EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 17(3) 2024 105-115
DOI 10.14456/ea.2024.39
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Assessment of Gas Flaring on Air Quality in the Al-Rumaila Oil Field Region in Basra Governorate, Iraq

Hussein T Khreebsh and Nayyef M Azeez*

Department of Ecology, College of Science, University of Basrah, Iraq

*Corresponding author: Nayyef.azeez@uobasrah.edu.iq
Received: April 7, 2024; Revised: April 28, 2024; Accepted: June 10, 2024

Abstract

Natural gas flaring is one of the most important challenges faced by global and local energy sources and the environment. The study investigates the impact of natural gas flaring on the environment and climate in the Basra Governorate. Measurements were conducted at six stations from September 2023 to April 2024, analyzing air pollutants such as black carbon (BC), particulate matter ($PM_{2.5}$, PM_{10}), formaldehyde (HCHO), and total volatile organic compounds (TVOCs) around the location of the flares. Statistical analysis employed a one-way ANOVA test with a significance level set at $p \leq 0.05$, coupled with correlation assessments between air pollutant concentrations, wind speed, and temperature. Results indicate that all pollutants exceeded local and World Health Organization permissible limits, except for TVOCs. Notably, $PM_{2.5}$ and PM_{10} exceeded permissible levels only in February, with a decrease observed in PM_{10} concentrations. Moreover, increased daily precipitation showed greater removal efficiency, particularly for $PM_{2.5}$ and PM_{10}. Pollutant concentrations vary by station, influenced by proximity to sources. Site 2 showed high TVOCs (0.0367 mg/m^3) and HCHO (0.0225 mg/m^3), suggesting local industrial emissions. Station 3 had high black carbon (21718.2 ng/m^3) but low TVOCs (0.0095 mg/m^3), indicating nearby heavy industrial activity. Station 5 recorded the highest $PM_{2.5}$ (97 µg/m^3) and PM_{10} (180.7 µg/m3) levels, likely from construction and natural dust. Conversely, site 6, near the city center, showed lower overall pollutants, indicating no effects from the oil fields in North Rumaila, though PM levels remained elevated due to natural sources. The government should enforce stricter regulations, and oil companies should adopt best practices to reduce flaring and pollution.

Keywords: Air pollutants; Emission sources; Gas flaring; Iraq; Meteorological condition

1. Introduction

The air becomes polluted when it changes in composition such as impurities or other gases are mixed with it to harm the life of organisms that live and breathe in it. Several substances contribute to air pollution (Hassen *et al.* 2023; Ahmed and Azeez 2023). Many countries consider air pollution in urban areas as an environmental problem, the source of which is mainly combustion activities, initiated mostly by industrial operations and automobiles. Combustion originates from various air pollutants that are noxious to humans and nature. Air pollution is a complex problem due to industrial flourishment. However, this is not considered a new phenomenon, because many historical records have pointed out this issue (Mohamedali *et al.,* 2020). Natural gas (NG) is a fossil energy source that forms deep beneath the Earth's surface. It is found in oil wells, either dissolved in crude oil or present separately in the form of a cap on top of the oil. Unless used for commercial purposes, the gas is either burned off upon reaching an oil well surface or vented directly into the atmosphere without burning. The composition of natural gas varies depending on its location. Each well had a different gas composition and different amounts of each component (Al Muhyi and Aleedani, 2023). Gas flaring is a process in which natural gas is associated with the burning of crude oil during production. It is also a method of burning natural gas in a controlled form, which cannot be processed for sale or use because of technical and economic reasons (Elehinafe *et al.,* 2022). Gas flaring is also a type of combustion device designed to safely and efficiently destroy waste gases generated in a plant during normal operation. Globally, this practice has continued since oil production started more than 160 years ago (Oluwole, 2021). Gas flaring has become a significant issue in environments where petroleum is produced with inadequate infrastructure to use the generated natural gas. There are three types of gas flaring, namely ground flares, Elevated and pit flares (Elehinafe *et al.,* 2022). Iraq's proven reserves of conventional natural gas amount to (3.5 trillion cubic meters, tcm), placing Iraq 11th among the global reserve holders. Most of it is concentrated in Basra Province the southern part of Iraq (Al Muhyi and Aleedani, 2023).

The air pollutants included in this study were black carbon (BC), particulate matter ($PM_{2.5}$, PM_{10}), formaldehyde (HCHO), and total volatile organic compounds (TVOCs). Formaldehyde exists in open-air atmosphere because of the photo-oxidation of the normally present methane and various organic compounds and as emissions from plants, Additional anthropogenic efforts to quantify formaldehyde in the environment include vehicle exhaust, ignition operations, and manufacturing activities such as resin production (Mohamedali *et al.,* 2020).

Total volatile organic compounds (TVOCs) represent emissions from chemicals and toxins, TVOCs can cause serious damage to the human body, from minor irritation of the eyes, throat, and nose to cancer, depending on the amount and period of exposure (Mohamedali *et al.,* 2020). TVOCs can cause symptoms ranging from minor irritability to levels of toxicity that ultimately result in death (Othman *et al.,* 2022).

PM_{10} (particulate matter with an aerodynamic diameter of ≤ 10 μm) comprises the largest proportion of inhalable particulate matter. PM_{10} has garnered increasing attention from researchers due to its significant impact on human health. Exposure to high concentrations of PM_{10} has been linked to elevated mortality rates and increased incidence of respiratory and cardiovascular diseases (Salman *et al.,* 2024). Air pollution consists of particles of two sizes: coarse ($PM_{2.5\text{-}10}$) and fine ($PM_{2.5}$). Although both size ranges have health implications, fine $PM_{2.5}$ particulate matter is of particular concern. These particles have the ability to penetrate deep into the lungs, causing significant health issues and prompting extensive research efforts (Hassoon and Al-Dabbagh, 2023).

Black carbon aerosol (BC) is a component of fine particulate matter ($PM_{2.5}$). $PM_{2.5}$ is particulate matter with a diameter of 2.5 micrometers or less and is small enough to invade even the smallest airways. Combustion engines (most notably diesel engines), burning of wood and coal, power plants using heavy oil or coal, burning of agricultural waste, forest fires, and gas burning are the main sources of BC. The health effects of exposure to $PM_{2.5}$, PM_{10}, and BC are similar; however, they are estimated to be much higher for BC than for $PM_{2.5}$ and PM_{10}, that is, with the same concentration (Fowler *et al.,* 2016; Taheri *et al.,* 2019).

This study aimed to investigate the effects of air pollutants emitted from gas flaring in the North Rumaila oil field on air quality in the field and its surrounding areas in the Basra Governorate. The air pollutants included in this study were black carbon (BC), particulate matter ($PM_{2.5}$, PM_{10}), formaldehyde (HCHO), and total volatile organic compounds (TVOCs).

2. Methodology

2.1 Study area

A super-giant Rumaila oil field is situated in southern Iraq, approximately 20 miles (32 km) from the Kuwaiti border. It is made up of a north dome and a south dome with two anticlines. The Rumaila Reservoir includes layered sandstone and carbonate (Zubair and Mishrif formations) that extend up to 4 km and return to the Cretaceous age. The field is estimated to contain 12% of Iraq's oil reserves.

It is the world's third-largest production field and delivers approximately one-third of Iraq's total oil supply. The giant onshore field, which has been producing since 1954, is still left with an estimated 17 billion barrels of recoverable oil reserves (Bashara and Hadi, 2023).

2.2 Experimental measurements

The pollutants were measured monthly at six sites (Table 1 and Figure 1). Sites 1 to 4 were located around the flares in the North Rumaila field about 400 - 500 m from the flares, while site 5 was approximately 3 km from site 4. Site 6 was near the city center (39 km from site 4). The selection of these sites was based on the dominant wind direction, as pollutant transfer was possible from the flares to the city center (downward flare locations to understand the flare effect on the air quality). The sampling sites were chosen as the following using GPS instruments.

Many devices have been used to measure air pollutants and meteorological factors such as wind speed, humidity, and temperature. The measurements were conducted during rainy and non-rainy months, where the comparison was made during the measurement and monthly observations of the measuring stations. The measurement stations were chosen to assess the dispersion of pollution plumes from their sources toward the

Table 1. Geographic coordinates of the flares and Sampling Sites in Basra, south of Iraq

#Site	Latitude	Longitude
1	30°33'43.2"	47°20'4.2"
2	30°34'6.6"	47°19'12"
3	30°36'29.16"	47°19'50.52"
4	30°34'50.52"	47°21'8.28"
5	30°30'45.756"	47°26'52.584"
6	30°32'46.32"	47°44'57.48"

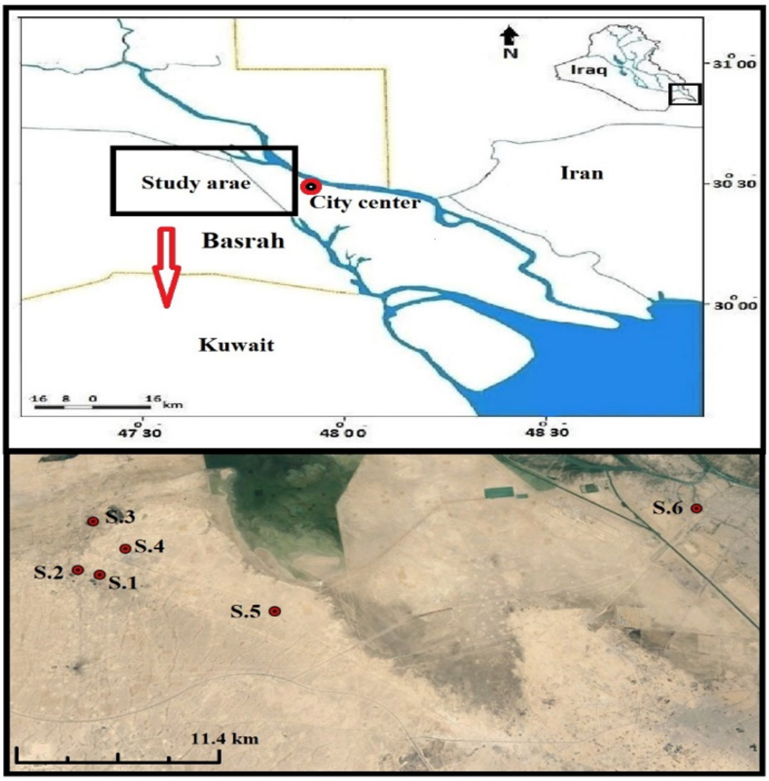

Figure 1. Map of the study area around gas flares

surrounding areas and the city center of Basra within the study area. This arrangement aimed to determine how the pollutants spread from their origins to the nearby regions and the urban center. The data of this study were obtained from the measured stations, which were directly measured over eight months using many air pollutants devices as shown below.

As part of the investigation into air pollution, a variety of apparatuses were utilized and selected based on their capacity to precisely measure airborne contaminants (de Souza, 2022). The chosen devices and the pollutants that they were intended to assess are detailed below;

1. Temtop H2 Device: Employed for its capability to measure total volatile organic compounds (TVOCs) and formaldehyde (HCHO), It provides readings in milligrams per cubic meter (mg/m^3). The importance of monitoring these compounds lies in their ubiquitous presence in the indoor environment and their potential adverse health effects. It is manufactured in China.

2. Aethalometer: This instrument was used to assess the concentration of black carbon (BC), a primary component of fine particulate matter resulting from incomplete combustion processes. Measurements were reported in nanograms per cubic meter (ng/m^3), highlighting the instrument's ability to detect low levels of black carbon in the atmosphere. It is manufactured in USA.

3. Multifunctional Air Detector: This device offered a comprehensive analysis by measuring a range of pollutants, including particulate matter ($PM_{2.5}$ and PM_{10}), HCHO, and TVOCs. The detector provided measurements in milligrams per cubic meter (mg/m^3) for HCHO and TVOCs, and in micrograms per cubic meter ($\mu g/m^3$) for particulate matter, thereby offering a detailed view of particulate and gaseous pollutants in the air.

4. An air velocity meter and heavy-duty hygrothermometer model 407445 devices were used to measure the wind speed and direction, air temperature, and humidity at each site.

2.3 Quality assurance

To ensure data quality in the air pollution study, a rigorous approach to instrument calibration and maintenance, as well as data collection and handling, would be essential. This includes regularly calibrating instruments using certified reference materials to maintain accuracy and consistency. Regular maintenance and cleaning would prevent instrument malfunctions and ensure reliable data collection. Additionally, taking replicate measurements at each station, collecting field blanks to assess potential contamination, and implementing data validation and screening processes would further enhance data quality and reliability.

2.4 Statistical analysis

The results were analyzed using a one-way ANOVA test at $P \leq 0.05$, to show significant variance and coefficient of correlation between pollutant concentrations, wind speed, and temperature. Statistical calculations were performed using the SPSS software (v. 26).

3. Results and Discussion

3.1 Wind speed and directions

The wind rose plot depicts wind speeds and directions during the measurement period (Figure 2). The prevailing wind directions were northwesterly and southwesterly. This signifies that pollutants originating from the gas flaring areas are being transported towards the city center of Basra, where residential communities are situated. This observation highlights the potential hazard posed by gas flaring activities in Basra Governorate. The predominant northwesterly winds in the study area act as a vector for carrying air pollutants, in the form of smoke plumes, toward the populated urban areas. This scenario underscores the environmental concerns associated with gas flaring operations and the potential impact on air quality for the local population.

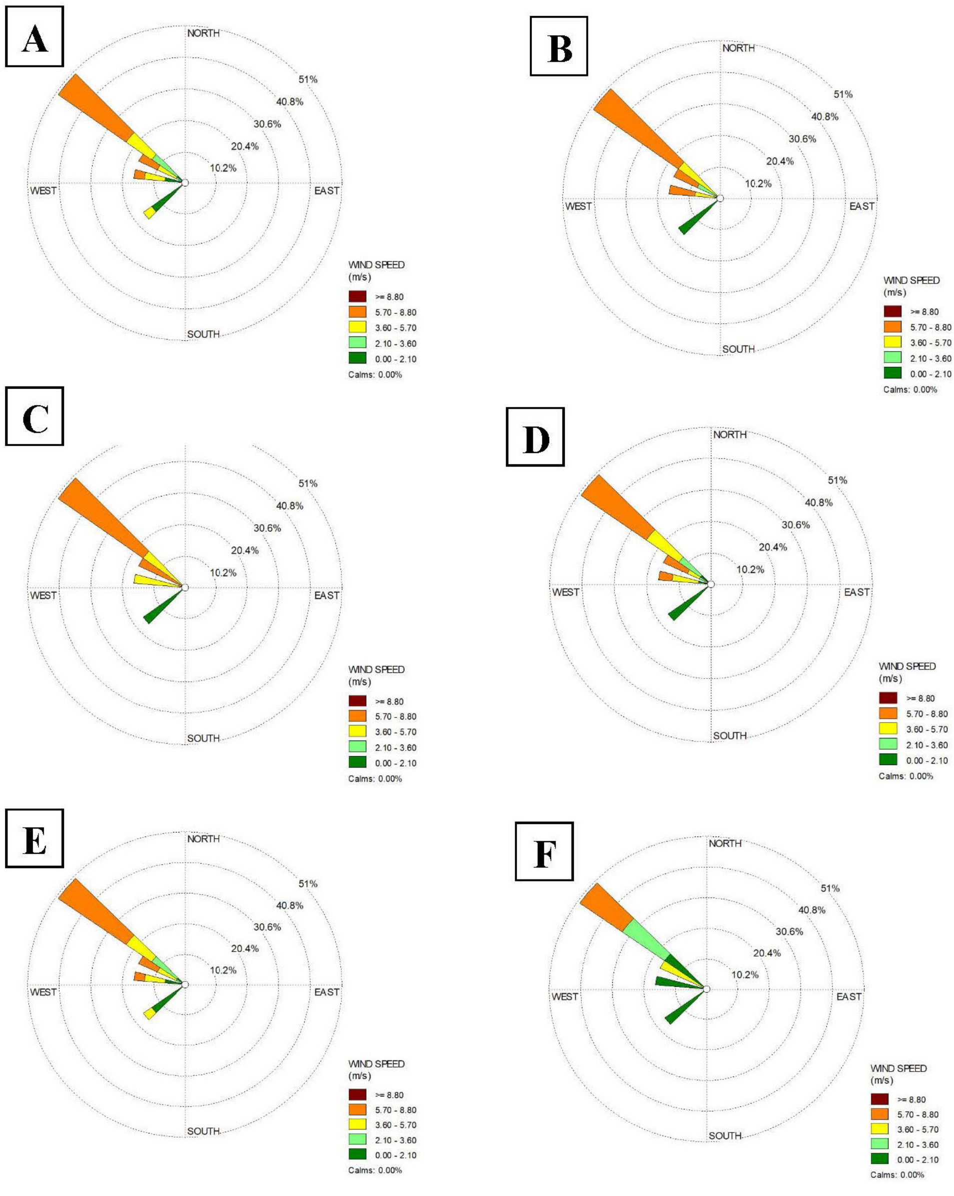

Figure 2. Wind rose for all monitoring stations (Stations A, B, C, D, E, and F correspond to the locations specified in Stations 1-6)

3.2 Temperature

Temperature analysis from six stations around gas flares over eight months (Figure 3) shows significant variations, with temperatures from September highs of up to 46 °C at Station 4 to November lows between 21 °C and 23 °C. The lowest readings were in February, reaching a minimum of 17.8 °C at Station 3, followed by a sharp increase to a peak of 34.9 °C at Station 6 by April. Notably, Station 6 consistently recorded higher temperatures during the colder months, while Station 3 had the lowest, indicating distinct local climate conditions. The overall temperature fluctuated between 17.8 °C and 34.9 °C, emphasizing the dynamic nature of regional climates and underscoring the importance of localized climate monitoring for enhanced weather forecasting and climate research.

3.3 Variations in pollutant concentrations

Figure 4 shows that this study's range of HCHO concentrations varied from 0.001 to 0.045 mg/m³, which is lower than the HCHO concentrations documented by Mohamedali *et al.* (2020) and Saleh *et al.* (2022). Their studies reported HCHO concentrations ranging between 0.035 – 0.3 mg/m³ and 0.0061 - 0.0699 mg/m³ respectively. The results demonstrated significant variations in HCHO concentrations across different measurements and stations within this study. Figure 3 illustrates the HCHO concentrations during the measurement period for six stations, with many concentrations exceeding the permissible limit of 0.001 mg/m³ as set by Mohamedali *et al.* (2020). This exceedance is attributed to the ongoing combustion of natural gas in the study area. The highest concentration recorded was 0.4 mg/m³ at the fourth station, located in the center of the North Rumaila oil field, in November. The low wind speeds at this station, attributed to the height of surrounding buildings and the area's low temperature, contributed to this peak concentration. Conversely, the lowest concentration (0.001 mg/m³) was observed at the sixth station in September, a result of the higher temperatures at that location (Hassoon and Al-Dabbagh, 2023).

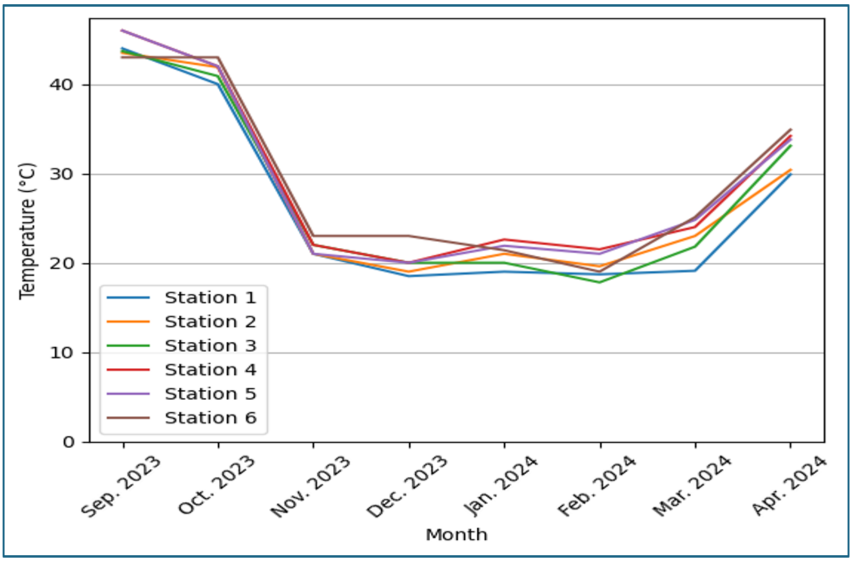

Figure 3. Temperature at measuring stations during the study period

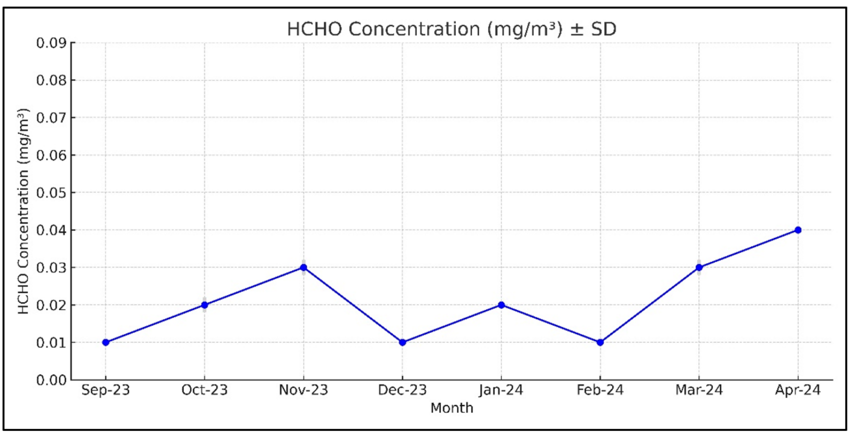

Figure 4. HCHO concentrations at measuring stations during the study period

Figure 5 showed the TVOCs concentrations in this study ranged from 0.002 to 0.15 mg/m³, which is lower than the TVOCs concentrations recorded by Ubaid (2020) and Mohamedali *et al.* (2020), which ranged between 0.001 – 0.669 mg/m³ and 0.008 - 2.479 mg/m³, respectively. The results indicated significant variation in the concentrations of TVOCs during the measurements in this study, but a non-significant variation ($p = 0.967$) among the stations for TVOCs concentrations. Figure 4 also displays the concentrations of TVOCs during the measurement period for six stations, where all concentrations were below the permissible limit of 0.5 mg/m³, according to Mohamedali et al. (2020). This is attributed to the conversion of TVOCs into other organic compounds at a distance of 72 m from the source of emission, whereas all stations were located more than 1000 m away (Zielinska *et al.,* 2014). The highest value, 0.15 mg/m³, was recorded at the second station at the third gas pressing station, situated more than 1500 m away in December. The lowest value, 0.002 mg/m³, was observed at the sixth station in September, attributed to the high temperature and the station's considerable distance from the oil field (Hassoon and Al-Dabbagh, 2023).

The range of $PM_{2.5}$ concentration in this study varied from 15 to 380 µg/m³ (Figure 6), which is higher than the concentrations recorded by Shaheed et al. (2021). Their studies reported average $PM_{2.5}$ concentrations ranging between 4-180 µg/m³ and 48.76-145 µg/m³, respectively. The results demonstrated significant variation in $PM_{2.5}$ concentrations during measurements and across stations within this study. Figure 5 illustrates the $PM_{2.5}$ concentrations during the measurement period for six stations, where all concentrations exceeded the permissible limit set by the World Health Organization (25 µg/m³) and the standards of the Iraqi Ministry of Environment (Local standard). This excess is attributed to continuous gas flaring, where the highest concentration (380 µg/m³) was observed at the fifth station in November, elevated due to automobile and industrial activities in the vicinity, alongside emissions from gas-burning (Fawole *et al.,* 2016). Conversely, the lowest concentration (15 µg/m³) was recorded at the first station in February, attributed to precipitation being a major mechanism for aerosol particle removal from the atmosphere (Zheng *et al.,* 2019).

Figure 7 illustrated that the PM_{10} concentrations in this study ranged from 20 to 505 µg/m³, exceeding the levels recorded by Shaheed *et al.* (2021) who reported average PM_{10} concentrations ranging between 5-201 µg/m³ and 64.63 - 198 µg/m³, respectively. The results reveal significant variations in PM_{10} concentrations during the measurements and across stations within this study. Figure 6 also displays the PM_{10} concentrations during the measurement period for six stations, with most concentrations surpassing the World Health Organization's permissible limit of 50 µg/m³, though some

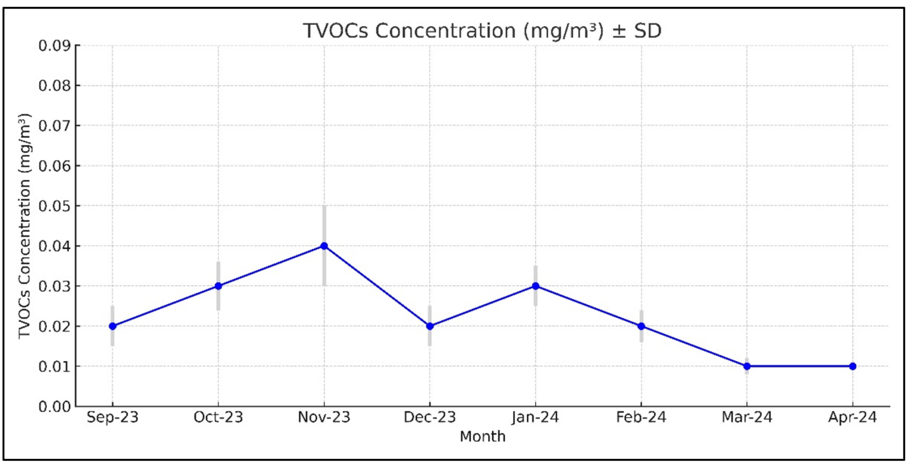

Figure 5. TVOCs concentrations at measuring stations during the study period

measurements remained below the Iraqi Ministry of Environment's allowable limit of 100 µg/m³. The highest concentration of 505 µg/m³ was observed at the fifth station in November, attributed to emissions from the Rumaila oil field stacks. These emissions eventually settle in the surrounding area, influenced by the prevailing wind direction and atmospheric stability, which affect the transformation and deposition of PM_{10} concentrations (Hassoon and Al-Dabbagh, 2023). Conversely, the lowest concentration, 20 µg/m³, was noted at the second station in February, underscoring precipitation as a key mechanism for aerosol particle removal from the atmosphere (Zheng *et al.,* 2019).

The range of BC concentration (figure 8) in this study was from 1226 to 47845 ng/m³, which is higher than the BC concentration recorded by Alsabbagh *et al.* (2023), who studied BC concentration in that study which ranged between 3700-7900 ng/m³. The results indicated a significant variation between the concentrations of BC during measurements and stations in this study. The results show the concentrations of black carbon during the measurement period for six stations where all concentrations were

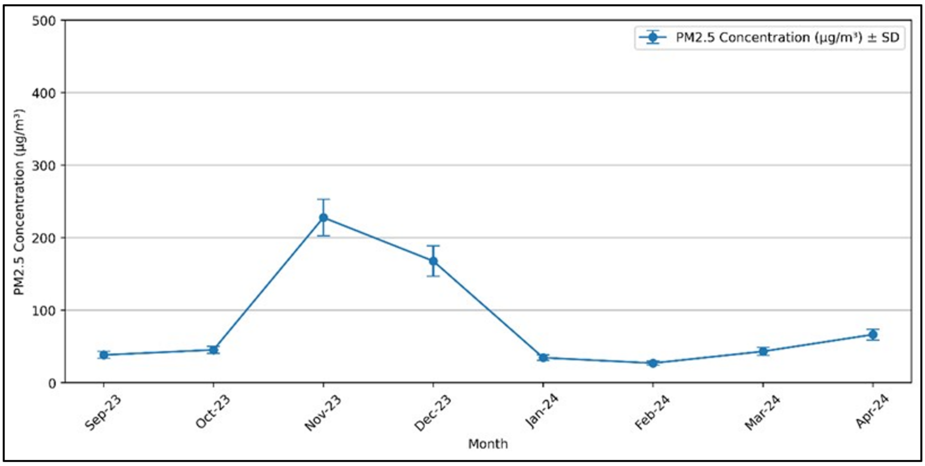

Figure 6. $PM_{2.5}$ concentrations at measuring stations during the study period

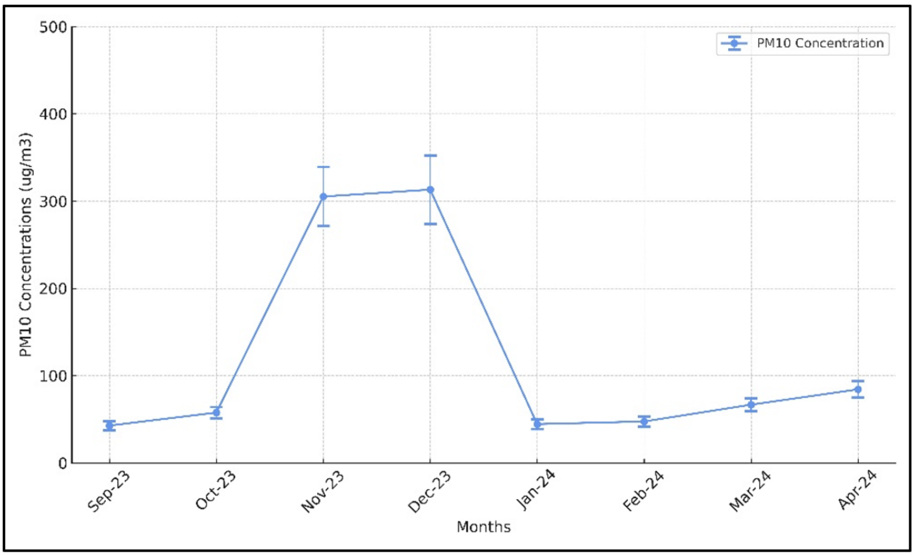

Figure 7. PM_{10} concentrations at measuring stations during the study period

above the permissible limit of 1000 ng/m³ (Alsabbagh *et al.,* 2024; Kim *et al.,* 2016). The highest value, 47845 ng.m³, was at the third station in October. These profiles show that the effect of BC emission was much higher close to the BC emission sources and calm wind (Taheri *et al.,* 2019), hence the concentration was very high at the third station. The lowest value, 1226 ng/m³, was at the fifth station in September.

Monthly fluctuations in Black Carbon (BC) concentrations are driven by a complex interplay of factors. Emission sources like gas flaring contribute varying levels of BC throughout the study period. Meteorological conditions, including wind patterns, atmospheric stability, and precipitation, significantly influence the dispersion and removal of BC particulate matter. Additionally, chemical reactions in the atmosphere and long-range transport of BC from distant sources can further impact local concentrations. Understanding these factors is crucial for accurately assessing air quality trends and developing effective mitigation strategies.

Since both the control and the communities in the study area are rural communities, the oil industries' activities negatively impacted the air quality in the study area. In addition to industrial activities, emissions from anthropogenic, domestic, and automobile sources also contributed to the levels of pollutants measured in the area.

3.2 Correlation of temperature and wind speed with air pollutants

The correlation coefficients between meteorological factors (temperature and wind speed) shown in Figures 2 and 3, and various pollutants (HCHO, TVOCs, $PM_{2.5}$, PM_{10}, and BC) shown in Figures 4 to 8, were analyzed across multiple stations downwind from gas combustion sources. HCHO exhibited stronger negative correlations with temperature at some stations, with significant values indicating a substantial impact of temperature on HCHO levels. Correlations for TVOCs and $PM_{2.5}$ displayed mixed responses to changes in temperature and wind speed, with some stations showing significant inverse correlations. The correlations for PM_{10} and BC further illustrated the complex interaction between air pollutants and meteorological conditions, with BC exhibiting a highly significant positive correlation with temperature at one station. This comprehensive dataset underscores the nuanced relationship between air quality parameters and environmental factors, highlighting the importance of station-specific analyses in understanding pollution dynamics. Significance levels provide insight into the strength of these correlations, with $p < 0.01$ denoting very significant correlations, based on two-tailed tests.

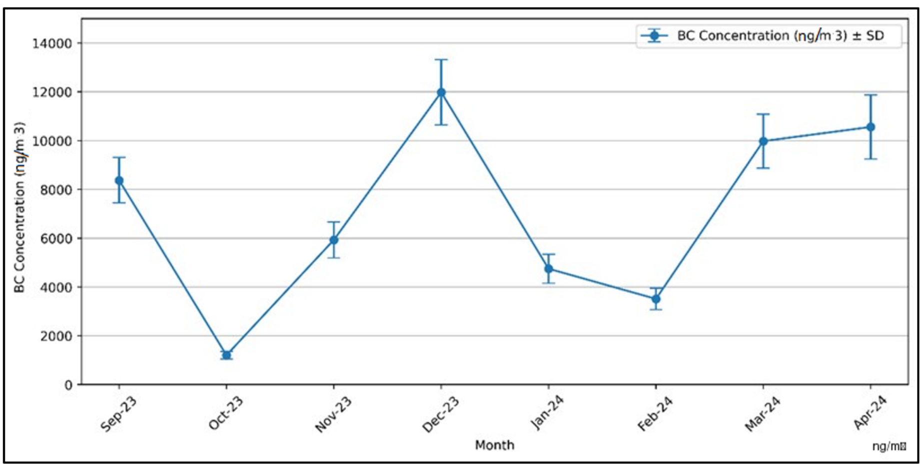

Figure 8. BC concentrations at measuring stations during the study period

4. Conclusion

This study monitored air pollution from gas flaring at the Al-Rumaila oil field in Basra, Iraq, over eight months. It revealed that all measured pollutants, except for total volatile organic compounds (TVOCs), exceeded local and World Health Organization (WHO) limits. High concentrations of $PM_{2.5}$, PM_{10}, and black carbon were observed near the flaring sources. Negative correlations between most pollutants and temperature and wind speed indicated a build-up under calmer, cooler conditions. The prevailing northwesterly and southwesterly winds suggest potential pollutant transport towards populated areas in Basra city center. The government should enforce stricter emission regulations and enhance air quality monitoring, while oil companies should adopt best practices to minimize flaring and invest in cleaner technologies to protect public health and reduce pollution.

Acknowledgment

Acknowledgment to the Head and Staff of the Ecology Department, University of Basrah, and the South Oil Company for their support.

References

Ahmed HS, Azeez NM. Indoor Carbon Dioxide Air Quality and Thermal Comfort in Primary School Classrooms of Maisan Province, Iraq. EnvironmentAsia. 2023; 16(3): 94-103.

Al Muhyi Haleem Ali A, Younis Khalil Aleedani F. The Effect of Natural Gas Flaring on Air Pollution and its contribution to Climate Change in Basra City. Al-Kitab Journal for Pure Sciences. 2023; 5(1): 25-38.

Al-Jaf SJ, Al-Taai OT. Impact of carbon dioxide concentrations on atmospheric temperature changes over Iraq and some neighboring countries. Plant Archives. 2019; 19: 1450-1456.

Alsabbagh MR, Al-Muhyi AH, Azeez NM. Methane and Hydrocarbon Emission Rates from Oil and Gas Production in the Province of Basra, South of Iraq. IOP Conference Series: Earth and Environmental Science. 2023; 1215(1).

Alsabbagh MRK, Al-Muhyi B, Azeez A. Influence of Natural Gas Flaring on Air Pollution in Basra Province by Using a Screen 3 View Model "Environmental Pollution". 2023 (master thesis).

Bashara ZR, Hadi FA. Estimation of Shear Wave Velocity for Shallow Depth Using Artificial Neural Network Technique: A Case Study in Rumaila oil field. Iraqi Geological Journal. 2023; 56(1): 114-128.

deSouza PN. Key Concerns and Drivers of Low-Cost Air Quality Sensor Use. Sustainability. 2022; 14(1): 584.

Elehinafe FB, Nwizu CI, Odunlami OB, Ibukun FD. Natural Gas Flaring in Nigeria, its Effects and Potential Alternatives – A Review. Journal of Ecological Engineering. 2022; 23(8): 141-151.

Fawole OG, Cai X-M, MacKenzie AR. Gas flaring and resultant air pollution: A review focusing on black carbon. Environmental Pollution. 2016; (216): 182-197.

Hassen W, Hnaien N, ben Said L, Albati FM, Ayadi B, Rajhi W, et al. Air pollution dispersion in Hail city: Climate and urban topography impact. Heliyon. 2023; 9(10).

Hassoon AF, Al-Dabbagh SK. Iraqi Geological Journal Effect Dynamic Stability of Atmospheric Boundary Layer on Plume Downward Flux Emitted from Daura Refinery Stacks. In Iraqi Geological Journal. 2023; (1A).

Kim JB, Kim KH, Yun ST, Bae GN. Detection of Carbonaceous Aerosols Released in CNT Workplaces Using an Aethalometer. Annals of Occupational Hygiene. 2016; 60(6): 717-730.

Mohamedali SA, Ameen MH, Saeb Tais A, Hamad RO. Repercussion of Petroleum Industry and Vehicle Emissions on Kirkuk Air Quality Using GIS. 2020.

Motte J, Alvarenga RAF, Thybaut JW, Dewulf J. Quantification of the global and regional impacts of gas flaring on human health via spatial differentiation. Environmental Pollution. 2021; 291: 118213.

Ojewale O. Are Nigeria's promises to end gas flaring merely hot air? ISS Today. 2021.

Othman MH, Azeez NM, Al-Gizzi IA. Investigation of Air Quality in Medical Centers in Different Places in Basra Province, South of Iraq. International Journal of Science and Management Studies (IJSMS). 2022.

Saleh IA, Ezzo AA, Abdel-Latif NM, Mohammed AM. Formaldehyde Risk Assessment in Indoor/Outdoor Environment in Cairo, Egypt. Egyptian Journal of Chemistry. 2022; 65(7): 175-188.

Salman NA, Al-Mishrey MK, Al-Saad HT, Rushdi AI. Air pollution in the southern part of Iraq and its health risks. In Aerosol optical depth and precipitation. Springer; 2024: 107-122.

Shaheed SH, Ghawi AH, Al-Obaedi JTS. Air pollution assessment at University of Al-Qadisiyah associated with traffic from neighbouring roads. Journal of Physics: Conference Series. 2021; 1895(1).

Taheri A, Aliasghari P, Hosseini V. Black carbon and $PM_{2.5}$ monitoring campaign on the roadside and residential urban background sites in the city of Tehran. Atmospheric Environment. 2019; 218.

Zheng Z, Xu G, Li Q, Chen C, Li J. Effect of precipitation on reducing atmospheric pollutant over Beijing. Atmospheric Pollution Research. 2019; 10(5): 1443-1453.