

Measuring SO₂, CO₂, and Radon Gases Concentration in the Areas Surrounding the Dora Refinery

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ABSTRACT

This research aims to evaluate the levels of some air pollutant gases, namely sulfur dioxide (SO₂), carbon dioxide (CO₂), and radon (Rn²²²) in the residential areas surrounding the Dora refinery, south of Baghdad. Several locations were selected from residential areas representing different directions relative to the refinery, taking into account the distance from the emission source and the environmental characteristics of the site. In this study, gas detection techniques were applied, using a multi-gas detector in the areas surrounding the Dora refinery. Concentrations were collected over three consecutive months, with 89 readings taken at 14 locations in the areas surrounding the Dora refinery. The results showed that the average value of sulfur dioxide (SO₂) was 0.8 ppm, equivalent to 2.288 mg/m³, with the highest reading at 2.8 ppm, equivalent to 8.008 mg/m³ recorded at the Jadriya intersection. While the lowest reading was recorded at Al-Zafaraniya intersection, which reached 0.3 ppm, which is equivalent to (0.8580 mg/m³), which is less than the limit recommended by the World Health Organization. As for carbon dioxide gas (CO₂), the highest reading was recorded in the Jadriya area, site 4, which reached 888.6 ppm. The lowest reading was recorded in the Dur Al-Masafie area, site 3, which reached 234.7 ppm. As for radon gas (Rn²²²), the highest reading was recorded at 317.834 Bq/m³ in the Al-Saydiya area, site 1, and the lowest reading was recorded in the Al-Taama/Al-Dawra area, where it reached 13.542 Bq/m². No value higher than the internationally recommended values was recorded. This study highlights the importance of periodic monitoring of the concentrations of polluting gases in the air, especially in areas adjacent to oil facilities, due to their direct environmental and health impacts on the population.

Keywords: Daura refinery, SO₂, Air pollution, Gas concentration, Radon gas.

1. INTRODUCTION

Air pollution is one of the most serious problems facing the world. It results from the air containing harmful gases, dust, vapors, and odors, which can harm human health. Pollution

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has been a widely recognized problem since ancient times (**Mohamed et al., 2016**). SO₂ is a component of environmental pollution, with suspended particles measuring 2.5 micrometers in diameter resulting from combustion emissions (**Abbas and Rajab, 2022**). SO₂ is a pollutant produced by various human activities, such as oil refining and the burning of fossil fuels in power plants. It is a rich element that is released into the Atmosphere as a result of natural, and human phenomena. (**Ibrahim et al., 2014; and Khokhar et al., 2004**). The SO₂ is one of the most dangerous chemical threats to the environment in the world (**Ibrahim et al., 2014**). A toxic gas released into the atmosphere during combustion can cause acid rain, acidifying soil and streams, affecting plants, and corroding buildings. It causes various respiratory diseases upon prolonged exposure (**Ibrahim and Jabbar, 2011**). Emissions can spread depending on weather conditions, such as wind direction and speed, fluctuations, disturbances, and atmospheric stability. SO₂ emissions continue with the increased use of fossil fuels (**Nurhisanah et al., 2022**). It is also produced naturally from lava explosions. Volcanoes are very strong sources of SO₂ (**Prata and Bernardo, 2007; Von Glasow et al., 2009**). Sulfur dioxide is a significant global health hazard and can cause changes in atmospheric characteristics. According to the World Health Organization, 92% of the world's population lives in areas with poor air quality (**Kosan et al., 2018**). Also, when it flows continuously, it leads to the formation of smog (**Li et al., 2019**). The amount of sulfur dioxide increases with the increase in demand for energy, especially that which runs on fossil fuels, which leads to more pollution in the Atmosphere (**Kim et al., 2021**). CO₂ is a naturally occurring gas in the air, with a concentration of approximately 360 ppm in fresh air and can reach higher levels. It is most intense and active in areas with high population density and human and industrial activity. In residential buildings and enclosed spaces, its concentration is higher than in open, ventilated spaces (**Claude and Foradini, 2002**). It is a general global concern. Its release is due to global warming caused by the burning of fossil fuels, the lack of green spaces, and deforestation (**Machida et al., 2008**). Radon is a noble gas in the periodic table. It is heavier than air and is therefore found at the bottom of the atmosphere (**Hussein and Khalaf, 2013**). It is a major cause of environmental pollution and the spread of radioactive materials in the air (**Mahdi, 2017**).

This study aims to assess air pollution levels in the areas surrounding the Dora Refinery by measuring the concentrations of Rn²²², CO₂, and SO₂, as these are important environmental indicators related to health and environmental impacts. Radon gas is a naturally occurring radioactive gas that causes lung cancer when exposed to it for long periods. SO₂, a gas produced from fossil fuels, affects air quality and causes lung irritation. CO₂, a gas produced by industrial activities and emissions associated with fuel combustion, negatively impacts climate change. To this end, the study was conducted in this research and compared with permitted international references.

2. MATERIAL AND METHOD

2.1 Study Area

The Dora Refinery is the main refinery of the Midland Refineries Company in Iraq. It is located south of Baghdad, on the western side of the Tigris River. The Dora Refinery operates 24 hours a day, refining large quantities of crude oil to produce a range of petroleum products that meet market demand. Therefore, it is considered one of the biggest air pollution problems in Baghdad. It was built in 1953 and is one of the oldest refineries in Iraq. It was expanded in 1956, with new units being built, employing more than 6,550 engineers

and workers across various departments. The refinery is surrounded by a small, liquefied petroleum gas (LPG) filling plant and the Imam Hassan neighborhood to the east. The Al-Jam'iyah neighborhood is located to the west and southwest. The Dora Expressway is located to the east and southeast, and the city of Karrada is located to the north, as shown in **Fig.1. (Shubbar, 2017)** It produces 140,000 barrels of various petroleum derivatives per day. It is located in an area of 2,500,000 square meters, to which oil is transported from the northern oil fields, from the fields of Kirkuk and Khanaqin. It produces gasoline, gas, jet fuel, gas oil, diesel, lubricants, asphalt, and other derivatives **(Shubbar et al., 2018)**.



Figure 1. Location of AL-Daura Refinery in Baghdad Province. **(Ahmed et al.,2021)**

2.2 Measurement Method

The Forensics Detectors device manufactured by Amazon Model FD-4S was used. It is a portable gas analyzer classified as a field detection device. It is lightweight and battery-operated and is capable of measuring several organic and inorganic gases at low concentrations (ppm) simultaneously in real time **(Wilson et al., 2019)**. The device works based on highly sensitive electrochemical sensors capable of detecting gas concentrations within the range (ppm), and its response time is ≤ 30 . It operates within a temperature range of 0-122°F.

2.3 Study Period

The concentrations of sulfur dioxide SO_2 , mono dioxide CO_2 , and Radon gases emitted from the Dora refinery were calculated for three months, April, May, and June 2025, at different distances from the refinery's center to a few kilometers around it **(Thaer and Roomi, 2021; Ferm and Svanberg, 1998)**. The Dora refinery operates around the clock and processes large quantities of crude oil, producing approximately 210,000 barrels per day, which represents a daily source of pollution **(Ahmed et al., 2021)**. Sulfur dioxide SO_2 , mono dioxide CO_2 , and Radon gas measurements were conducted in the residential areas surrounding the refinery. This study included the refinery center and 28 major areas surrounding the refinery: Dijlah, Al-Jam'iyah, Al-Jazeera Al-Thani, Al-Iskan, 60th Street, Al-Zafaraniya, Al-Hatem Al-Saadoun, Dora Expressway, Pearl of Baghdad, the refinery's buildings, Al-Salam Residential Complex, the refinery intersection, Al-Karrada, and Al-Jadriya. The total number of samples was 29, distributed across 29 sites, with approximately 6 samples per area. These samples or measurements were taken during the spring season, from April to June, a period of three months, during which the weather conditions are characterized by variable winds, pollutant accumulation, and moderate temperatures. The



exposure time for each sample was one full hour to ensure accurate average concentrations reflecting the pollution level in each area during the measurement period.

3. CALIBRATION

To ensure sensor accuracy, general gas sensors must be calibrated at regular intervals. Sensor manufacturers typically recommend calibrating the device at intervals between calibrations. Individual toxic gas detectors may be calibrated with a specific toxic gas, while multi-gas detectors may be calibrated with their calibration gas mixture. Gas sensor calibration consists of two main steps. First, the reference zero reading must be determined using pure nitrogen or synthetic air. Second, the sensor's operating range must be calibrated using a standard gas mixture. Ideally, a target gas mixture balanced in natural air is used as the calibration (Khan et al., 2019; Ishikawa et al., 2009). Calibration is performed by the manufacturer or by a separate gas laboratory. The U.S. Environmental Protection Agency stipulates that continuous monitoring devices must be calibrated at least annually to ensure accurate readings (William and Danie, 2011; Zhang et al., 2020).

4. RESULTS AND DISCUSSION

The SO₂, CO₂, and Radon²²² gases levels in the air surrounding the Dora refinery were monitored using an atmospheric gas level measuring Forensics Detectors device (Ahmad et al., 2014; Rall, 1974). Based on the results of the inventory of SO₂, CO₂, and Radon²²² gases emissions, it was found that sulfur dioxide emissions are dominated by industrial sources, representing 77% of the total SO₂, CO₂, and Radon²²² gases emissions (Bhanarkar et al., 2005; Schmidt et al., 1990). The results of measurements conducted around the Dora refinery in residential areas and selected external roads showed a variation in the concentrations of SO₂, CO₂, and Radon²²² gases in the atmosphere. Table 1 shows the overall results of SO₂, and CO₂ concentrations in 29 locations around the Dora refinery.

Table 1. The SO₂ and CO₂ gas values and concentrations, and the location of the selected areas around the Daura Refinery.

Code	Area name	SO ₂ (ppm)	SO ₂ (mg/m ³)	CO ₂ (ppm)	Latitude	Longitude
S1	Doura Refinery	1.7	4.86	876.8	33.274978	44.427170
S2	AL-Jameia/First site	0.7	2	354	33.255088	44.428954
S3	AL-Jameia/Second site	0.6	1.7	337.4	33.253091	44.422864
S4	AL-Jameia/Third site	0.7	2	467.5	33.259382	44.420875
S5	Refineries Intersection	0.7	2	784	33.261413	44.417960
S6	Dour AL-Masafi 1site	0.6	1.7	344	33.283967	44.443357
S7	Dour AL-Masafi 2site	0.5	1.4	466.3	33.284474	44.441791
S8	Dour AL-Masafi 3site	0.4	1.14	234.7	33.281919	44.441746
S9	AL-Salam Area	0.5	1.4	773.7	33.251064	44.429035
S10	East of Dora	0.8	2.28	554	33.257774	44.440558
S11	Hay Dijla 1site	0.5	1.4	558.8	33.246250	44.424628
S12	Hay Dijla 2site	0.4	1.14	537.5	33.242909	44.423193
S13	Hay Dijla 3 site	0.6	1.7	578.2	33.252323	44.431859
S14	Dora Expressway	0.6	1.7	376.9	33.248780	44.421390
S15	Hatem AL-Saadoun	0.5	1.4	576.3	33.245238	44.413048



S16	AL-Zaafaraniya	0.3	0.85	253.4	33.293035	44.453497
S17	Street 60	1.4	4	389.77	33.239777	44.394601
S18	Hay AL-Askan	0.5	1.4	581.3	33.252275	44.381317
S19	The second AL-Jazirat	1.5	4.2	400.71	33.259737	44.386924
S20	AL-Karrada 1site	0.9	2.57	407.5	33.287491	44.405752
S21	AL-Karrada 2site	0.7	2	389.1	33.297775	44.431007
S22	AL-Karrada 3site	0.6	1.7	395.4	33.295396	44.421690
S23	AL-Karrada 4site	0.7	2	465	33.291146	44.411302
S24	AL-Karrada 5site	0.8	2.28	480	33.290691	44.419202
S25	AL-Karrada 6 site	0.8	2.28	576.9	33.288046	44.406211
S26	AL-Jadriya 1 site	0.9	2.57	653.5	33.284969	44.398905
S27	AL-Jadriya 2 site	2.8	8	65.9	33.281220	44.388917
S28	AL-Jadriya 3 site	0.8	2.28	741.8	33.383913	44.372826
S29	AL-Jadriya 4 site	0.7	2	888.6	33.271522	44.364055

Stability classes are highly dependent on atmospheric parameters. They cannot be measured directly inside the refinery due to the strict safety measures in place. In addition, stack height and wind speed significantly affect the measurement procedure inside the refinery. The average value of SO₂ gas was 0.8 ppm, which is lower than the internationally permitted limit of 5 ppm as a time reference average for 8-10 continuous working hours. The highest value of SO₂ gas was recorded at 2.8 ppm at the Jadriya intersection, while the lowest value of 0.3 ppm was recorded at the Zafaraniya intersection. The highest value of CO₂ gas was recorded at 888.6 ppm at the Jadriya area, site 4, and the lowest value was recorded at 234.7 ppm at the refinery's Dur Al-Masaf area, site 3. **Fig. 2** shows the relationship between the study sites and SO₂ concentrations in the air, reflecting the increasing influence of emission sources close to residential areas.

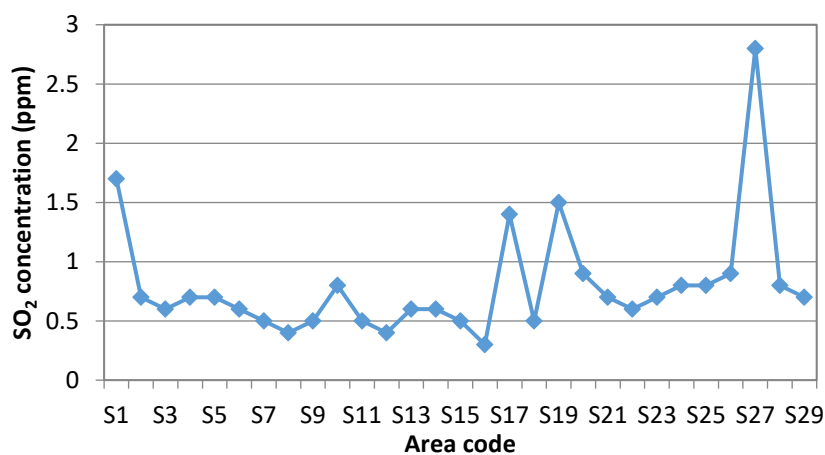


Figure 2. The SO₂ concentration in ppm units measured in the Air surrounding the filter across the studied sites.

This part of the study measured atmospheric carbon dioxide (CO₂) levels at several selected locations around the Dora Refinery to assess the pollution levels from this gas generated by industrial activities and refinery emissions. The following graph compares the gas concentrations at the locations where the study was conducted, helping to identify the most affected areas and deviations from safe environmental levels.

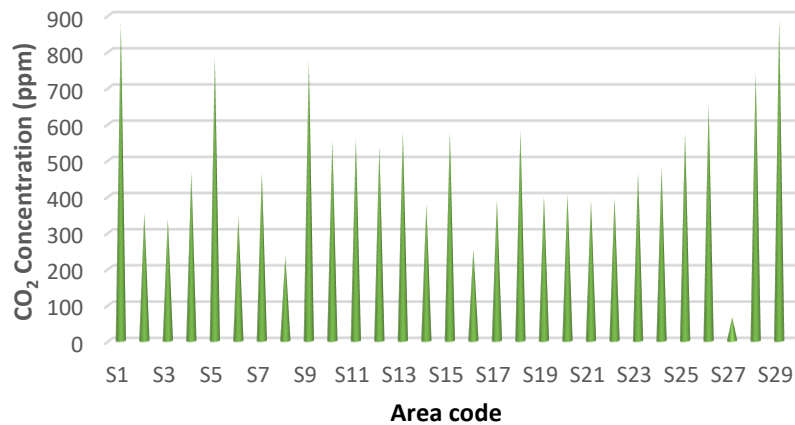


Figure 3. The relationship between the concentration of CO₂ and the studied areas surrounding the refinery.

Fig. 4 shows the wind speed and the pollutants coming out of the chimney at 10 meters and 30 meters. Wind speed and chimney height are very important to keep the pollutants away as much as possible.

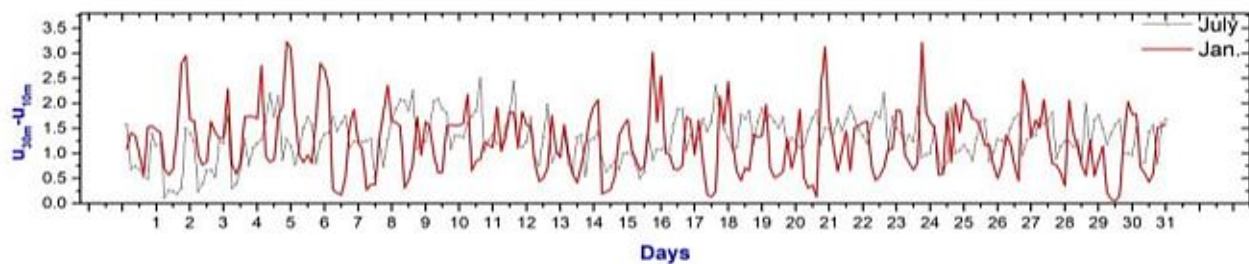


Figure 4. Daily wind speed difference between 10m and 30m according to stability class and power Law (Ahmed et al., 2021).

Table 2. The indoor Radon gas concentrations in the selected areas with the symbol and latitude and longitude for each area.

Code	Area name	Radon (pCi/L)	Radon (Bq/m ³)	Latitude	Longitude
H ₁	AL-Saydiya first location	0.482	17.834	33.258205	44.353089
H ₂	AL-Saydiya second location	0.432	15.984	33.227746	44.362351
H ₃	AL-Jameia / Doura	0.372	13.764	33.25088	44.428954
H ₄	AL-Jazeraa / Doura	0.45	16.65	33.259737	44.386924
H ₅	AL-Tumaa / Doura	0.366	13.542	33.254189	44.394823
H ₆	Abu Tayyara / Doura	0.415	15.355	33.248661	44.413879
H ₇	Abu Dusheer / Doura	0.47	17.39	33.218288	44.384993
H ₈	AL-Karrada first location	0.402	14.874	33.307180	44.428860
H ₉	AL-Karrada second location	0.406	15.022	33.295148	44.424401
H ₁₀	AL-Jadriya first location	0.416	15.392	33.287869	44.395973
H ₁₁	AL-Jadriya second location	0.423	15.651	33.283599	44.387624
H ₁₂	AL-Zaafaraniya	0.433	16.021	33.279302	44.453304



Fig. 5 shows the relationship between radon gas concentrations and the selected areas where concentrations were measured. The highest value of radon gas concentration was recorded in the Al-Saydiyah area, the first site, where it reached 17.834 Bq/m^3 . The lowest value was recorded in the Al-Ta'mah/Al-Dawrah area, where it reached 13.542 Bq/m^3 .

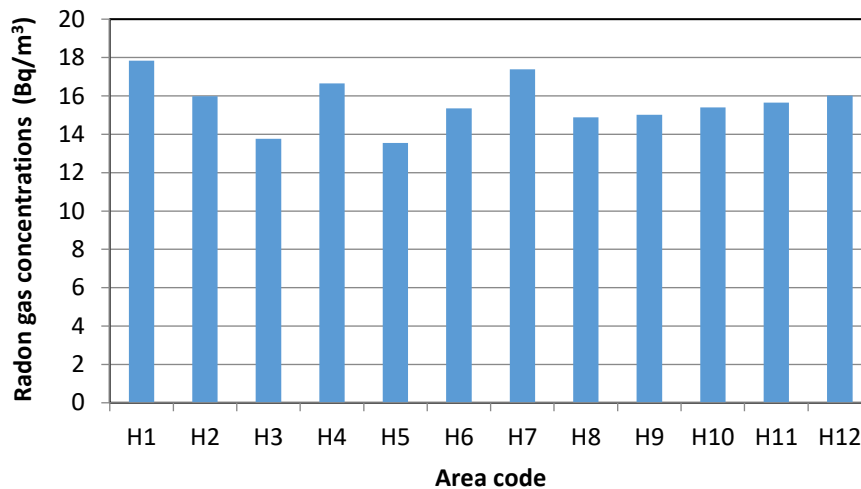


Figure 5. shows the relationship between radon gas concentrations in Bq/m^3 units and selected areas.

When analyzing the relationship between the studied gases and other factors such as temperature, humidity, and wind speed, we found that the relationship is positive. As shown in **Fig. 6**, wind speed means that gases are dispersed and move further and further away from residential areas in the atmosphere, but this may not prevent pollution. In the summer, we find that pollution increases more, due to the weakness of the green infrastructure and the failure to implement the required environmental reform rules in cities (**AL-Obaidi et al., 2023; Hicks and Liss, 1976**). The results showed that sulfur dioxide concentrations may vary depending on the proximity to the emission source in the areas surrounding the Dora refinery, and no values were recorded that exceeded the standard values permitted according to international standards and the World Health Organization. The international standards that were set for the minimum exposure value about (75 ppb) for a working hour, according to the US Environmental Protection Agency (**gov, 2010**). While the World Health Organization set the minimum exposure limit at $20 \mu\text{g/m}^3$ for a working hour (**WHO, 2024**). The European Union set the minimum exposure limit at 125 mg/m^3 for a working hour, and $350 \mu\text{g/m}^3$ for a year (**EEA, 2014**). Especially as many Countries rely on policies to reduce pollutant concentrations to make decisions based on their health impacts (**Pandey et al., 2005**). Gas surveys must be continuous, and radical solutions must be found (**Sitanggang et al., 2023**). As for carbon dioxide, the permissible exposure limit recommended by the World Health Organization is not to exceed 1,000ppm (**WHO, 2010**) in enclosed spaces. According to the U.S. Occupational Safety and Health Administration, it should not exceed 5,000 ppm (**OSHA, 1989**) over an eight-hour workday. As for radon gas, no values higher than the internationally recommended values have been recorded. In the United States, the reference radon level of 148 Bq/m^3 (**US EPA, 2002**). In the European Union, the radiation level for which protective measures must be taken ranges from 500 to 1500 Bq/m^3 (**ICRP, 2009**). The World Health Organization has set a reference average for radon gas concentration in buildings, not to exceed 100 Bq/m^3 (**WHO, 2021**). The Ministry of Environmental Protection, based on the recommendations of the International Commission

on Radiological Protection, has set the maximum value for radon gas concentration at 200 Bq/m³ (ICRP, 2019).

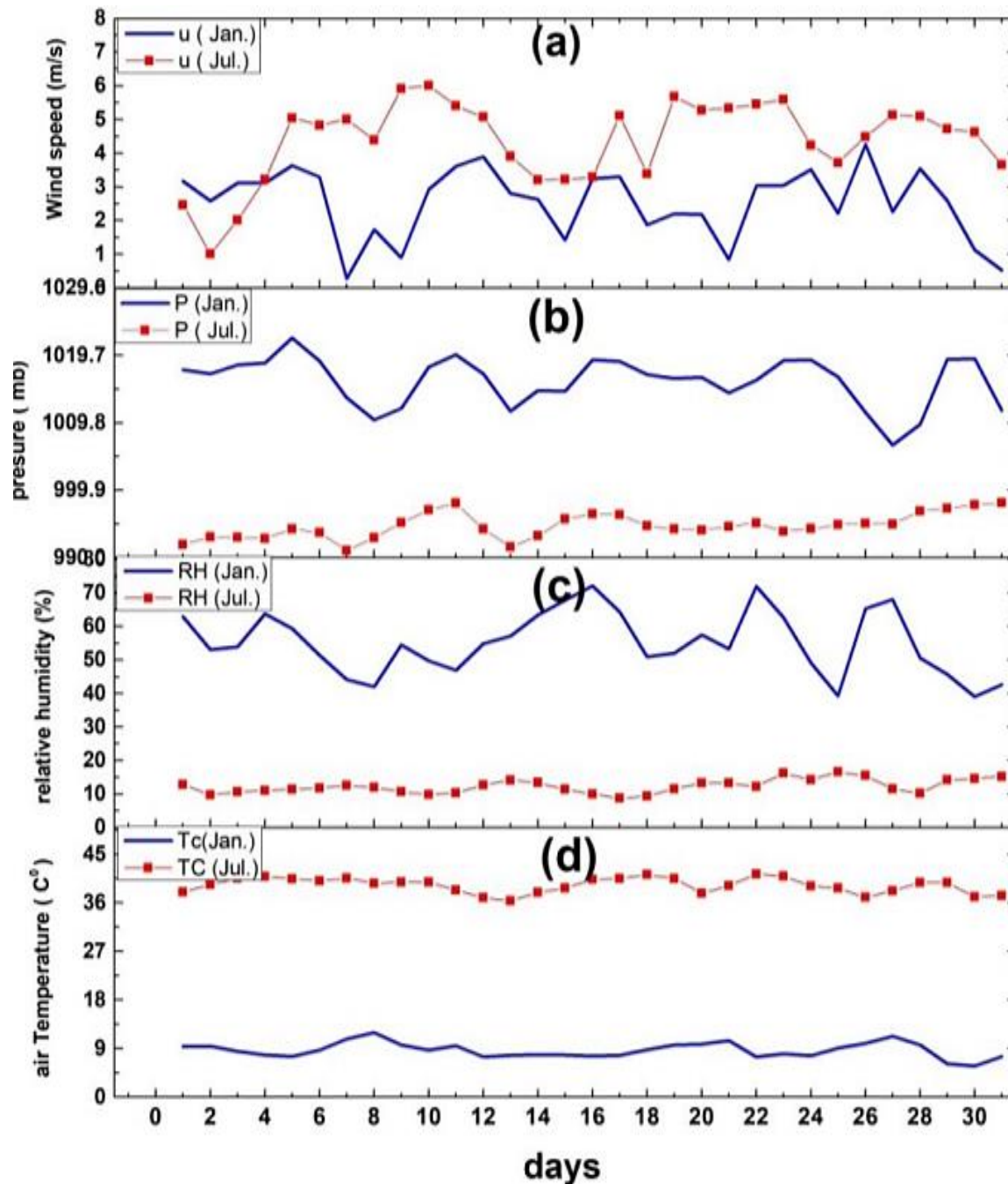


Figure 6. Average daily recorded atmospheric elements, (a) wind speed, (b) Atmospheric pressure, (c) Relative humidity, (d) Temp. at two months.

6. CONCLUSIONS

Through measurements and research, it was concluded that concentrations of SO₂, CO₂, and Radon²²² gases increase under stable conditions due to reduced atmospheric turbulence. The areas most affected by emitted pollutants are those with prevailing winds. Wind speed has a clear effect on pollutant dispersion; therefore, pollutant concentrations decrease with



increasing wind speed. The diameter and height of the chimney, and the velocity of the gas exiting it, play a major role in reducing pollutants and spreading them over greater distances. However, this does not prevent pollution at ground level, nor does it mean it is environmentally friendly, as distant areas will be affected by pollutants. The presence of statistically significant differences between different regions indicates a clear impact of the refinery on air quality in the surrounding areas. Continued gas emissions may lead to serious health risks, especially for people with respiratory diseases. It is essential to conduct periodic pollution surveys around the refinery and surrounding areas. Green spaces should also be increased, and trees planted in all areas surrounding the refinery. Increasing the height and diameter of the chimney helps reduce pollutant concentrations in areas near the refinery. The use of modern methods and techniques reduces combustion and limits emissions.

Credit of Author Contribution

Ahmed Atta: Writing – original draft, Validation, Software, Methodology. Nasser A. Ahmed: Reviewing & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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قياس تركيز غاز ثاني أكسيد الكبريت وثاني أكسيد الكربون وغاز الرادون في المناطق المحيطة بمصفاة الدورة

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الخلاصة

يهدف هذا البحث الى تقييم مستويات بعض الغازات الملوثة للهواء، وهي ثاني أكسيد الكبريت (SO_2) وغاز ثاني أكسيد الكربون (CO_2) وغاز الرادون (Rn^{222}) في المناطق السكنية المحيطة بمصفاة الدورة جنوب مدينة بغداد. تم اختيار عدة مواقع من المناطق السكنية تمثل اتجاهات مختلفة بالنسبة للمصفاة، مع الأخذ بنظر الاعتبار المسافة عن مصدر الانبعاث والخصائص البيئية للموقع. في هذه الدراسة، تم تطبيق تقنيات الكشف عن الغازات، باستخدام كاشف الغاز المتعدد في المناطق المحيطة بمصفاة الدورة. تم جمع التركيزات على مدى ثلاثة أشهر متتالية، مع أخذ 89 قراءة في 14 موقعاً في المناطق المحيطة بمصفاة الدورة. وأظهرت النتائج أن متوسط قيمة غاز ثاني أكسيد الكبريت (SO_2) كان (0.8ppm)، أي ما يعادل (2.288mg/m^3)، مع تسجيل أعلى قراءة (2.8ppm)، أي ما يعادل (8.008mg/m^3)، في تقاطع الجادرية. في حين سجلت أقل قراءة في تقاطع الزعفرانية والتي بلغت (0.3ppm) والتي تعادل (0.8580mg/m^3) وهي أقل من الحد الموصى به من قبل منظمة الصحة العالمية. أما غاز ثاني أكسيد الكربون (CO_2) حيث ان تم تسجيل أعلى قراءة في منطقة الجادرية الموقع الرابع والتي بلغت (888.6ppm). وان ادنى قراءة سجلت في منطقة دور المصافي الموقع الثالث والتي بلغت (234.7ppm). وغاز الرادون (Rn^{222}) حيث ان تم تسجيل أعلى قراءة بلغت (17.834Bq/m^3) في منطقة السيديّة الموقع الاول، وان ادنى قراءة تم تسجيلها في منطقة الطعمة/الدورة حيث ان بلغت (13.542Bq/m^3). حيث ان لم يتم تسجيل اي قيمة اعلى من القيم الموصى بها عالمياً. تبرز هذه الدراسة أهمية المراقبة الدورية لتراكيز الغازات الملوثة في الهواء، خصوصاً في المناطق المجاورة للمنشآت النفطية، لما لها من تأثيرات بيئية وصحية مباشرة على السكان.

الكلمات المفتاحية: مصفاة الدورة، ثاني أكسيد الكبريت، تلوث الهواء، تركيز الغاز، غاز الرادون.