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Evaluation of Air Pollution with NO_2, SO_2, and $PM_{2.5}$ in Nasiriyah City Center, South of Iraq

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Abstract

Air pollution is considered one of the most dangerous types of pollution because of the problems and risks it causes to living organisms on the surface of the Earth. This paper studied the emission of air pollutants (nitrogen dioxide, NO_2, sulfur dioxide, SO_2, and particulate matter $PM_{2.5}$) in the city center of Nasiriyah. The data were taken from the European Mediterranean Weather Forecast (ECMWF) during the year (2022). The pollutant roses were plotted, which show the most pollutant source from the northwest direction of the electric power plant in the city and another source from the south (Nasiriyah refinery and Saba oil field). The daily rates of NO_2, SO_2 and $PM_{2.5}$ concentrations (in $\mu g/m^3$) were studied and evaluated during the four months. The Air Quality Index (AQI) was calculated and the results showed that the NO_2 and SO_2 categories were good while for $PM_{2.5}$ was unhealthy for people with respiratory diseases and unhealthy causing the daily AQI (160 $\mu g/m^3$ as the annual mean) to be high in 2022.

Keywords: Pollution roses; Air pollutants; Air quality index; Nasiriyah city center

تقييم تلوث الهواء بـ (NO_2 ، SO_2 و $PM_{2.5}$) في مركز مدينة الناصرية جنوب العراق

جمال سهيل عبد الركابي[1]، منعم حكيم الجبوري[2], حسين خليفه جليب*[3]
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الخلاصة

يعتبر تلوث الهواء من أخطر أنواع التلوث لما يسببه من مشاكل ومخاطر للكائنات الحية على سطح الارض. في هذا البحث تمت دراسة انبعاث ملوثات الهواء (ثاني أكسيد النيتروجين، ثاني اوكسيد الكبريت والجسيمات الدقيقة $PM_{2.5}$) في مركز مدينة الناصرية. تم أخذ البيانات من بيانات المركز الاوربي خلال عام (2022). تم رسم وردة الملوثات والتي تبين ان المصدر الرئيسي للتلوث كان من الاتجاه الشمالي الغربي لوجود محطة الطاقة الكهربائية في المدينة ومصدر آخر من الجنوب (مصفاة الناصرية وحقل صبة النفطي)، كما تمت دراسة وتقييم المعدل اليومي لتركيزالملوثات (ثاني أكسيد النيتروجين، ثاني أكسيد الكبريت والجسيمات الدقيقة $PM_{2.5}$ (ميكروجرام/متر مكعب)) خلال أربعة أشهر من السنة. في الجزء الثاني من البحث تم حساب مؤشر جودة الهواء، وقد اظهرت النتائج ان فئة ثاني اوكسيد النتروجين وثاني اوكسيد الكبريت كانت جيدة. اما

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فئة المؤشر للملوث $PM_{2.5}$ كانت غير جيدة وخصوصا للاشخاص الذين يعانون من الحساسية لان قيمة مؤشر جودة الهواء كانت (160ميكروغرام / متر مكعب) وتعتبر مرتفعة للملوث $PM_{2.5}$ خلال عام 2022 .

1. Introduction

Air pollution is a global environmental problem that is raising human health concerns. There is an urgent need to monitor, study and forecast air quality to identify and control the harmful health effects of low air quality, especially in developing countries [1]. The major air pollutants emitted from power stations and petrochemical industries include sulfur oxides, nitrogen oxides (NO_x), and Particulate Matter (PM) [2]. Short-term meteorological variations can significantly impact air [3, 4]. For example, wind direction plays an important role in transporting air pollutants from their emitted regions to others; atmospheric stability, topography, etc. [5, 3]. Pollution roses, sometimes called concentration roses, are used to calculate the average concentrations of a pollutant at a receptor from multiple emission sources over a period (usually a day) as a function of wind direction [5, 4]. Factors affecting air quality include climatic conditions, local emission sources, trans boundary flow of pollutants, emission control methods, and human activities. In 2010, the United States Environmental Protection Agency (EPA) amended the National Ambient Air Quality Standards (NAAQS) for nitrogen dioxide (NO_2) to include a health-based primary limit for hourly NO_2 and to require air quality monitoring using a variety of methods [6]. There are typically two sources of NO_2 gas emissions to the atmosphere: chemical processes occurring in the atmosphere or direct emission sources (primary pollutant) [7].

The latest global estimates indicate that exposure to ambient fine particles (e.g., $PM_{2.5}$: particulate matter with a diameter of 2.5 micrometers or less) caused around 4.2 million deaths worldwide in 2015, representing 7.6% of total global deaths [8]. According to the World Health Organization (WHO), in 2023, it was estimated that congenital abnormalities claim the lives of 295,000 babies annually, with 95% of these fatalities taking place in low- and middle-income countries [9]. According to Ravindra et al. in 2021 [10]. Prenatal exposure to ambient $PM_{2.5}$, NO_2, sulfur dioxide (SO_2) and ozone has led to very serious health problems in newborns, such as pulmonary stenosis, tetralogy of Fallot, abdominal septal defect, cleft lip, limb deformities and other diseases and deformities. Researchers analyzed 2010–2019 air quality data, concentrating on several harmful air pollutants, such as carbon monoxide, carbon dioxide, particular matter, NO_2, SO_2, O_3, ammonia, and more. The study brought attention to the concerning increase in NO_2 and $PM_{2.5}$ [11,12]. Precipitation, air temperature, and wind are the three predictor factors that have a substantial correlation with the Air Quality Index (AQI)[12, 13]

In Iraq, pollution in all its forms is a major problem and is present in more than one place. There is water pollution, air pollution, and soil pollution [14, 15, 16]. Air pollution in Nasiriyah, a city in southern Iraq, is caused by several major primary and secondary sources that contribute to the degradation of air quality. The primary sources include industrial activities, transport and natural factors. Industrial emissions from oil production and refining, chemical production, cement production, and power plants, especially those burning fossil fuels, such as oil or gas, and small factories, are significant sources of air pollution. Nasiriyah is known for several significant oil (e.g., Nasiriyah, Gharraf and Subba) and gas (Rafidain) fields that contribute to the country's energy sector and are shown in Figure 1. They can release large amounts of pollutants, including SO_2, nitrogen oxides (NO_x), Volatile Organic Compounds (VOCs) and PM.

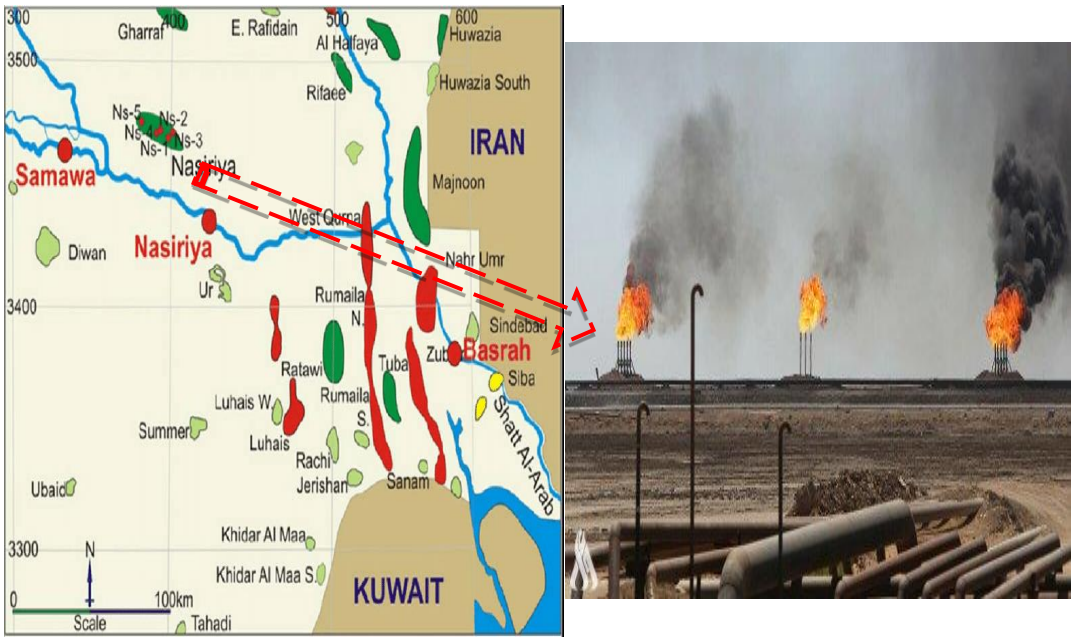

Figure 1: Location of oil wells and fields, north of Nasiriya with photograph of their flamers

Secondary sources include open burning of municipal waste, burning of agricultural residues, poor waste management infrastructure and agricultural activities (e.g., chemical fertilizers and pesticides). This releases various harmful pollutants, such as dioxins, furans, CO, and particulate matter, ammonia, methane and other gases into the air. The center of Nasiriyah is located in a region prone to dust and sandstorms [17], which naturally contribute to high levels of particulate matter in the air [18]. These natural events can significantly increase PM_{10} and $PM_{2.5}$ levels, affecting visibility and respiratory health.

Air pollution contributes to the deterioration of the natural environment, affecting agriculture, water resources and the overall health of the ecosystem. Nasiriyah's economy, which relies heavily on agriculture, industry and oil production, can be negatively affected by air pollution. The city is close to several important archaeological sites, including the ancient city of Ur. Air pollution can damage these sites, threatening the preservation of Iraq's cultural heritage. Given these factors, tackling air pollution in Nasiriyah is vital for the health, environment, economy and cultural heritage of the region.

The aims of this paper were focused on determining of the sources of air pollution in the city center of Nasiriyah, identified and studied, including gaseous and particulate pollutants (NO_2, SO_2, and $PM_{2.5}$) during 2022. Their daily variations were analyzed during the four seasons (winter, spring, summer, and autumn) represented by the months: January, March, June, and September, respectively. Their pollution roses and AQI were also investigated for all seasons of this year.

2. Study Area

The city of Nasiriyah (also known as Thi-Qar province) is located in southern Iraq, with latitude 31.03° N and longitude 46.26° E (Figure 2). Its population is about 2,095,172. Its area is 13,839 km^2 and includes 20 administrative units. It has a desert climate characterized by low rainfall in winter and high temperatures in summer [19]. There are many oil fields in Thi-Qar province, laboratories, and the Nasiriyah power station, which is located within the center of the city.

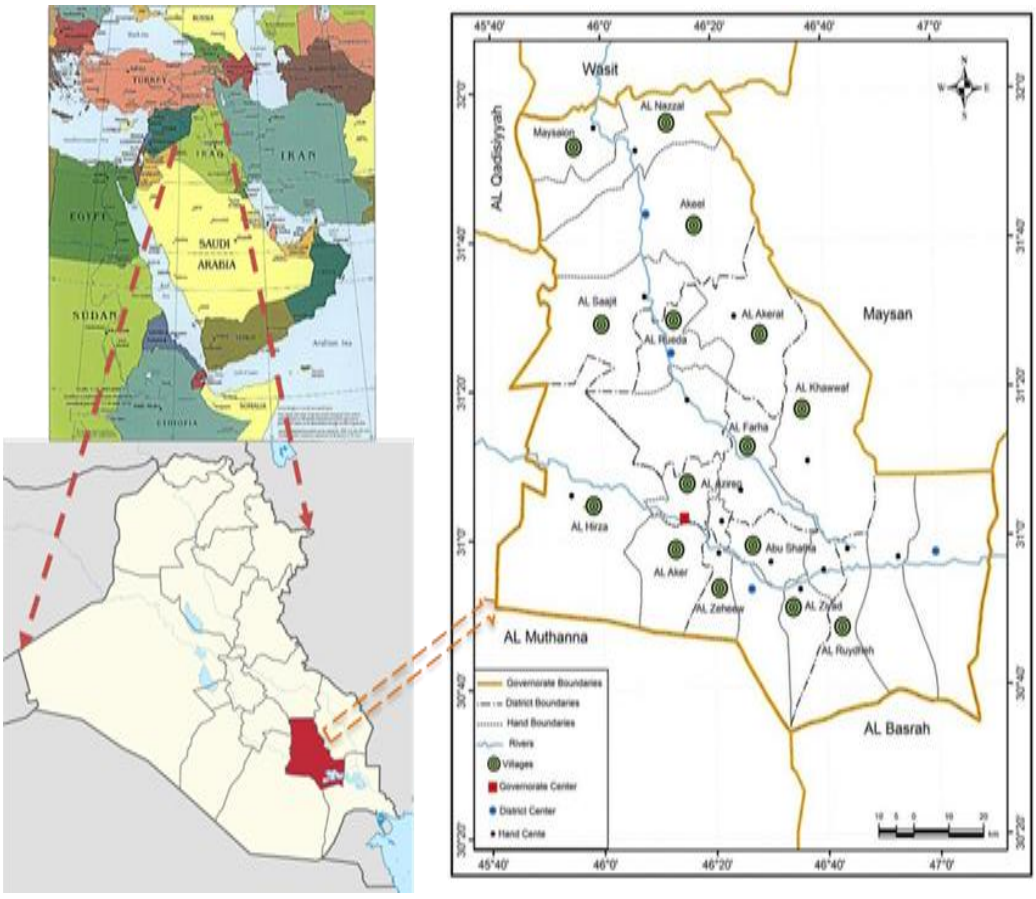

Figure 2: Map of Nasiriyah city (right side) and its location on Iraq map (left side).

3. Data Sources and Methodology

Daily data of the pollutants (NO_2, SO_2, and $PM_{2.5}$) and meteorological variables (wind speed and its direction) for Nasiriyah city center were obtained from European Centre for Medium-Range Weather Forecasts (2022)(ECMWF) (www.ecmwf.int/en/era5-land) for a single point (latitude: 31.03° N and longitude: 46.26° E). A lake program was used to draw the pollutants rose (www.weblakes.com/software/air-dispersion/).

4. Wind and Pollution Roses

Wind and pollution roses are graphical tools used in meteorology or air pollution to display the distribution or frequency of wind speed or pollutant concentrations with respect to wind direction. They help understand the relationship between wind speed (air pollution) and wind direction patterns. The data of the concentration of a specific pollutant (e.g., NO_2, SO_2, and $PM_{2.5}$) and wind direction observed at the same period of time were collected. Wind direction is often divided into eight sectors (N, NE, E, SE, S, SW, W, NW), and wind speed or pollutant concentration data are classified into different categories (low, moderate, and high). Polar plots are used to understand the origin of air pollution sources; different colors or tints are displayed to depict different concentration levels; the dark colors indicate low pollutant concentrations. The length of each bar or segment shows the frequency or intensity of the wind speed or pollutant concentration for a specific wind direction [2].

5. Air quality index AQI

The AQI is a scale that provides real-time information on the amount of pollution in the air and is used to report daily air quality issues directly to the public. It is developed by the Environmental Protection Agency (EPA) as a simple, color-coded, unitless index that is an

effective way to communicate air pollution concentration to the general public. The AQI is divided into six categories, ranging from 0 to 500 (no units), to indicate the quality of the air and its health concerns[20]. Each category with a specific color corresponds to a different level of health concern. The color makes it easy for people to quickly determine whether air quality has reached unhealthy levels in their communities, as shown in Table 1. The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, an AQI value of 50 or below represents good air quality, while an AQI value over 300 represents hazardous air quality.

Table 1: Air quality index categories developed by EPA [21]

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	...air quality conditions are:	...as symbolized by this color:
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

AQI is also used for each pollutant by the equation [17, 20, 22]

$$(1) Ip = [I_{Hi} - I_{Lo} / PB_{Hi} - PB_{Lo}]/(CP - PB_{Lo}) + I_{Lo}$$

Where Ip is the pollutant index, CP is the condensed concentration of pollutant P, PB_{Hi} is the concentration breakpoint i.e., $\geq CP, PB_{Lo}$ is the concentration breakpoint i. e., $\leq CP$, I_{Hi} is the AQI value related to PB_{Hi}, and I_{Lo} is the AQI value related to PB_{Lo}. Microsoft Excel 2010 was used to plot monthly means of all studied pollutants (NO_2, SO_2 and $PM_{2.5}$) in this research.

6. Results and Discussion

6.1 Daily variations of pollutants (NO_2, SO_2. $PM_{2.5}$) during seasons middle months

In this paper, the daily rate values of the pollutants (NO_2, SO_2, and $PM_{2.5}$) concentrations were plotted during January, March, June, and September, representing the four seasons of the year. In general, the daily values of NO_2 concentration varied greatly across all months with relatively high concentrations found in September. The average value for the pollutant NO_2 was (2.073 µg/m^3) for the month of January and was the lowest value compared to other monthly rates; the maximum value of (3.130 µg/m^3) was during March. The maximum daily value was (3.72 µg/m^3) on the 19th of June. The difference in daily average values during the months of the year is due to several factors, including the speed and direction of the wind and atmospheric stability; the pollution values were within permissible limits, as shown in Figure 3. It is noteworthy that the above concentrations are lower than the recommended limit (25 µg/m^3 24-hour mean) for NO_2 concentrations stated by WHO.

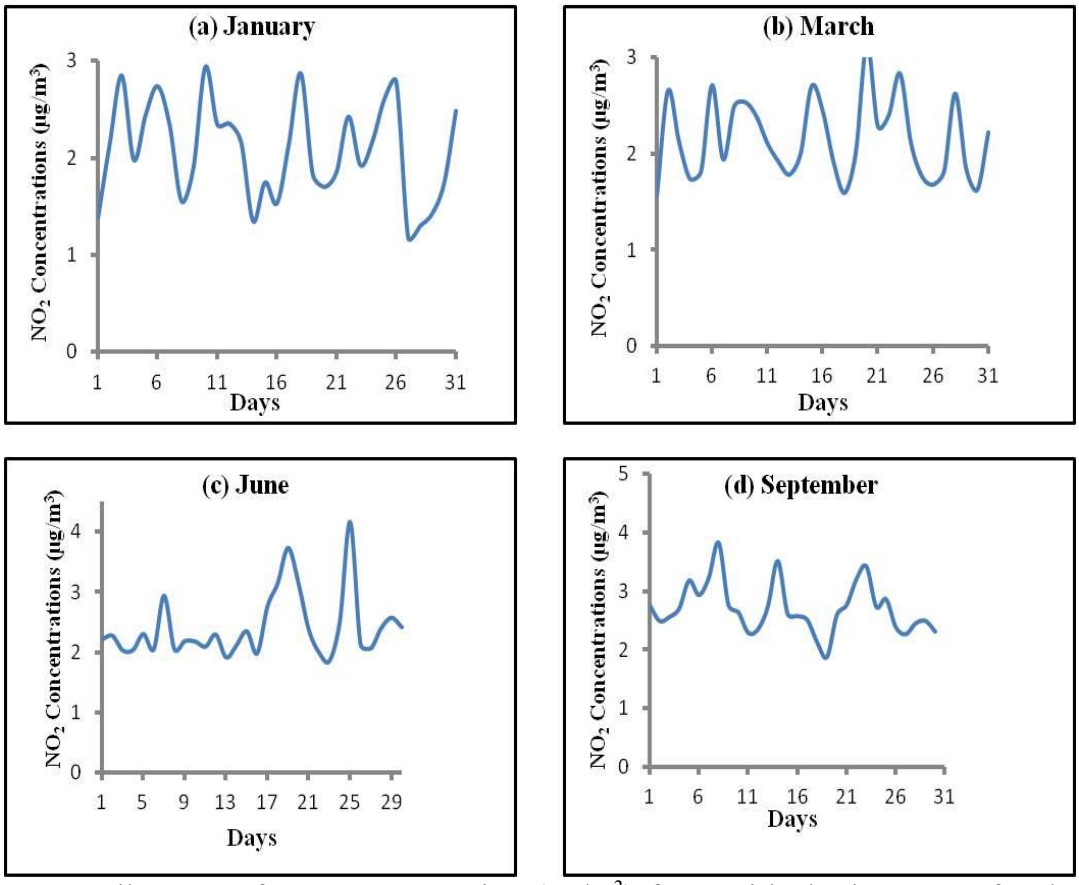

Figure 3: Daily rates of NO_2 concentration (µg/m^3) for Nasiriyah city center for the four months.

The highest daily concentration of SO_2 pollutant observed in January was 17.814 µg/m^3 on the 24th. The maximum monthly mean was (7.663 µg/m^3) during March because of the wind speed, which was high and its direction was north-westerly most days of the month. All SO_2 concentration values during the study period were within permissible limits, as shown in Figure 4. The lowest values of SO_2 concentrations were found in summer (June) and autumn (September) with high instability associated with high convection, especially in the daytime. Inversely, in winter (January) and spring (March), these concentrations were lower due to the relative stability with low heat convection and wind speed. Fortunately, all these concentrations are within the international permissible levels reported by WHO, which is 40 µg/m^3 24-hour mean for the SO_2 pollutant [21].

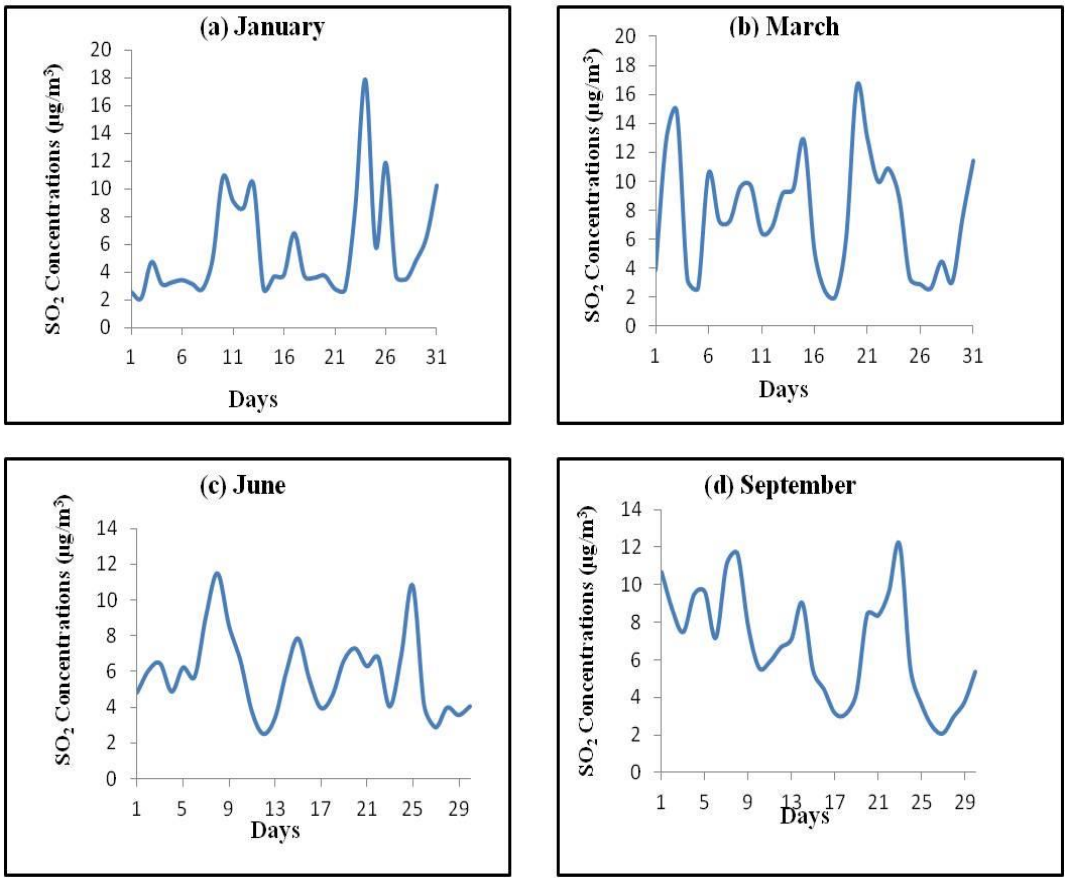

Figure 4: Daily concentrations of SO_2 (µg/m^3) for Nasiriyah city center

The values of pollution concentrations for $PM_{2.5}$ were very high during the study period, and this is due to dust and sand storms, desertification and drought [23]. There are several sources for the emission of these concentrations towards the center of the city of Nasiriyah, and almost all of the concentrations were outside the permissible limits. The value of the monthly rate for January was (57.853 µg/m^3). The minimum value of the daily mean for March was (24.325 µg/m^3) observed at the first day of the month, as shown in Figure 5. The highest concentrations were more frequently in the beginning of March in which more dust storms may occur because of local conditions or affected by regional air masses [17]. The highest $PM_{2.5}$ concentrations are the domain feature not only in Nasiriyah, but also in other southern provinces, like Basrah [24].

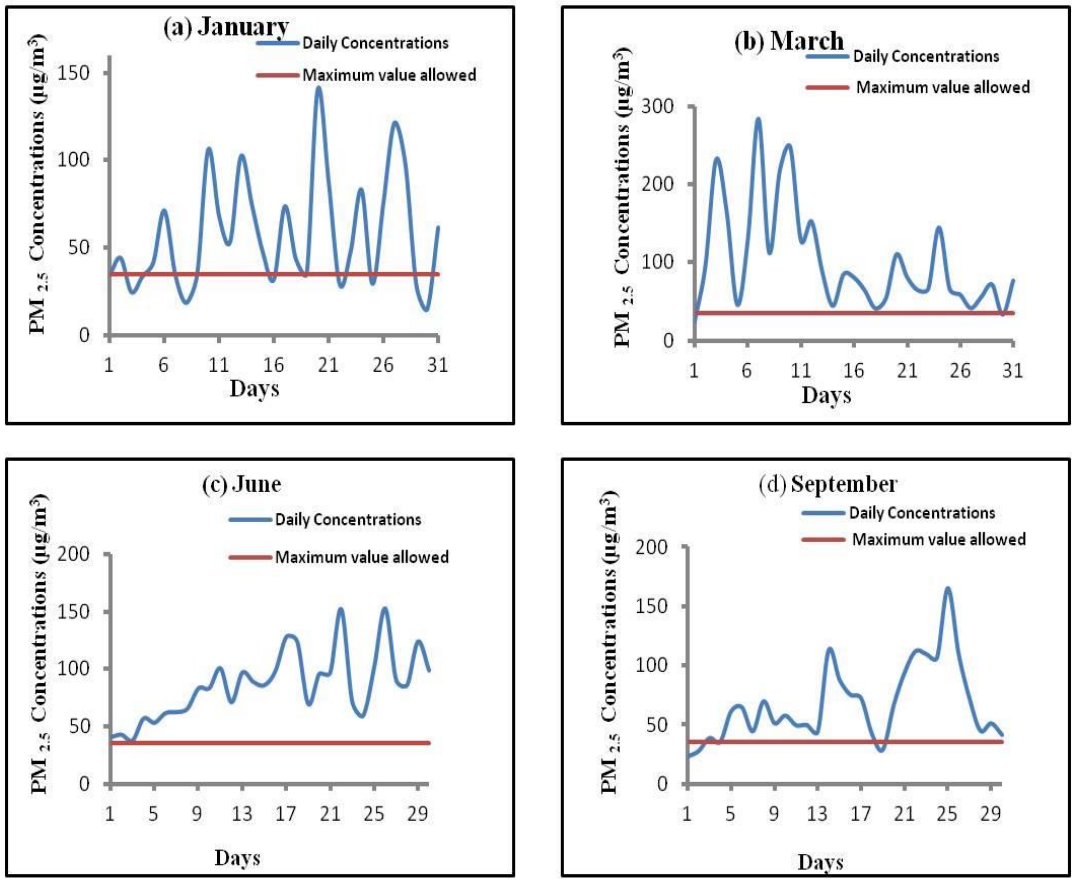

Figure 5: Daily rates of $PM_{2.5}$ concentrations ($\mu g/m^3$) for Nasiriyah city center

6.2 Wind and pollution roses

Numerous variables influence the quality of the air in a city. These can include: the state of the weather; local sources of emissions; and the trans boundary flow of air pollutants. Before analysing the pollution roses, using daily wind speed and wind direction data for same year at the same grid point, wind rose was plotted as shown in Figure 6. The prevailing wind direction in Nasiriyah frequently coming from the northwest. This pattern is common in the region, especially during the summer months, due to the influence of the Shamal winds, which are north-westerly winds that blow across Iraq. Wind speed with values ranging between 4-7 m/s is more frequent throughout the year, which is often influenced by the surrounding desert landscape.

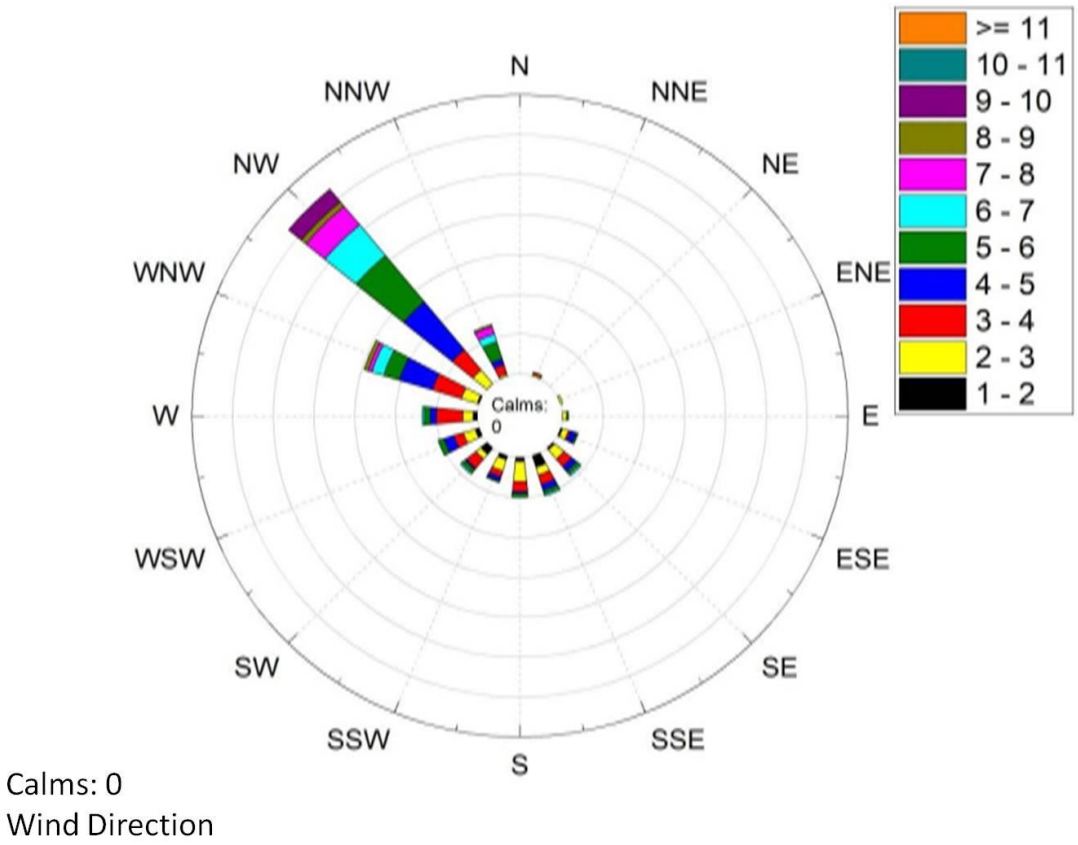

Figure 6: Wind rose of daily wind speed (in m/s) in Nasiriyah center during 2022

The prevailing wind direction mentioned above, which influences the pollutant transport, can carry the pollutants from the oil well area to the city center, affecting the air quality downwind of these sources. The three pollutants (NO_2, SO_2, $PM_{2.5}$) could be analysed by plotting their pollution roses. Since the sources of pollution in the city center of Nasiriyah have been identified, and since the wind direction plays an important role in the transport of air pollutants, one of the most important sources of pollution affecting the city is the electric power plant, which is located northwest of the study area, and the wells of oil fields, which are located northwest of the city, as shown in Figure 1. This is because the prevailing winds transport the pollutants resulting from the emission of various gases as a result of the burning of fossil fuels from the pollution sources towards the city. The second source of pollutant emissions comes from the Nasiriyah refinery, which is located south of the city, in addition to the Saba oil field. The other sources of pollutants are the burning of fossil fuels by vehicles and electrical generators in the city. Figures 7-9 show the pollution roses of the daily NO_2, SO_2, and $PM_{2.5}$ concentrations. However, the daily NO_2 concentrations between 2 and 3 $\mu g/m^3$ (yellow colour) are more frequent coming from the well, while the high concentrations above 3 $\mu g/m^3$ are less frequent.

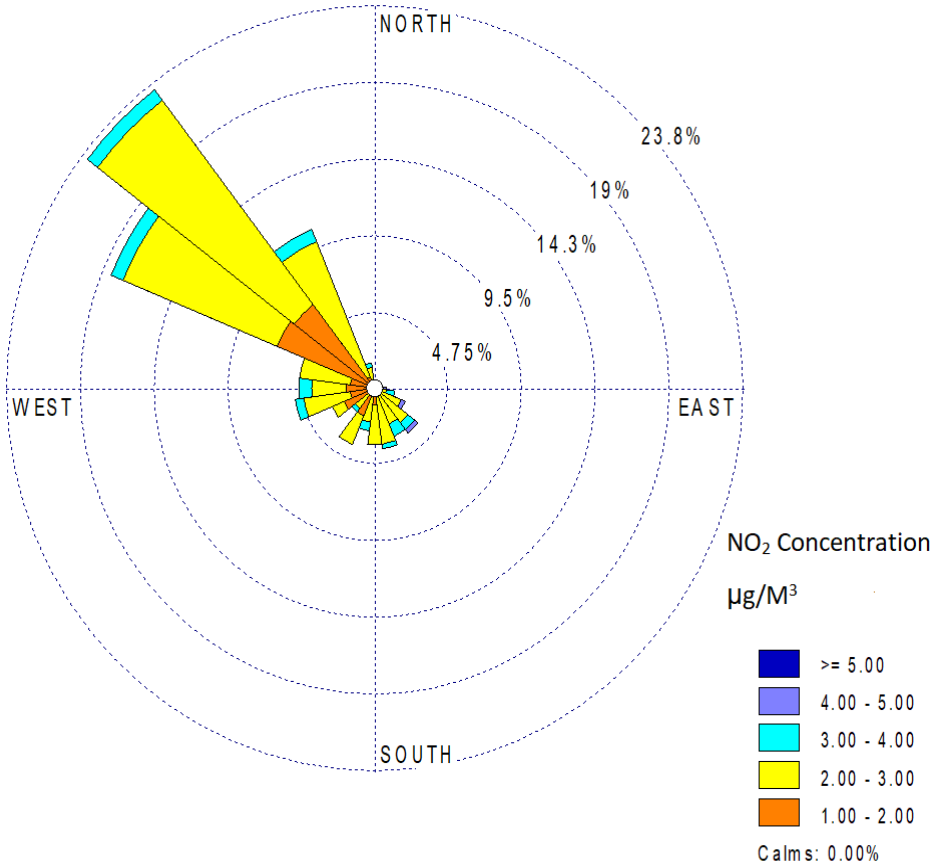

Figure 7: Pollution rose of daily NO_2 concentration in ($\mu g/m^3$) in Nasiriyah center during 2022

Figure 8 shows the daily SO_2 concentrations affecting the city center in 2022. It is interesting that the lowest concentrations with the range 2-6 $\mu g/m^3$ are more frequent with about 16% coming with the upwind of northwest direction. It is not surprising given that the maximum concentrations are diluted while moving with unstable air. The SO_2 concentrations with values from 10-14 $\mu g/m^3$ (red colour) were always found in the air ambient surrounding the city. Finally, the low ratios of the highest concentrations with low frequencies came from the east, south and west directions.

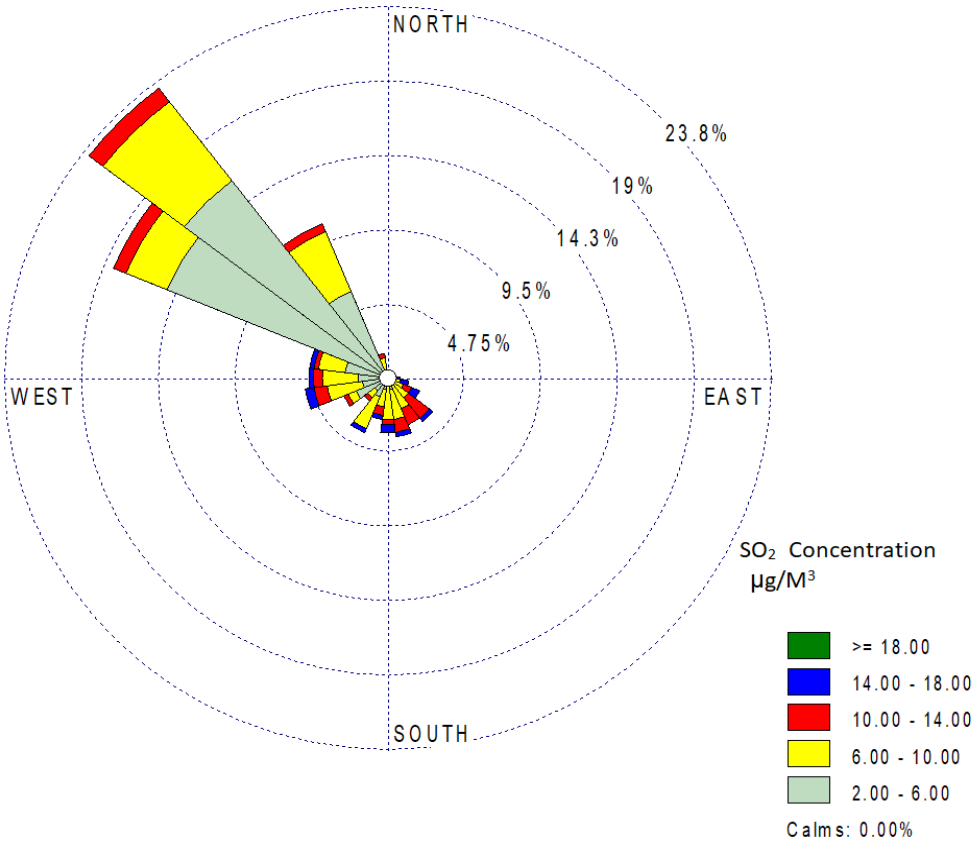

Figure 8: Pollution rose of daily SO_2 concentration in ($\mu g/m^3$) in Nasiriyah center in 2022

There are many intervals of the $PM_{2.5}$ starting from zero to 240 $\mu g/m^3$ with the majority in the range 40-80 $\mu g/m^3$, especially in the northwest direction (see Figure 9). These concentrations were almost from the northwest direction where the oil wells are. The lowest ratios with highest concentrations (200-240 $\mu g/m^3$) appeared in the air quality of the west and south of the city. The slightly lower concentrations of the two merged intervals (i.e., 120-200 $\mu g/m^3$) were coming from the northwest. Unfortunately, these values of all $PM_{2.5}$ concentrations during the study year of 2022, were much larger than the permissible values of (35 $\mu g/m^3$ annual mean) as reported by EPA [21]. Therefore, it is confirmed that the life in Nasiriyah center is unhealthy and genuine actions are needed to reduce and mitigate the serious pollution caused by $PM_{2.5}$.

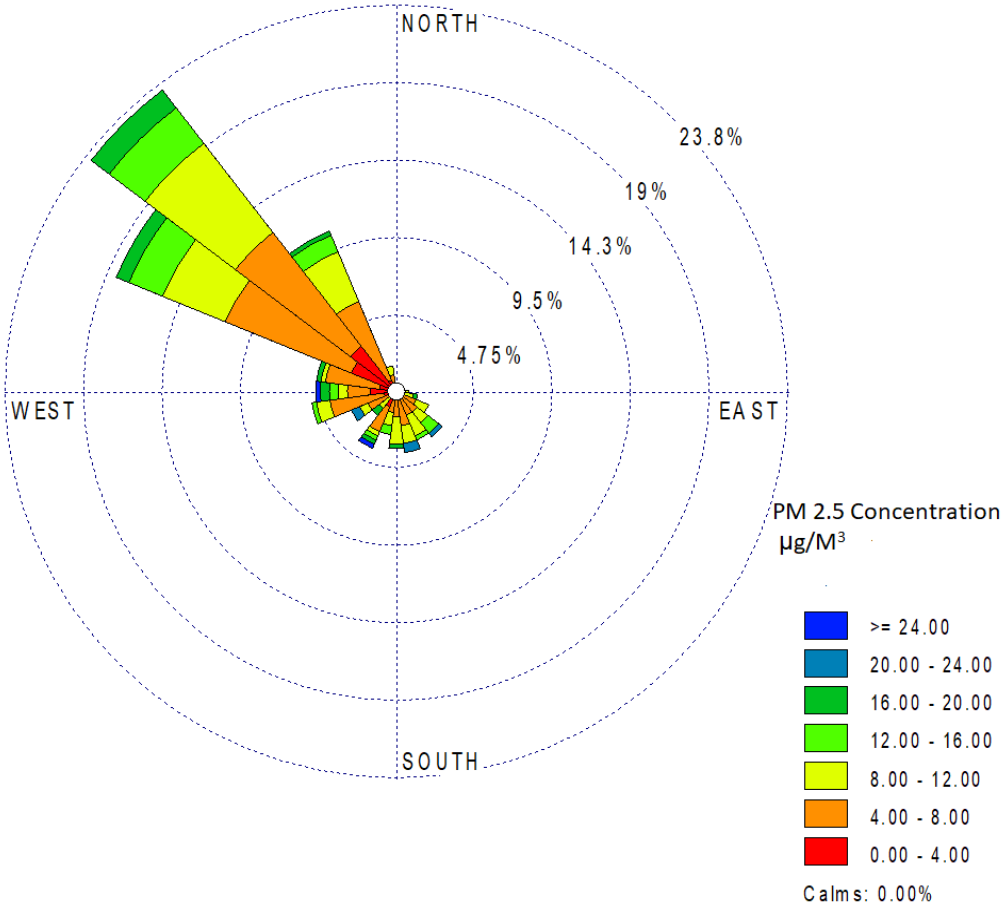

Figure 9: Pollution rose of daily $PM_{2.5}$ concentration (x**10)** in Nasiriyah center during 2022

6.3 Air quality index

Based on the daily concentrations of all pollutants studied in this paper, AQI was calculated using Eq. 1 in January, March, June, and September of 2022. According to the categories described in Table 1, the monthly AQI values for Nasiriyah city are presented in Table 2. maximum value of AQI for NO_2 was 5 in June and for SO_2 was 10 in March, and the AQI category was good. Therefore, all values of AQI for both NO_2 and SO_2 pollutants were under the permissible levels in all months. While AQI values for $PM_{2.5}$ were very high and category was unhealthy. Drought caused by the large desert surrounding the city, the presence of oil fields, the electric power station, and the refinery, are causes for the AQI high values for $PM_{2.5}$, as shown in Table 2. Land degradation and desertification in the surrounding areas contribute to the frequency and intensity of dust storms.

Table 2: Monthly AQI values for NO_2, SO_2, and $PM_{2.5}$ in Nasiriyah during 2022

Pollutant	Month	AQI Values	Category	Health message	Color
NO_2	Jan.	3	Good	None	
	Mar.	4	Good	None	
	Jun.	5	Good	None	
	Sep.	2	Good	None	
$PM_{2.5}$	Jan.	150	Unhealthy for sensitive group	Sensitive groups should reduce heavy exertion and prolonged	
	Mar.	174	Unhealthy	Sensitive groups should reduce heavy exertion and prolonged	
	Jun.	166	Unhealthy	Sensitive groups should reduce heavy exertion and prolonged	
	Sep.	156	Unhealthy	Sensitive groups should reduce heavy exertion and prolonged	
SO_2	Jan.	7	Good	None	
	Mar.	10	Good	None	
	Jun.	7	Good	None	
	Sep.	8	Good	None	

Through the results, it was noticed that the values of $PM_{2.5}$ were high in the center of Nasiriyah city due to drought and desertification in that year; rainfall rates were low and there was little vegetation covers [25]. There were also many oil extraction fields, a refinery, and an electric power station, considered sources of air pollutants and their spread by winds towards cities [26, 27].

7. Conclusion

Most of the emissions were from the Nasiriyah electrical station. The speed and direction of wind play a major role in transporting pollutants towards the city center. Concentrations of the NO_2 and SO_2 pollutants were within permissible limits, and their values were low, while $PM_{2.5}$ concentration was high and higher than the permissible limits. The annual AQI was about 160, red category; the high $PM_{2.5}$ concentration is responsible for this unhealthy pollution in 2022 at Nasiriyah city center. The high concentration of $PM_{2.5}$ in Nasiriyah city center is a cause for concern, necessitating immediate attention to both environmental management and public health interventions. Addressing the sources of pollution and implementing strategies to reduce $PM_{2.5}$ levels can significantly improve the health and quality of life for the city's residents. To reduce the accumulation of these pollutants in Nasiriyah, windbreaks can be built, afforestation can be carried out, and green belts can be created around the city. Renewable and environmentally friendly energy sources can be used instead of fossil fuels, which are a source of environmental pollution. Pollution sources (such as power plants, petrochemical separation plants, etc.) should also be located far from city centres. The general direction of the prevailing winds must be considered when constructing such facilities.

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