entrance)	Point 2 (Pertalite Area)	Point 3 (Exit)	
Morning (07:00–10:00)	5	8,25	5	6,08
Afternoon (12:00–15:00)	6,58	7,5	7,5	7,19
Evening (15:00–18:00)	6,75	8,83	6,41	7,33
Average Concentration (ppm)	6,11	8,19	6,3	

The data indicate that the highest fluctuation of Carbon Monoxide (CO) concentration occurred in the Pertalite filling area of the gas station (Point 2), where the concentration reached 8.83 ppm during the afternoon period. In contrast, the lowest concentrations were recorded at two monitoring points, namely the entrance area (Point 1) and the exit area (Point 3), both during the morning measurements. Based on the average concentration by location, Point 2 showed the highest average value at 8.19 ppm. Similarly, in terms of time variation, afternoon measurements produced the highest average CO concentration, reaching 7.33 ppm.

Table 5. Carbon Monoxide (CO) Concentration at Gas Stations 24,361.58

Measurement Location	CO Concentration (ppm)			Average Concentration (ppm)
	Point 1 (Entrance)	Point 2 (Pertalite Area)	Point 3 (Exit)	
Morning (07:00–10:00)	6,08	11,6	6,75	8,14
Afternoon (12:00–15:00)	7,25	9,91	6,83	7,99
Evening (15:00–18:00)	9,16	11,16	11	10,44
Average Concentration (ppm)	7,49	10,89	8,19	

Based on the measurement results, the CO concentration reached its peak in the Pertalite filling area (Point 2) during the afternoon period, with a value of 11.16 ppm. In contrast, the lowest concentration was recorded at the exit area (Point 3) during the morning period, measuring 6.75 ppm. Cumulatively, Point 2 demonstrated the highest average pollutant concentration compared to the other monitoring points, with an average concentration of 10.89 ppm. Meanwhile, the afternoon period represented the time with the most significant average CO exposure, reaching 10.44 ppm.

After obtaining the carbon monoxide (CO) measurement results, the average concentration values for each gas station were calculated and subsequently converted from ppm to mg/m³ as follows:

Table 6. Average Carbon Monoxide (CO) Concentration at Gas Stations in Kota Baru District, Jambi City

Parameter	SPBU 24.361.70	SPBU 24.361.51	SPBU 24.361.04	SPBU 24.361.13	SPBU 24.361.58
Carbon Monoxide (CO)	8,44	11,9443	10,3869	7,856	10,1349
	Mg/m ³	Mg/m ³	Mg/m ³	Mg/m ³	Mg/m ³

Based on the review of the average CO concentration across all observation points, SPBU 24.361.51 was identified as the location with the highest level of air pollution burden, with a concentration of 11.9443 mg/m³. In contrast, relatively better air quality conditions were observed at SPBU 24.361.70, where the lowest CO gas concentration was recorded at 8.44 mg/m³.

Health Complaints

The results obtained through interviews and questionnaire distribution revealed several health complaints experienced by respondents working at gas stations in Kota Baru District. The identified complaints included eye irritation, dizziness, nausea, and fatigue. Detailed information regarding the frequency distribution of these health complaints is presented in the following section:

Table 7. Distribution Analysis of Health Complaints at Gas Stations in Kota Baru District, Jambi City

No.	Health Complaints	Yes		No	
		N	%	N	%
1	Sore Eyes	16	26,2	45	73,8
2	Dizziness	21	34,4	40	65,6
3	Nausea	10	16,4	51	83,6
4	Fatigue	33	54,1	28	45,9

Based on the table above, the highest reported health complaint was fatigue, experienced by 33 respondents (54.1%), while the lowest reported complaint was nausea, experienced by 10 respondents (16.4%).

Table 8. Various Symptoms Experienced by Fuel Station Operators at Gas Stations in Kota Baru District, Jambi City

No.	Reported Symptoms	Frequency	Percentage (%)
1	No symptoms	16	26
2	Dizziness, fatigue	8	13
3	Fatigue	11	18
4	Dizziness	6	11
5	Nausea, dizziness	1	2
6	Nausea, dizziness, fatigue, eye irritation	6	11
7	Eye irritation	3	5
8	Fatigue, eye irritation	7	11
9	Eye irritation	2	3
Total		61	100

Referring to the results presented in Table 8, it can be observed that the majority of respondents among fuel station operators were categorized as asymptomatic, totaling 16 individuals (26%). Meanwhile, the lowest frequency was found for nausea complaints, which were reported by only one respondent (2%).

Exposure Assessment

The parameters used to calculate non-carcinogenic intake were determined based on several data sources. The CO concentration (C) was obtained from the average results of direct measurements conducted at gas stations in Kota Baru District, Jambi City. Meanwhile, body weight (Wb) data were collected through direct physical measurements of the respondents. Information regarding exposure duration (Dt), exposure frequency (fE), and exposure time (tE) was gathered through interviews and research questionnaires.

The intake rate (R) applied in this calculation was 0.83 m³/day, derived using the corrected intake rate formula. In addition, the average time period (tavg) was established at 10,950 days. This value refers to the standard duration applied for non-carcinogenic substances such as CO, calculated based on a 30-year exposure period (30 years × 365 days/year).

Table 9. Distribution of Population Intake Values at Gas Stations in Kota Baru District, Jambi City

No.	Cluster	Lifetime	Realtime
1	SPBU 24.361.70	0,68602mg/kg/day	0,16578mg/kg/day
2	SPBU 24.361.51	0,88763mg/kg/day	0,26977mg/kg/day
3	SPBU 24.361.04	0,98171mg/kg/day	0,16361mg/kg/day
4	SPBU 24.361.13	0,62018mg/kg/day	0,16308mg/kg/day
5	SPBU 24.361.58	0,77790mg/kg/day	0,16422mg/kg/day

Based on the intake estimation results using the mean values, variations in the highest and lowest intake levels were identified across different locations. The highest intake value for the *realtime* category was recorded at SPBU 24.361.51, amounting to 0.26977 mg/kg/day, whereas the highest value for the *lifetime* category was found at SPBU 24.361.04, reaching 0.98171 mg/kg/day. Conversely, the lowest intake value under the *realtime* scenario was observed at SPBU 24.361.13

(0.16308 mg/kg/day), while the lowest value for the *lifetime* scenario was also identified at SPBU 24.361.13 (0.62018 mg/kg/day).

Dose-Response Assessment

The *Reference Concentration* (RfC) value was calculated using concentration variables adjusted to the national ambient air quality standard stipulated in Government Regulation No. 41 of 1999, namely 10 mg/m³. This calculation adopted the default values provided in the Environmental Health Risk Assessment (EHRA/ARKL) guidelines issued by the Ministry of Health of the Republic of Indonesia as intake parameters, including R = 0.83 m³/hour, tE = 8 hours/day, fE = 250 days/year, and Dt = 30 years. By applying a standard body weight value of 55 kg and an average exposure duration (*tavg*) of 10,950 days, the estimated reference value can be formulated using the intake equation below:

$$\text{RfC} = \frac{C \times R \times tE \times fE \times Dt}{Wb \times tavg}$$

$$\text{RfC} = \frac{10 \times 0,83 \times 8 \times 250 \times 30}{55 \times 10950}$$

$$\text{RfC} = \frac{498000}{602250}$$

$$\text{RfC} = 0,826899 \text{ mg/kg/day}$$

Based on Government Regulation (PP) No. 41 of 1999, the safe inhalation threshold or *Reference Concentration* (RfC) for human exposure to carbon monoxide (CO) gas in Indonesia is established at 0.826899 mg/kg/day.

Risk Characterization

Risk characterization is a method used to estimate the level of health risk among populations exposed to specific risk agents. The level of risk is expressed through the *Risk Quotient* (RQ) value, which is obtained by comparing the results of exposure analysis (intake) with the dose-response value (RfC). The calculation results of RQ values for fuel station operators in Kota Baru District, both under present-time (*realtime*) exposure conditions and the projected 30-year (*lifetime*) exposure scenario, are presented as follows:

Table 10. Risk Characterization

No.	Cluster	Nilai RQ	
		Realtime	Lifetime
1	SPBU 24.361.70	0,829634171	0,200494925
2	SPBU 24.361.51	1,073445402	0,32624321
3	SPBU 24.361.04	1,187227477	0,197871246
4	SPBU 24.361.13	0,750009251	0,197224655
5	SPBU 24.361.58	0,940746145	0,198601964

Based on the table above, the results of the risk characterization analysis indicate that under actual exposure duration (*realtime*), respondents at gas stations SPBU 24.361.04 (1.073445402) and SPBU 24.361.51 (1.187227477) experienced potential health risks due to carbon monoxide (CO) exposure. This finding is evidenced by the *Risk Quotient* (RQ) values of several operators at both stations exceeding one ($RQ \geq 1$), which indicates an unsafe exposure level with potential adverse health effects. Considering that the *Environmental Health Risk Assessment* (EHRA) method is also intended to project future health risks, the researchers conducted an additional risk estimation for a 30-year exposure period (*lifetime* scenario). The calculation results demonstrated that the projected RQ values remained within the safe category.

Discussion

Characteristics of Fuel Station Operators

Age is a major risk factor influencing the vulnerability of fuel station (SPBU) operators to carbon monoxide (CO) exposure, due to the decline in lung function and the increased accumulation of toxins with advancing age. A study conducted in vehicle workshops demonstrated a significant relationship between age and blood COHb levels ($p=0.037$, $OR=0.688$), which is comparable to the condition

experienced by SPBU operators exposed to vehicle exhaust emissions. Older workers are at greater risk of acute symptoms such as dizziness, nausea, and shortness of breath caused by hypoxia.

Based on gender distribution, male respondents predominated, totaling 37 individuals (60.7%), while female respondents accounted for 24 individuals (39.3%). This finding supports the study by Ginting et al., which reported that males dominate occupations as fuel station operators. Furthermore, Aulia et al. stated that older age, male gender, and working periods exceeding three years are risk factors for decreased vital lung capacity among SPBU operators ($p < 0.05$). Men are considered more susceptible to pulmonary function decline due to chronic CO exposure.

The educational background distribution showed that the majority of SPBU operators were senior high school/vocational school graduates, totaling 51 individuals (83.6%). A study at Pertamina fuel stations in Medan found a significant relationship between knowledge and compliance with personal protective equipment (PPE) use ($p = 0.008$), as well as between attitude and PPE compliance ($p = 0.003$), despite most respondents having limited knowledge and poor attitudes. This indicates that formal education and training can reduce CO exposure by encouraging protective behavior. Meanwhile, among operators at Gunung Batu fuel stations, good PPE knowledge reached 86.7% due to training; however, actual PPE usage behavior remained poor (100% incomplete use), indicating that educational approaches should be accompanied by adequate PPE facilities.

The research data revealed considerable variation in respondents' body weight, ranging from 48 kg to 89 kg. Excess body weight or obesity affects respiratory health by increasing respiratory rate and altering ventilation mechanisms, making obese SPBU operators more vulnerable to carbon monoxide exposure. A study conducted at UMY found a significant relationship between obesity and respiratory rate ($p = 0.000 < 0.05$), where obesity caused respiratory muscles to work harder due to fat accumulation in the chest wall and abdominal area. This condition increases oxygen consumption and carbon dioxide production, thereby accelerating hypoventilation and CO₂ retention among workers exposed to emissions.

The findings showed that all respondents (61 individuals) had the same daily exposure duration of seven hours. Although all respondents experienced similar exposure durations, they worked in three different shifts. This duration is slightly below the default daily exposure value established by the US-EPA (8 hours/day), but generally aligns with the findings of Farizal et al., who reported similar working durations among SPBU operators. Research by Marisa & Wahyuni (2019) in Bengkulu fuel stations also reported that working an average of seven hours per day caused exposure to lead and CO, which inhibited hemoglobin formation, similar to the findings of this study despite the slightly shorter duration than the eight-hour standard. These findings confirm that even seven hours of exposure is sufficient to contribute to cumulative CO risk.

The average annual exposure frequency varied across locations: 328 days at SPBU 24.361.51, 333.50 days at SPBU 24.361.04, 330 days at SPBU 24.361.70, 326.22 days at SPBU 24.361.13, and 334 days at SPBU 24.361.58. These findings indicate that exposure frequency at all study locations exceeded the US-EPA occupational default value of 250 days/year. These differences were influenced by the internal policies of each SPBU owner regarding employee leave arrangements. Exposure frequency in this study was calculated based on the accumulation of effective working days in one year after deducting leave or holidays. These findings are also consistent with the study by Cita Asri, which reported varying exposure frequencies across different fuel stations.

The exposure duration (Dt) among respondents ranged from one to nineteen years. In this study, exposure duration was defined as the length of time respondents inhaled air containing carbon monoxide in the workplace, measured in years. Normality test results indicated variations in average working duration at each location: SPBU 24.361.51 (9.12 years), SPBU 24.361.04 (5 years), SPBU 24.361.70 (7.25 years), SPBU 24.361.13 (7.89 years), and SPBU 24.361.58 (6.33 years). These findings are consistent with studies conducted at fuel stations in Makassar, which reported that longer working periods influenced increased blood lead (Pb) levels due to bioaccumulation. Increased Pb levels also reflected increased parallel CO exposure from vehicle emissions. This study indicates that

the longer operators work, the more frequently they are exposed to chemical substances (Friska Ayu, Budi Djauday, Aprianita Siregar, Dita Amanda D, Tri Martiana, 2011).

Regarding smoking status, 48 respondents (78.7%) had a smoking history, while 13 respondents (21.3%) were non-smokers. This finding is consistent with research conducted in Gorontalo, which reported that 83.5% of SPBU operators were smokers and that smoking habits were associated with respiratory disorders and reduced lung capacity. Marieta and Lestari, in the *Farmaka* journal, also reported that smoking can cause cardiovascular diseases, cancer, chronic obstructive pulmonary disease (COPD), emphysema, chronic bronchitis, cataracts, osteoporosis, hearing impairment, alopecia areata, infertility, and impotence.

The results involving 61 respondents indicated a relatively high level of compliance with the use of personal protective equipment (PPE). Mask usage was reported by 40 respondents (65.6%), while 20 respondents (32.8%) did not wear masks and 1 respondent (1.6%) only occasionally used a mask. Interestingly, this high level of compliance was not strongly associated with management support, as all five SPBU locations only occasionally provided masks for employees. Similar conditions were observed in glove usage, where 52.5% of respondents (32 individuals) reported wearing gloves, while 44.3% (27 individuals) did not use gloves and 3.3% (2 individuals) rarely used them. However, questionnaire results showed that 78.7% of respondents stated that glove facilities were not provided by management. The primary reasons for reluctance to use PPE were discomfort during work and technical difficulties, such as challenges in handling cash transactions while wearing gloves. These findings align with previous studies showing that PPE compliance is not solely influenced by facility availability, but also by personal awareness and perceived need for self-protection. Marlina's study found that most workers continued to use complete PPE despite limited facilities due to awareness of occupational disease risks. Similarly, Pamela's study at SPBU X Surabaya found that the main causes of PPE non-compliance were human factors, including discomfort, work experience, and lack of managerial supervision.

Hazard Identification

Carbon Monoxide (CO) Concentration

Based on the results of carbon monoxide (CO) concentration measurements conducted at five research locations, the average CO levels were found to be 844 mg/m³ at SPBU 24.361.70, 11.9443 mg/m³ at SPBU 24.361.51, 10.3869 mg/m³ at SPBU 24.361.04, 7.856 mg/m³ at SPBU 24.361.13, and 10.1349 mg/m³ at SPBU 24.361.58. Overall, three gas stations in Telanaipura District, Jambi City, recorded average CO concentrations exceeding the air quality standard established by Government Regulation No. 41 of 1999, namely 10,000 mg/m³ or equivalent to 10 mg/m³. These findings indicate that the ambient air quality related to CO parameters at these gas station locations falls into an unsafe category and exceeds the applicable environmental health standards.

Carbon monoxide (CO) is a colorless, odorless, and tasteless gas consisting of one carbon atom covalently bonded to one oxygen atom. This gas is produced through incomplete combustion of carbon-containing compounds, such as those generated by internal combustion engines, and is highly flammable, forming carbon dioxide (CO₂) when oxidized.

The location of gas stations along major roads significantly contributes to environmental pollution, particularly due to the high traffic volume during morning, afternoon, and evening peak hours. This finding is consistent with the study conducted by Hamzah et al., which demonstrated that the higher the motor vehicle volume on a roadway, the greater the concentration of CO gas in the surrounding environment.

According to the study by Yulianti et al., higher temperatures increase CO concentration levels, as elevated ambient temperatures are associated with increased CO concentrations in the air. Conversely, higher wind speeds reduce CO concentrations because pollutants disperse and spread more rapidly to surrounding areas, thereby lowering the concentration at a specific point.

Research conducted by Ningsih et al. also reported that increasing vehicle density at a specific location tends to reduce vehicle speed, leading to incomplete combustion and increased carbon monoxide emissions. Thus, higher traffic volume is directly associated with increased CO emissions.

Health Complaints

Based on a survey of 65 respondents, several health complaints were identified with the following prevalence rates: fatigue (54.1%), dizziness (34.4%), eye irritation (26.2%), and nausea (16.4%). Although the reported symptoms were generally mild, exposure to high concentrations of carbon monoxide (CO) gas poses a serious risk of poisoning. Early symptoms of CO poisoning commonly include dizziness and nausea; however, chronic or acute exposure may lead to severe health effects such as respiratory dysfunction, cardiac damage, impaired motor coordination, and even death.

The findings revealed that most respondents experienced health disturbances primarily related to fatigue and dizziness. The highest reported complaint was fatigue (54.1%), followed by dizziness (34.4%), eye irritation (26.2%), and nausea (16.4%). Although these complaints remain categorized as mild symptoms, the findings indicate a tangible impact of carbon monoxide (CO) exposure within the workplace environment. These results are consistent with the study by Anida Leila, which reported that early symptoms of CO poisoning include dizziness, nausea, fatigue, and eye irritation, with fatigue (77.2%), headache/dizziness (73.7%), blurred vision/eye irritation (59.6%), and nausea being the most prevalent symptoms.

Exposure Analysis

The daily intake analysis indicated that gas exposure among workers at the five gas station locations generally remained within acceptable health safety standards. However, in real-time exposure analysis, two gas stations exceeded the Reference Concentration (RfC) value of 0.826899 mg/kg/day, namely SPBU 24.361.51 (0.88763 mg/kg/day) and SPBU 24.361.04 (0.981717 mg/kg/day). Meanwhile, under lifetime exposure projections, all gas stations were categorized as safe for the next 30 years.

Siswati's study explained that non-carcinogenic intake (Ink) is calculated using the formula:

$$Ink = \frac{C \times R \times tE \times fE \times Dt}{Wb \times tavg}$$

where tE , fE , Dt , and high intake values are directly proportional to the exposure concentration (C). The greater these values, the higher the individual intake and the greater the risk ($RQ > 1$). This concept was demonstrated in a study involving TSP dust exposure among industrial workers⁴¹.

Hidayatulloh et al. also stated that CO concentration values are directly proportional to intake values. Intake rate and activity patterns are variables directly associated with intake levels; therefore, higher values of these variables result in greater intake values.

Dose-Response Analysis

Gusti Aria explained that dose-response analysis in Environmental Health Risk Assessment (ARKL) is used to estimate the ability of a risk agent to trigger adverse effects in vulnerable populations, such as workers or children. In this context, the Reference Concentration (RfC) serves as a measure of non-carcinogenic toxicity for inhalation exposure routes, equivalent to the Reference Dose (RfD) for gases or aerosols. The RfC value is adopted from the EPA IRIS database, where:

$$RQ = \frac{Intake}{RfC}$$

An RQ value greater than 1 indicates a significant health risk.

In this study, the determination of the Reference Concentration (RfC) value was carried out through mathematical calculations using the intake formula. The gas concentration parameters used in the calculation referred to ambient air quality standards regulated under Government Regulation (PP) No. 41 of 1999, particularly concerning the safe concentration limit of carbon monoxide (CO) for the human respiratory system. Furthermore, the calculation incorporated default values established in the Environmental Health Risk Assessment (ARKL) guidelines issued by the Indonesian Ministry of Health. Through the integration of these regulatory standards and technical health guidelines, the specific RfC value for inhalation exposure to CO gas in this study was determined to be 0.826899 mg/kg/day.

Risk Characterization

Risk Quotient (RQ) in ARKL is an indicator used to characterize non-carcinogenic hazards, calculated by dividing daily intake by the reference dose (RfD/RfC):

$$RQ = \frac{Ink}{RfC}$$

An RQ value ≤ 1 indicates that the risk is under control, meaning that intake remains below the safe lifetime exposure threshold, whereas an RQ value > 1 indicates a probability of significant health effects requiring intervention.

Based on the data analysis in this study, the real-time health risk levels among operators at the five observed gas station locations consistently showed two Risk Quotient (RQ) values exceeding the threshold of one ($RQ > 1$), namely SPBU 24.361.04 (1.187227) and SPBU 24.361.51 (1.07344). These findings indicate that carbon monoxide (CO) exposure parameters in these two workplace environments are generally categorized as unsafe.

However, under lifetime exposure projections (30 years), all five gas stations demonstrated Risk Quotient (RQ) values below one ($RQ < 1$), namely SPBU 24.361.51 (0.326423), SPBU 24.361.04 (0.197871), SPBU 24.361.70 (0.200495), SPBU 24.361.13 (0.197225), and SPBU 24.361.58 (0.198602). These findings are consistent with the study conducted by Asri Cita, which also found that all gas stations had lifetime RQ values below the safe threshold ($RQ < 1$) over a 30-year exposure period.

When the intake value of hazardous substances is compared with permissible chemical reference values such as the Reference Concentration (RfC) or Reference Dose (RfD), health hazard characteristics can be explicitly identified through Risk Quotient (RQ) calculations. Health risks are directly and proportionally related to intake values; therefore, the higher the intake received by individuals due to chronic or acute exposure, the greater the potential health risks experienced, including non-carcinogenic effects such as respiratory irritation, neurological disorders, and chronic fatigue among workers.

CONCLUSION

The Environmental Health Risk Analysis (EHRA) study on carbon monoxide (CO) exposure among gas station operators in the Kota Baru District comprehensively revealed significant health risks under real-time exposure conditions. The study involved 61 respondents from five gas station locations, namely SPBU 24.361.70, 24.361.51, 24.361.04, 24.361.13, and 24.361.58. The findings demonstrated that two primary locations, SPBU 24.361.04 and SPBU 24.361.51, exhibited substantial health risks with Risk Quotient (RQ) values of 1.187 and 1.073, respectively, both exceeding the safe threshold value of 1 based on the comparison between intake levels and the Reference Concentration (RfC) of 0.826899 mg/kg/day as stipulated in Government Regulation No. 41 of 1999. These findings indicate that actual CO exposure in these workplace environments consistently falls into the unsafe category. The highest average CO concentrations were recorded at SPBU 24.361.51 (11.9443 mg/m³) and SPBU 24.361.04 (10.3869 mg/m³), exceeding national standards and directly correlating with the highest lifetime intake values of 0.98171 mg/kg/day and 0.88763 mg/kg/day, respectively.

These workplace environmental conditions contributed to the emergence of health complaints among the operators, with the most commonly reported symptoms being fatigue (54.1%) and dizziness (34.4%). These results are consistent with the real-time Environmental Health Risk Analysis, which identified unsafe risk levels ($RQ > 1$) at SPBU 24.361.04 with an RQ value of 1.18 and SPBU 24.361.51 with an RQ value of 1.07. Nevertheless, the projected risk assessment for the next 30 years (lifetime exposure) across all research locations generally remained within the safe category, with RQ values below 1.

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