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Air quality levels in the industrial city of Jubail, Saudi Arabia

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Ambient air quality remains a significant health and environmental challenge in developing cities, primarily due to increasing gas emissions from fossil fuel use. Harmful outdoor air pollutants constitute a critical environmental and public health concern, as poor air quality directly impacts human health, leading to respiratory and cardiovascular diseases. This study aimed to assess ambient gaseous air pollutants—specifically sulfur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), and non-methane hydrocarbons (NMHC)—in Jubail Industrial City, Saudi Arabia. Hourly fixed-site air quality monitoring data were collected from three monitoring stations distributed throughout Jubail, covering the period from January 2020 to December 2022, alongside recorded hourly meteorological conditions. Standard monitoring equipment was employed to measure pollutant concentrations at all three locations. Notably, the highest emissions of CO, SO_2, and NMHC occurred in 2021, while the highest emissions of NO, NO_2, and NOx were recorded in 2022, with 2022 generally exhibiting the highest gas emissions and 2020 the lowest. Variations in gaseous contaminants were observed, influenced by changes in meteorological conditions and human activities. However, the levels of gaseous emissions remained within acceptable limits according to the air quality index. Consequently, policies implemented during and after the COVID-19 lockdown effectively reduced the accumulation of gaseous emissions to below harmful levels. Maintaining these measures is crucial for ensuring ongoing air quality improvements.

KEYWORDS

ambient air quality, jubail industrial city, gaseous pollutants, meteorological influence, industrial emission, Saudi Arabia

Introduction

Air pollution has emerged as a global concern, posing significant risks to human health, contributing to environmental challenges, and impacting mortality rates in both developed and developing nations (Saber et al., 2020; Biswas et al., 2020; Al-Kallas et al., 2021; Filonchyk, 2022). The consequences of poor air quality are particularly severe in urban areas (NRC, 2001; EEA, 2015). The rapid increase in pollution is closely linked to factors that can harm human health, such as industrial activities and the widespread use of automobiles.

Anthropogenic emissions are the primary driver of rising air pollution levels, with atmospheric phenomena occurring on various spatial scales that further amplify the environmental impact (Miranda et al., 2015). Common gaseous pollutants are air contaminants in the form of gases that pose risks to human health and the environment. These include pollutants such as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), and volatile organic compounds (VOCs). Along with suspended particles like PM10 and PM2.5 (World Health Organization, 2024).

Ambient air quality is a critical environmental and public health concern because poor air quality directly impacts human health, leading to respiratory and cardiovascular diseases. Pollutants like particulate matter, ozone, and nitrogen oxides harm ecosystems, reduce biodiversity, and contribute to climate change. Ensuring good ambient air quality is essential for protecting public health and preserving environmental integrity especially in rapidly industrializing cities. Rising emissions of greenhouse gases such as carbon dioxide, methane, and nitrous oxide—predominantly from fossil fuel consumption—have led to increased levels of harmful outdoor air pollutants, posing significant risks to human health and the environment (World Health Organization, 2024). In developing industrial cities like Jubail, Saudi Arabia, the monitoring and management of air quality are paramount to mitigating these risks.

This study focuses on assessing the ambient gaseous air pollutants in Jubail, a city known for its extensive petrochemical and industrial activities. The key pollutants of interest include sulfur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), and non-methane hydrocarbons (NMHC). These pollutants are influenced by various meteorological parameters such as temperature, wind speed, relative humidity, and pressure, which are crucial for understanding the dynamics of air quality in the region (Environmental Protection Agency, 2020 and Rovira et al., 2021).

The objective of this study is to analyze the trends in gaseous pollutant concentrations in Jubail from 2020 to 2022 and examine the relationship between air pollutant levels and meteorological conditions including, temperature, pressure, solar radiation, wind speed at 10 m, and wind direction at 10 m. Additionally, the study compares Jubail's air quality levels with national and international standards to provide insights into the effectiveness of current air quality management practices.

The concentration of aerosols, containing both organic and inorganic components, has significantly increased since the onset of the Industrial Revolution (Wang et al., 2017). High levels of gases, including primary pollutants such as NOx and SOx, which are directly emitted into the air, along with secondary pollutants formed through chemical reactions involving tropospheric O_3, acids, and primary pollutants, have exacerbated the issue (Lelieveld et al., 2019; EPA, 2018).

Gaseous sulfur compounds (such as SO_2 and H_2S), along with suspended particulate matter, are considered harmful outdoor air pollutants. These pollutants arise from both anthropogenic and biogenic activities in industrial areas associated with population growth (Al-Zboon and Tening Forton, 2019; Ramli et al., 2020).

Al-Jubail was chosen as the focus of this study due to its status as an industrial city with extensive construction activities, water desalination plants, and petrochemical industries. The investigation explores the relationships between meteorological parameters and gas emissions, specifically NOx, NO, NO_2, SO_2, CO, and NMHC. These pollutants can be influenced by meteorological factors.

The objective of this study is to analyze the trends of SO_2, NO, NO_2, NOx, CO, and NMHC in Jubail, Saudi Arabia, and to examine the relationships between air pollutant concentrations and various meteorological parameters, including temperature and wind speed (WS). The air quality levels in Jubail's industrial city are then compared with national and international air quality trends and standards.

Materials and methods

In Jubail, the primary industries account for 7% of the world's petrochemical production, contribute 11.5% to Saudi Arabia's GDP, and make up 85% of the country's non-oil exports. With a steady annual growth rate of 6%, Jubail has attracted over 50% of Saudi Arabia's total foreign investment, with 68% of this investment focused on the city (2014 Annual Report of the RCJY).

The primary industrial sector in Jubail-1 includes hydrocarbon-based and heavy mineral facilities, while the secondary industries produce items such as petrochemical intermediates, plastics, steel, and agrochemicals. The industrial wastewater treatment network services both the primary and secondary sectors in Jubail-1. Meanwhile, Jubail-2 further expands the industrial landscape, incorporating primary, secondary, support, value park, and logistics areas. Jubail's industrial area, designed under the capital concentration method, includes 19 primary industries, 136 secondary industries, and 100 ancillary industries, creating over 100,000 jobs.

The selected industrial area was classified into three sites: 1, 6, and 9. Sites 1 and 9 represent industrial areas in Jubail-1, while Site 6 represents the industrial area in Jubail-2. The Global Positioning System (GPS) coordinates of all Air Quality and Meteorological Stations (Figures 1–6).

Air Quality and Meteorological Data were collected from three Air Quality Monitoring Stations (AQMSs), site 1 (27° 2′16.2″N-49°32′2.62″E), site 6 (26°55′11.85″N-49°28′59.37″E) and site 9 (27° 1′49.14″N- 49°36′40.54″E). The data, spanning from January 2020 to March 2023, focused on hourly fixed-site air quality measurements taken at ground level. The data were categorized into four-quarters: the first quarter (January–March), second quarter (April–June), third quarter (July–September), and fourth quarter (October–December). The monitored pollutants included SO_2, NO, NO_2, NOx, CO, and NMHC.

These fixed-site monitoring stations also recorded hourly meteorological conditions, including temperature, pressure, relative humidity (RH), wind speed (WS), and wind direction (WD). Average concentrations for each pollutant were calculated according to the procedures outlined in the US EPA technical report (Environmental Protection Agency, 2020). The instrumentation and analytical methods varied depending on the detection techniques for each trace species: NO and NO_2 were measured using chemiluminescence (APNA370), SO_2 using UV fluorescence (APSA370), and CO using infrared absorption (APMA370).

Quality control of the air quality data was conducted following standard operating procedures. Microsoft Excel's regression tool was used for statistical analysis to explore temporal variations in air pollutants, with comparisons made against air quality standards from international organizations (such as WHO and EEA) and regional regulations (such as those set by the Royal Commission for Jubail and Yanbu (RCJY); Organization that manages the cities of the petrochemical industry and energy-intensive industries).

Routine air quality measurements for all examined emissions were reported in micrograms per cubic meter, except for CO, which was reported in grams per cubic meter.

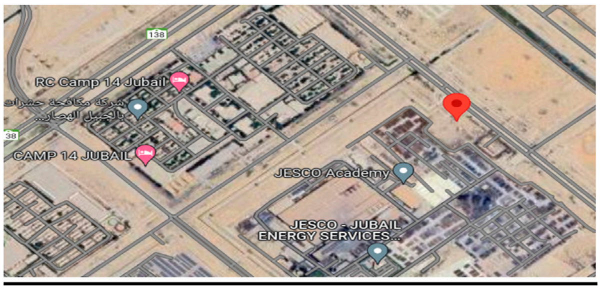

FIGURE 1
Site view of AQ monitoring station site 1.

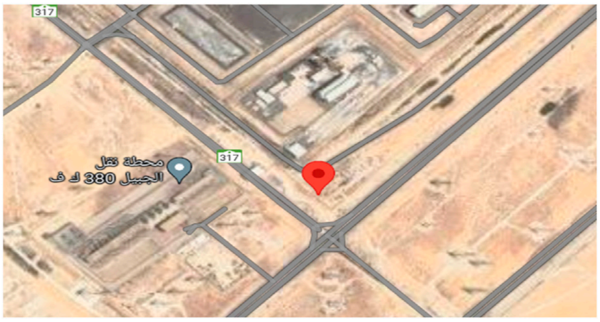

FIGURE 2
Site view of AQ monitoring station site 6.

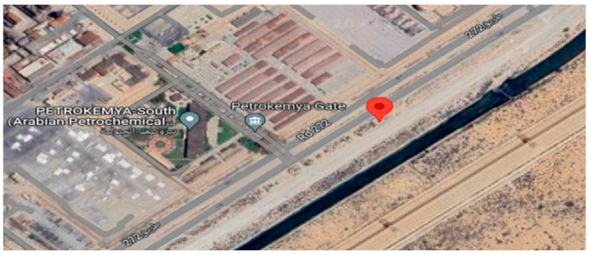

FIGURE 3
Site view of AQ monitoring station site 9.

FIGURE 4
Site view of AQ monitoring station site 6.

FIGURE 5
Site view of AQ monitoring station site 1.

FIGURE 6
Site view of AQ monitoring station site 3.

Surface measurements for outdoor emissions, including SO_2, NO, NO_2, NMHC, and CO, were obtained, and the concentrations of these gases at the three AQMSs were compiled from RCJY reports covering the period from 2020 to 2022.

Results

The statistical metrics for gases emitted from the three Air Quality Monitoring Stations (AQMSs 1, 6, and 9) were calculated. Table 1 presents the quarterly average values for each emitted gas, which serve as the dependent variables, alongside the independent variables (temperature, pressure, solar radiation, wind speed at 10 m, and wind direction at 10 m) for the period 2020–2022.

To examine the quarterly trends for each component of the model, the following figures illustrate the quarterly variations for both the independent and dependent variables. In 2020, the fourth quarter recorded the highest average gas emissions at 0.49, while the first quarter had the lowest at 0.42. In 2021, the third quarter exhibited the highest average at 0.56, with the first quarter showing the lowest at 0.35. In 2022, the second quarter had the highest average at 0.44, while the fourth quarter recorded the lowest at 0.32 (Figures 7–9).

TABLE 1 Quarterly values of the arithmetic mean of the study variables.

Year	Q	CO	SO_2	NO	NO_2	NO_x	NMHC	TEMP	PRES	SR	WS 10 m	WD 10 m
2020	Q1	0.42	6.975	5.013	13.636	18.64	0.041	18.668	1010.968	18.443	4.039	195.898
	Q2	0.45	6.526	4.355	12.583	16.938	0.03	31.59	1001.113	26.903	3.815	184.318
	Q3	0.42	6.177	5.605	12.402	17.932	0.039	35.486	997.862	25.787	3.046	174.543
	Q4	0.48	7.398	7.379	15.63	23.008	0.042	23.835	1010.645	16.478	3.112	209.808
2021	Q1	0.35	7.733	7.09	15.699	22.788	0.05	18.808	1014.999	18.604	3.582	216.875
	Q2	0.37	7.957	7.075	17.717	25.258	0.042	32.881	998.707	28.038	4.594	201.303
	Q3	0.56	7.921	7.548	14.532	22.874	0.043	36.06	990.683	26.559	3.947	181.84
	Q4	0.53	6.949	8.393	16.969	25.359	0.035	24.674	1009.952	16.239	4.042	219.669
2022	Q1	0.43	6.703	7.421	16.731	24.152	0.038	18.825	994.608	18.403	4.685	213.575
	Q2	0.43	8.043	9.156	22.125	31.281	0.029	31.698	996.759	26.324	4.337	197.932
	Q3	0.34	5.339	6.598	15.62	22.09	0.033	32.046	995.038	23.887	3.856	171.764
	Q4	0.32	5.143	7.865	16.269	24.129	0.043	29.77	1002.665	19.149	2.873	172.191

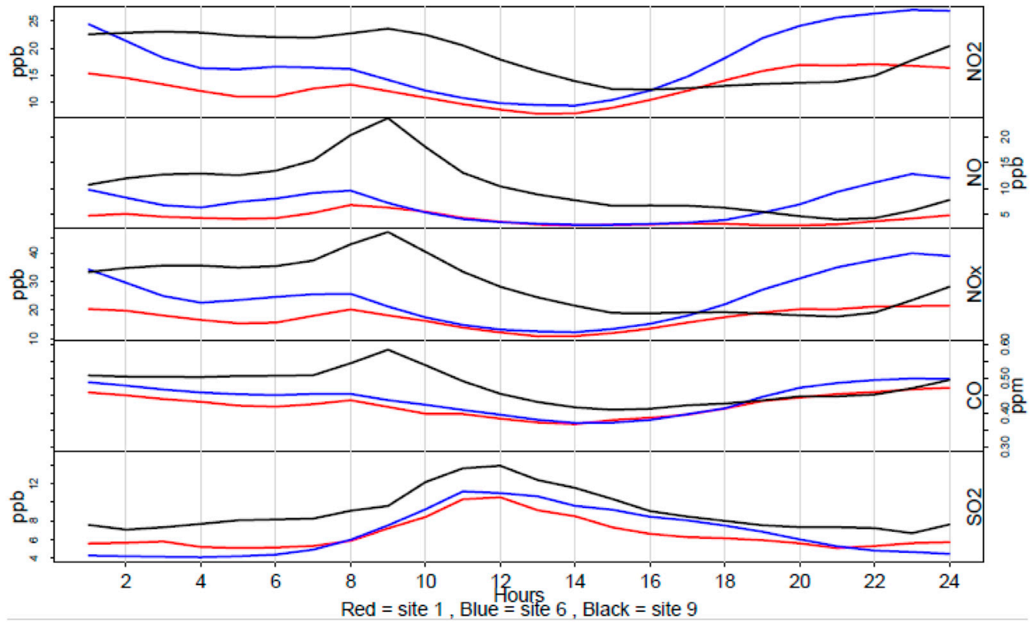

FIGURE 7
Distribution of hourly pattern of gaseous emission in Jubail City.

Table 2 lists the values of the arithmetic averages for the study variables according to the three geographical locations of the AQMSs (site 1, site 6, and site 9).

Based on Table 2 and Figure 10, site 9 exhibits the highest CO emissions, while site 1 has the lowest. Similarly, site 9 records the highest levels of SO_2, NO, NO_2, and NOx gases, with site 1 consistently showing the lowest values. For NMHC emissions, site 9 has the highest average, whereas site 6 has the lowest. In terms of temperature, site 9 has the highest value, and site 6 has the lowest. Regarding wind speed (WS), site 6 shows the highest average, while site 9 records the lowest. Lastly, site 6 exhibits the greatest deviation in wind direction (WD), with site 1 showing the least deviation.

Table 3 presents the annual values of the independent and dependent study variables. Notably, the highest emissions of CO, SO_2, and NMHC occurred in 2021, while the highest emissions of NO, NO_2, and NOx were recorded in 2022.

Table 4 shows the values of the arithmetic mean, standard deviation, and minimum and maximum limits for each of the study variables, specifying the critical values that exceeded the permissible values reported by the Royal Commission Environment Regulations (2015).

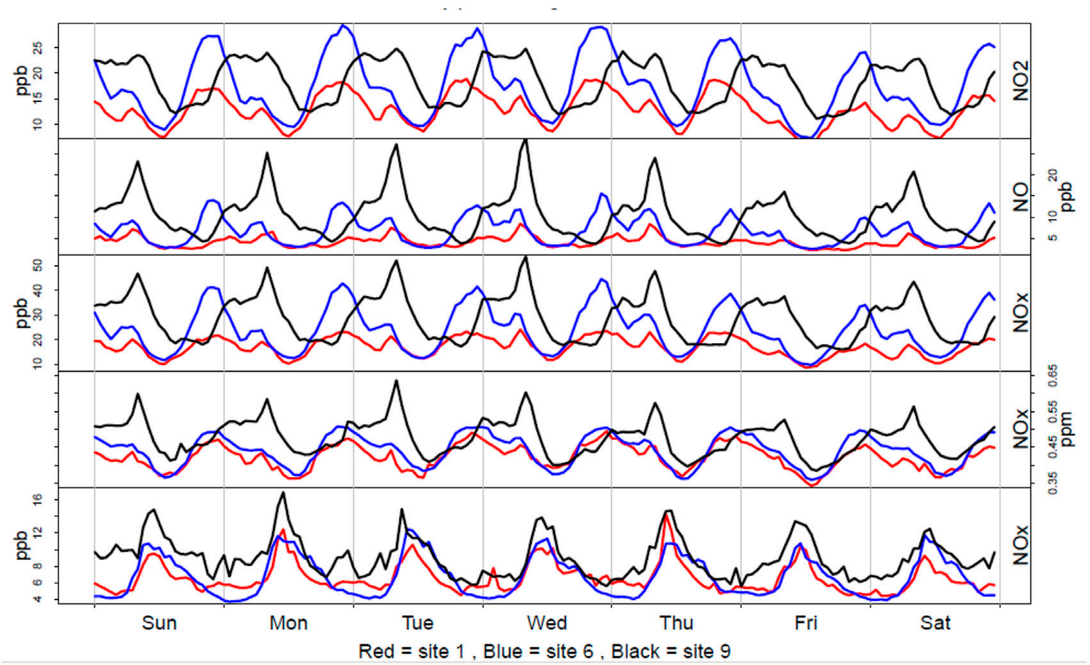

FIGURE 8
Distribution of daily pattern of gaseous emission in Jubail City.

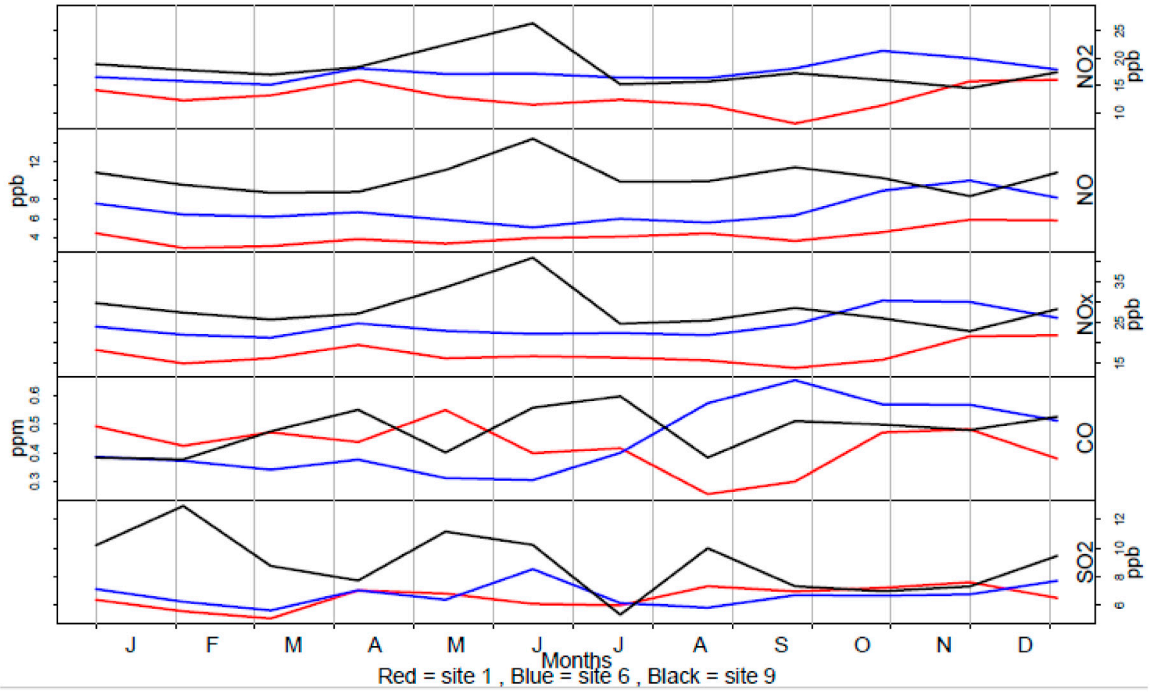

FIGURE 9
Distribution of monthly pattern of gaseous emission in Jubail City.

From Table 4, the average CO emission during the study period was 0.4, with a maximum value of 5.1, which remained below the regulatory limit of 35. The average SO_2 emission was 7.00, with a peak value of 277, also within the maximum limit of 280. The average NO emission was 6.9, with the highest recorded value being 275.1. The average NO2 emission was 15.80, and its maximum value of 160.1 did not exceed the limit of 350. The average NOx emission was 22.80, with the highest value being

TABLE 2 Arithmetic averages of the variables according to the geographical location.

SITE	CO	SO_2	NO	NO_2	NOX	NMHC	TEMP	WS 10m	WD 10m
1	0.409	6.091	3.928	12.358	16.608	0.048	27.922	3.135	214.056
6	0.435	6.429	6.673	17.248	23.907	0.005	26.864	5.400	216.382
9	0.465	8.498	10.117	17.782	27.867	0.063	28.559	3.108	158.283

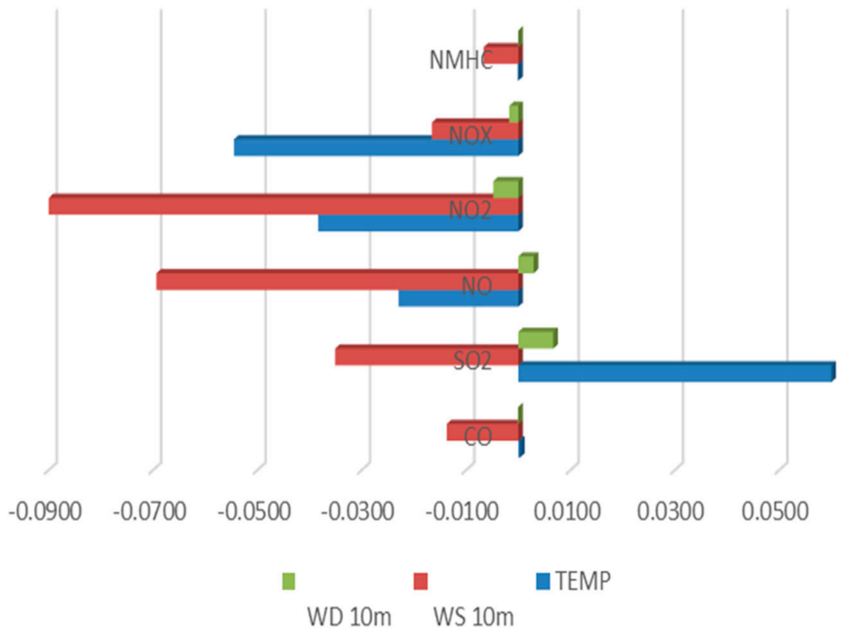

FIGURE 10
The values of the regression model coefficients for each of the emitted gases.

TABLE 3 Annual average values of the independent and dependent study variables.

Year	CO	SO_2	NO	NO_2	NOX	NMHC	TEMP	PRES	SR	WS 10 m	WD 10 m
2020	0.447	6.769	5.588	13.563	19.130	0.038	27.395	1005.147	21.903	3.503	191.142
2021	0.458	7.640	7.527	16.229	24.070	0.043	28.106	1003.585	22.360	4.041	204.922
2022	0.383	6.307	7.760	17.686	25.413	0.036	28.085	997.268	21.941	3.938	188.866

303.1. The average NMHC emission during the study period was 0.04, with a maximum of 0.24.

Table 5 presents the correlation coefficients between the independent and dependent variables in the model. A weak direct relationship was observed between temperature (TEMP) and CO and SO_2 emissions, while a weak inverse relationship was found with NO, NO2, and NOx emissions. No relationship was observed between temperature and NMHC. Additionally, there was a weak inverse relationship between wind speed (WS) and the concentrations of CO, NO, NO_2, NOx, and NMHC, but a weak direct relationship with SO2. An inverse relationship was also observed between wind direction (WD) and the concentrations of CO, NO_2, NOx, and NMHC, whereas a weak direct relationship was noted with SO2 and NO.

The regression model outlines the relationship between each independent variable (temperature, WS, and WD) and the dependent variables (CO, SO_2, NO, NO_2, NOx, and NMHC), illustrating the contribution of each independent variable to the emission of these gases. The model's explanatory power is represented by the adjusted R-squared value, which indicates how well the independent variables account for variations in the dependent variables.

From Table 6, the regression coefficients of the proposed models are significant (Sig F = 0.000), which is less than the significance level of 5%. Figure 10 shows the values of the regression model coefficients for each of the different gases.

TABLE 4 Statistical description of the study variables and permissible limits.

	Mean	Standard deviation	Minimum	Maximum	Limits
CO	0.4	0.3	0.0	5.1	35
SO_2	7.0	9.9	0.0	277.0	280
NO	6.9	11.2	0.0	275.1	NS
NO_2	15.8	12.4	0.0	160.1	350
NOX	22.8	20.7	0.0	303.1	NS
NMHC	0.039	0.057	0.000	0.240	NS
TEMP	27.8	9.6	0.0	50.0	-
WS 10m	3.9	2.6	0.0	19.4	-
WD 10m	196.2	111.9	0.0	360.0	-

TABLE 5 Pearson correlation coefficients between each of the independent and dependent variables.

	CO	SO_2	*NO*	NO_2	*NOX*	*NMHC*	*TEMP*	*WS 10m*
SO_2	0.030							
NO	0.166	0.083						
NO_2	0.237	0.136	0.564					
NOX	0.228	0.125	0.866	0.895				
NMHC	0.047	0.057	0.063	0.073	0.079			
TEMP	0.006	0.071	−0.038	−0.038	−0.041	0.000		
WS 10 m	−0.094	0.033	−0.190	−0.226	−0.239	−0.266	0.113	
WD 10 m	−0.044	0.070	0.007	−0.068	−0.037	−0.090	−0.125	0.151

TABLE 6 Coefficients of the regression equation for the proposed model between each of the independent variables and the emitted gases.

	TEMP	WS 10 m	WD 10 m	Significance F	Adjusted R square
CO	0.0003	−0.0137	−0.0001	0.000	0.617
SO_2	0.0614	−0.0351	0.0067	0.000	0.147
NO	−0.0229	−0.6935	0.0029	0.000	0.242
NO_2	−0.0383	−0.9541	−0.0048	0.000	0.509
NOX	−0.0545	−1.6570	−0.0017	0.000	0.314
NMHC	−0.0001	−0.0067	0.0000	0.000	0.103

Discussion

The primary challenge in improving ambient air quality is addressing the pollutants from domestic, agricultural, and industrial sources, which are predominantly released as gaseous emissions. To improve outdoor air quality, particularly in industrial areas near residential zones, regulatory thresholds for air pollution have been established and enforced on both regional and international levels. These guidelines are designed to assess the health impacts of severe pollution levels in industrial sectors.

In this study, the highest average SO2 emissions were recorded in the second quarter of 2022 (8.04 ppb), while the lowest average was observed in the fourth quarter of 2022 (5.14 ppb). Most of the SO2 levels at the studied sites were within the permissible limits set by the Royal Commission Environment Regulations (2015). Among the sites, site 9 had the highest average SO2 value (8.50 ppb), likely due to its proximity to petrochemical industries, whereas site 1 recorded the lowest (6.091 ppb), potentially due to reduced traffic and lower pollution levels in that area.

Heavy traffic was identified as the main source of NO2 pollution, with an influx observed on the roads during certain intervals. This pattern of temporal variability in NO2 levels, reported by Han et al. (2011) in other locations, can be explained by various hypotheses. During the study periods, several meteorological parameters were also monitored, including relative humidity (RH), temperature, wind direction (WD), and wind speed (WS). Pollutant levels are often influenced by meteorological conditions such as temperature, WD, WS, and RH (Danek et al., 2022).

Berezina et al. (2020) noted that O3 responses to changes in precursor emissions vary depending on the local VOC-to-NOx ratio in the atmosphere. O3 formation is particularly sensitive to VOC and NO2 concentrations. On weekends, lower NOx concentrations, due to reduced traffic, lead to a weaker inhibitory effect of NOx on O3 formation, resulting in higher O3 production.

The daily maximum 8-hour moving average for CO during the two measurement campaigns was 0.47 mg/m³, well below the national standard of 10 mg/m³. The CO levels reflect pollution primarily from road traffic (Das et al., 2022; Zhao et al., 2019; Nagpure and Gurjar, 2012; Wu and Wang, 2005).

Our analysis, using hourly data collected for gaseous pollutants, proposed a regression equation to explore the relationship between pollutants (NO_2, NO, SO_2, NMHC, and CO) and two meteorological variables (WS and temperature). The findings revealed a significant impact on NO_2 and CO concentrations, with increased WS leading to decreased NO_2 and CO levels, while temperature showed a direct correlation. Lower WS allows pollutants to accumulate, and higher temperatures cause more pollutants to remain airborne, trapped under a layer of warm air. Similar results were observed by He et al. (2017).

Regarding temperature, site 9 recorded the highest value, while site 6 had the lowest. For wind speed (WS), site 6 had the highest average, whereas site 9 had the lowest. Additionally, site 6 exhibited the greatest variation in wind direction (WD), with site 1 showing the least deviation. Site 9 displayed the highest concentrations of CO, SO2, NO2, and NMHC, likely due to its proximity to petrochemical industries, while sites 6 and 1 had the lowest concentrations, attributed to their location near the Royal Commission campus and academy buildings, which emit significantly fewer pollutants compared to petrochemical industries.

This study revealed a weak direct correlation between temperature (TEMP) and the concentrations of CO, SO2, NOx, and NMHC, consistent with findings by Ahmed and Alharbi (2020), which indicated an insignificant correlation between temperature and NOx levels. In contrast, Dandotiya et al. (2018) observed a slight inverse correlation between SO2 concentrations and increasing temperature, a trend also noted by Preradović et al. (2011), who found that SO2 levels decrease as temperature rises.

Liu et al. (2020) identified temperature as a key factor influencing CO concentration changes at most sites, with relative humidity (RH) also playing a significant role in altering CO levels in the eastern coastal regions. This study found a weak inverse relationship between temperature and the concentrations of NO, NO2, and NOx, mirroring the results reported by Khalil et al. (2016) and Dandotiya et al. (2018).

Additionally, this study identified an inverse relationship between WS and the concentrations of CO, NO, NO_2, NOx, and NMHC, consistent with findings by Dandotiya et al. (2018) and Khalil et al. (2016). While an inverse relationship was observed between WD and the concentrations of CO, NO_2, NOx, and NMHC, there was a weak direct relationship with SO_2 and NO. Conversely, Tasić et al. (2013) found that high WS reduces SO2 concentration due to the dilution effect, leading to inverse correlations between SO_2 and both WS and WD at nearly all monitoring stations.

In this study, temperature was found to be the most significant factor influencing the increase in gas emissions (CO, SO2). In contrast, Dandotiya et al. (2018) reported a marginally negative correlation between SO2 concentrations and rising temperatures, a trend also observed by Preradović et al. (2011). Liu et al. (2020) identified temperature as the dominant factor affecting CO concentration changes at most sites, with RH also recognized as a major meteorological factor influencing CO levels in the eastern coastal areas.

This study also noted that an increase in temperature resulted in decreased emissions of NO, NO2, NOx, and NMHC, in line with the findings of Khalil et al. (2016) and Acharya et al. (2018). A significant inverse relationship was observed between WS and the concentrations of CO, SO2, NO, NO2, NOx, and NMHC, similar to the findings of Khalil et al. (2016) and Dandotiya et al. (2018). Site 9 was identified as the highest emitter of gases, while site 1 was the lowest. Notably, significant differences were observed over the 3 years, with the highest gas emissions recorded in 2022 and the lowest in 2020 (Al-Zahrani and Abdul-Wahab, 2015).

Overall, the greatest reductions in SO_2 and NO_2 were observed in industrial areas, with minimal reductions in other pollutants during the lockdown period of 2020–2021. The higher reductions in certain pollutants during the COVID-19 lockdown can be attributed to the shutdown of major polluting sources. These reductions in Air Quality Indices (AQIs) were influenced by the lower source intensity, atmospheric chemistry, and favorable meteorological conditions.

Similar trends for selected air pollutants have been reported in different cities in India and various geographic locations globally (Kumar et al., 2020; Mahato et al., 2020; Otmani et al., 2020; Dumka et al., 2021). Given the similar trends observed in many cities, it would be prudent to assess the regional improvement in air quality due to the COVID-19 lockdown on a broader scale.

Site 1 consistently showed lower pollutant concentrations, potentially due to reduced traffic and overall lower pollution levels in that area. Both Sites 1 and 6 recorded the lowest concentrations, likely because they are located near the Royal Commission campus and academy buildings, which emit significantly fewer pollutants. In contrast, Site 9 exhibited higher pollutant levels, probably due to its proximity to petrochemical industries. The significantly higher concentrations of NO_2 and SO_2 at Site 9 can be attributed to lower wind speeds, which allow pollutants to accumulate, and higher temperatures that cause pollutants to remain airborne, trapped under a layer of warm air. This aligns with the fact that Site 9 had the lowest wind speed. For other pollutants, the effects of road traffic and higher temperatures were minimal.

The findings of this study highlight the complex interplay between industrial emissions, meteorological factors, and air quality in Jubail Industrial City. While the pollutant levels remained within regulatory limits, the variations observed underscore the need for continuous monitoring and adaptive policy measures to mitigate potential health risks. The effectiveness of policy interventions during and after the COVID-19 lockdown in reducing pollutant levels is evident. These measures, if maintained, could play a crucial role in ensuring sustained air quality improvements in Jubail and similar industrial cities.

Conclusion

A comprehensive evaluation was conducted on outdoor air pollutant levels within the Jubail industrial City and its surrounding areas from 2020 to 2022. The assessment focused on major hazardous gaseous emissions, including SO_2, NO, NO_2, NOx, CO, and NMHC. The findings revealed that industrial activities—such as those at petrochemical plants, power plants, fertilizer production facilities, oil stations, water treatment plants, and warehouses—along with specific meteorological factors, contributed to significant variations in gaseous concentrations where, petrochemical plants, power plants, fertilizer production facilities and oil stations represent highest source of pollutants emissions as they close to the recording air pollution monitoring stations. Notably, the highest emissions of CO, SO_2, and NMHC occurred in 2021, while the highest emissions of NO, NO_2, and NOx were recorded in 2022 with 2022 generally exhibiting the highest gas emissions and 2020 showing the lowest. However, the analysis of air quality data showed a downward trend in emissions from 2020 to 2022. The reasons behind these discrepancies were attributed to the exclusion of metrological factors and variations in industrial emissions indicating that could lead to an improvement in air quality over this period. Considering the frequency with which annual concentrations exceeded regulatory limits, the Air Quality Index (AQI) was deemed effective in assessing the gaseous emissions in the outdoor environment. To mitigate health risks associated with these emissions, especially during periods of increased human activity, temperature inversions, and heightened production rates in industrial facilities, targeted policies must be implemented and consistently maintained.

This study provides a comprehensive analysis of ambient gaseous air quality in Jubail Industrial City, revealing that while pollutant levels are within acceptable limits, ongoing industrial activities and meteorological factors continue to influence air quality. Sustained efforts in monitoring and regulatory enforcement are essential to maintaining these levels and protecting public health.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AIA: Writing–review and editing, Writing–original draft, Visualization, Software, Resources, Methodology, Investigation, Formal Analysis, Data curation, Conceptualization. KS: Writing–review and editing, Writing–original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal Analysis. MMA: Writing–review and editing, Writing–original draft, Visualization, Supervision, Methodology, Investigation. MTA: Writing–review and editing, Writing–original draft, Visualization, Methodology, Investigation, Formal Analysis. ASA: Writing–review and editing, Writing–original draft, Visualization, Methodology, Investigation, Formal Analysis. MA-W: Writing–original draft, Methodology, Investigation, Formal Analysis. AAA: Writing–review and editing, Writing–original draft, Visualization, Methodology, Investigation.

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Conflict of interest

Author AIA was employed by Saudi Electricity Company.

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