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The Concentration of Black Carbon Emissions from Natural Gas Flaring Activities in Basra Province, Iraq

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ABSTRACT

Black carbon (BC), a byproduct of incomplete combustion, originates as from various sources. Emissions from flaring activities, that include both black carbon and particulate matter, pose significant health risks and contribute to climate change. This research focused on the evaluation of air pollution dispersion in Basra Province by monitoring BC emissions. Utilizing an aethalometer, BC concentrations were measured at several locations within Basra Province known for their oilfield abundance. These locations included six degassing stations—Tuba, Alluhais, Artawi, North Rumaila, Majnoon and Nahran Omar—and two power plants, Alnajebia and Shatt Albasra. Measurement also accounted for wind direction, air velocity, and wind speed. The study found that all sites, which conducted natural gas flaring, exhibited BC concentrations that surpassed the recommended exposure limit (REL). During winter, the average BC concentration measured was 5.66±1.49µg.m^{-3}, with the lowest concentration of 3.7µg.m^{-3} at Majnoon oilfield and the highest at 7.85µg.m^{-3} at Artawi Degassing Station, approximately eight times above the REL. In contrast, the Spring showed an average BC concentration of 4.94±1.28µg.m^{-3}, with the lowest at 3.3µg.m^{-3} at Majnoon oilfield and the highest at 7.05µg.m^{-3} at the Altuba Degassing Station, around seven times the REL. The study conclusively found that BC levels at all monitored sites exceeded the REL, highlighting the role of incomplete combustion in these elevated emissions and attributing the high BC levels to natural gas flaring in these industrial areas.

Keywords:

Air pollution; Flares; Oil activities; Iraq

1. Introduction

Air is the most important and potentially dangerous pollutant for humans and the environment. It is defined as the presence of one or more pollutants in the atmosphere, both indoors and outdoors, in quantities, characteristics, and duration that affect living organisms. These pollutants include smoke, particulate matter, mist, fumes, gases, odours and vapours as taken from previous studies [1-4].

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Gas flaring is a process of burning natural gas associated with the extraction of crude oil. It causes acute damage to plants, animals, and humans mentioned by [5,6]. Flaring is a method commonly employed in the oil industry to eliminate unwanted flammable gases via oxidation at elevated temperatures. The main flaring products are greenhouse gases and black carbon (BC) [7-9]. Flaring gas negatively affects human health, causing cancer, lung damage, neurological and skin problems, reproductive and blood issues, emphysema, bronchitis, respiratory irritation, asthma, shortness of breath, mortality, and developmental effects taken from [10-12].

Sulphur dioxide (SO_2) and nitrogen oxides (NOx) are considered to be the primary sources of acid rain when they react with atmospheric moisture to form sulfuric and nitric acids. These pollutants adversely affect vegetation and acidify streams and lakes as mentioned in [13]. Pollutants emitted from flares, such as nitrogen dioxide, carbon dioxide, carbon monoxide, sulphur dioxide, particulate matter, and hydrogen sulphide, can acidify the soil and deplete its nutrients. The heat from flares has a negative impact on vegetation. The primary greenhouse gas emitted by flares is carbon dioxide, which contributes to climate change as reviewed in [14].

In addition to being recognized as a contributor to global warming through incomplete combustion processes, black carbon (BC) poses significant health risks. Therefore, it is crucial to develop mitigation methods to control the consequences of BC and to identify its sources by [15].

Particulate matter (PM) pollutants, including PM10, PM2.5, and PM0.1, are among the most harmful. The quantity and intensity of pollutant emissions, physicochemical changes in the atmosphere, and the significant movement of air pollutants influence air quality taken by [16].

Black carbon is a component of particulate matter (PM) that has short-term health impacts and contributes to global warming owing to its ability to absorb solar radiation mentioned by [17]. Carbonaceous aerosols contribute approximately 25% to the volume of particulate matter with a diameter less than 10 µm (PM10) across Europe taken from [18]. They are essential chemical elements found in fine particulate matter (PM2.5), which has significant effects on air quality, climate change, and human health taken from [19,20]. Monitoring is necessary because long-term monitoring of black carbon was conducted by [21].

According to the 2013 report by the Intergovernmental Panel on Climate Change (IPCC) on the global direct radiative forcing of black carbon aerosols, the average value was 0.4 Wm^{-2}. Black carbon has unique physical properties that strongly absorb visible light. Black carbon absorbs lighter than it reflects, warming the atmosphere through its interaction with sunlight [22]. Black carbon (BC) particulate matter (PM) emitted from flares during incomplete combustion is harmful to human health and climate change taken from [23,24]. The annual average of black carbon emissions from Russian flaring from 2012 to 2017 was 68.3 Gg/year as [25]. Iran ranked third among the top gas flaring countries in 2021, with an annual flared gas volume of 17.40 billion cubic meters (BCM), signifying significant economic loss and greenhouse gas emissions mentioned by [26].

Basra is the most important province in Iraq for oilfield extraction taken from [27,28]. Most air pollution in Basra is caused by emissions from industrial facilities. Air pollution is a concern in the province; Shehabalden and Azeez [29] conducted a study on the air quality index in Basra Province, located in the southern region of Iraq.

The lack of long-term urban BC observations is mainly because monitoring for BC has never been deemed necessary, and it is not currently monitored. There is a lack of black carbon monitoring in Basra Province. Therefore, this study aimed to investigate the distribution of air pollution in Basra Province through the emission of black carbon (BC). The study's hypothesis states that the concentrations of BC emissions from industries pollute the air surrounding Basra Province.

2. Methodology
2.1 Study Area

Basra Province is located in southern Iraq, bordered by the Arabian (Persian) Gulf, Kuwait, and Saudi Arabia to the southwest. It is connected to Iran to the east and bordered by the Iraqi provinces of Thi-Qar and Maysan to the north and Muthana Province to the west mentioned in [30].

Basra is a province in Iraq that is heavily contaminated with oil due to its numerous oilfields. Measurements were made at six degassing stations (Tuba, Allhais, Artawi, North Rumaila, Nahran Omar, and Majnoon) and two power plants (Alnajebia and Shatt Al-Basra). All sites had flaring gas (Figure 1).

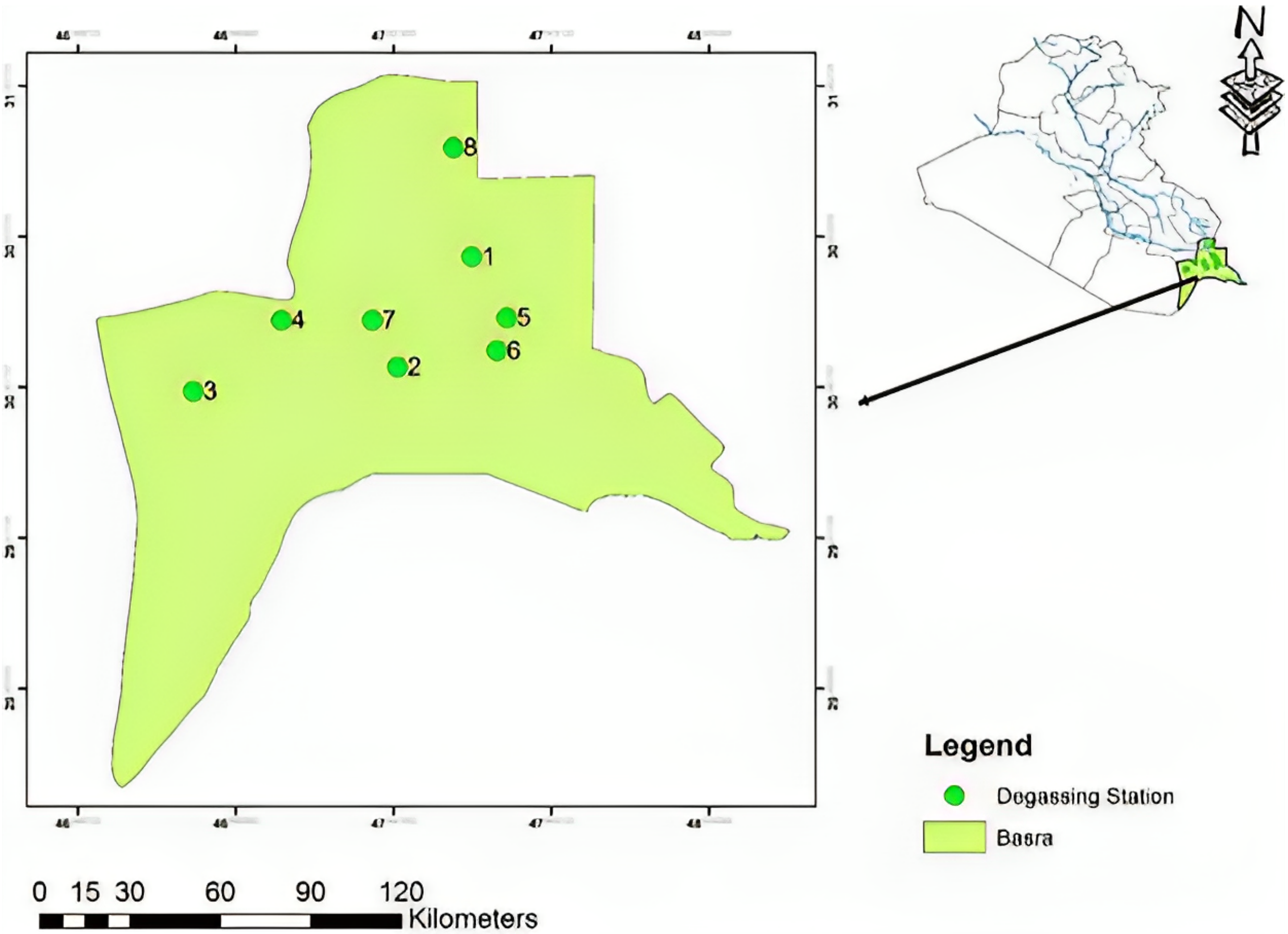

Fig. 1. The study area consisted of 8 degassing stations: (1) Nahran Omar, (2) Altuba, (3) Allhais, (4) Artawi, (5) Alnajebia, (6) Shatt AlBasra, (7) NorthRumaila, and (8) Majnoon.

i. Tuba Degassing Station: It is located approximately 35 km southwest of Basra, situated between Zubair (5 km) to the east and South Rumaila (2 km) to the west.
ii. Luhais Degassing Station: The Luhais Degassing Station is located near the administrative boundaries of Basra and Nasiriyah provinces. It is situated 105 km west of Basra and 100 km southwest of the North Rumaila oil field.
iii. Artawi Degassing Station: Artawi is located approximately 70 km northwest of Basrah City and about 12 km west of the Northern Rumaila Oil Field.

iv. The North Rumaila oilfield is located 50 km west of Basrah city in southern Iraq, approximately 32 km from the Kuwaiti border. The measurement was taken near Degassing Station 1 (DS1).
v. The Majnoon oil field is located approximately 60 km from the province of Basra, mainly along the Iraqi-Iranian border.
vi. The Nahran Omar Degassing Station is a significant oil reservoir in southern Iraq, situated approximately 34 km north of Basrah.
vii. The Shatt Al Basra Power Plant is a gas turbine power plant located 39.7 km south of Basra City, near Shatt Al Basra.
viii. The Alnajebia Power Plant is located approximately 6 km north of Basra city.

2.2 Measurement Device
2.2.1 Aethalometer device

An Aethalometer was used to measure black carbon (BC) taken from [31,32]. Aethalometers (model AE-21, Magee Scientific, USA) measure BC by detecting the attenuation of a high-intensity light beam at wavelengths of 880 and 370 nm caused by BC particles that are collected on a rolled quartz filter tape with cellulose fibre backing. The concentrations of black carbon were determined with a time resolution of 5 minutes. At a flow rate of 2 L/min, air was drawn from a height of 2 m above Earth's surface. A 2.5-mm sharp-cut cyclone intake prevents particles larger than 2.5 mm from entering the device as mentioned in [33]. Black carbon is a strong absorber at 880 nm. The Aethalometer measures the BC concentration in real-time using optical transmission and continuous filtering. A pump continuously draws in air to collect the particles deposited on the filter tape. The initial light beam travels over the unloaded filter tape before being compared with the loaded filter taken from [34].

2.2.2 Air velocity and wind direction

An air velocity meter (model 52235, Master Cool Company) was used to measure wind speed in the study area. An Acurite weather station was used to measure wind direction.

2.3 Monitoring Procedure

A Magee Aethalometer (model AE21) was used to measure black carbon concentrations. The aethalometer monitored the light absorption of the carbon particles in the near-infrared to near-ultraviolet range. The results from the 880 nm channel provide a quantitative measure of the black carbon content. The average concentrations of black carbon were measured monthly at eight stations in Basra Province, located at different locations. The distance from Basra City ranged from 6 to 105 km. In this area, there are natural gas fields where gas is burned, as well as oil fields and power plants. An aethalometer was used to measure the concentration of black carbon in $\mu g \cdot m^{-3}$ and was represented on the map of Basra using GIS software. The wind rose was plotted using the WRPLOT software.

Black carbon concentrations were measured for the first time at the Altuba Degassing Station, Allhais Degassing Station, Artawi Degassing Station, and Shatt Al Basra power plant during the winter and spring seasons from December 2021 to April 2022.

2.4 Data Analysis

Data analysis was performed using SPSS software. The values recorded at the pollutant monitoring sites represent mean BC concentrations. Statistical analysis of the data included analysis of variance.

3. Results

The BC was measured in units of (μg.m^{-3}) at eight stations in Basra province. The results showed that the BC concentration of black carbon varied from one site to another. The average concentration of BC in winter in each station (Nahran Omar, Altuba, Allhais, Artawi, Alnajebia, Shatt Al-Basra, North Rumaila, Majnoon) was (6.4, 7.05, 6.15, 7.85, 4.45, 4, 5.7, 3.7) μgm^{-3} respectively, as shown in Figure 2. It shows the distribution of black carbon concentration in the study area of Basra Province during winter. Colours represent the concentrations of black carbon. The ten colours range from blue, representing the lowest value, to red, representing the highest value. The lowest value was 3.7 μg.m^{-3} in the Majnoon oil field, represented by blue, and the highest value was 7.85 μg.m^{-3} in Altuba Degassing Station, characterized by red.

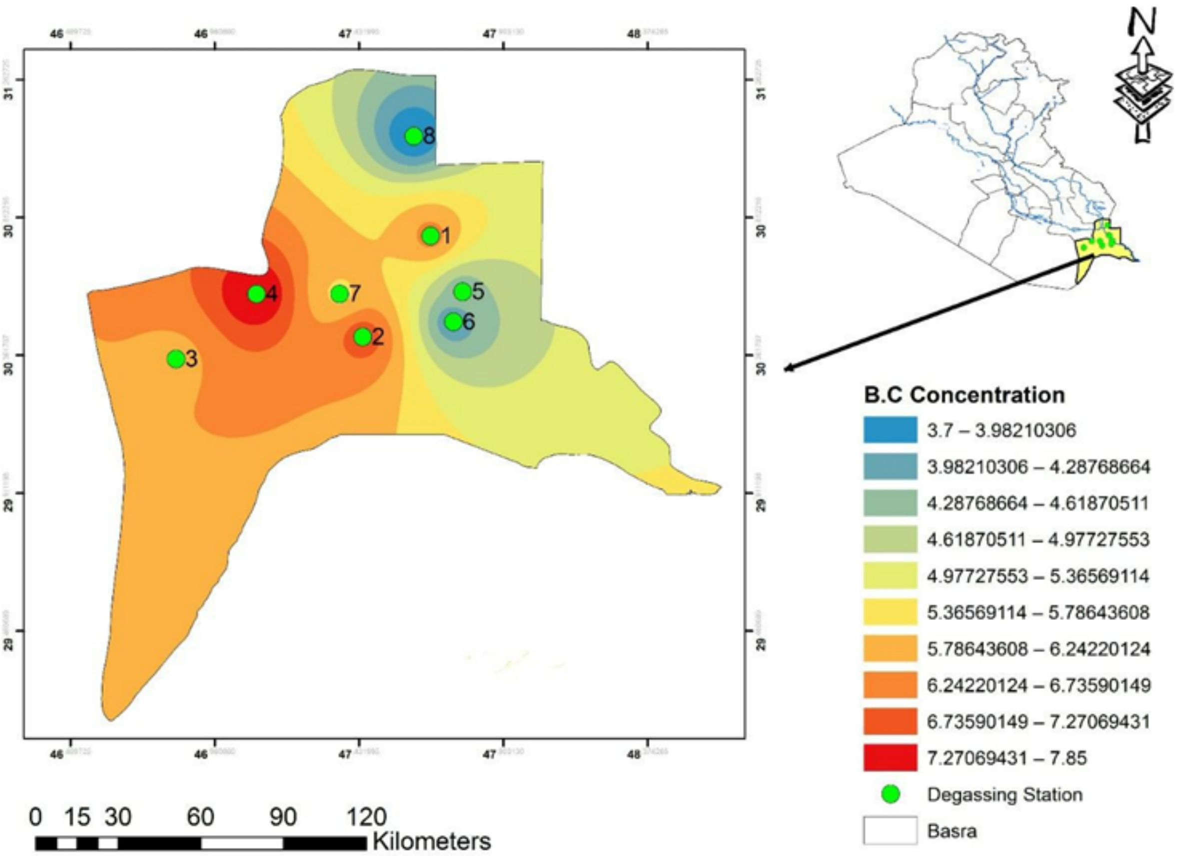

Fig. 2. Concentration of Black Carbon in Basra province measured in *μ*g.m-3 during Winter

The average concentration of BC in spring at each station (Nahran Omar, Altuba, Allhais, Artawi, Alnajebia, Shatt Al-Basra, North Rumaila, Majnoon) was (4.9, 7.05, 6.2, 5.4, 5.1, 3.8, 3.8, 3.3) μg.m^{-3}: It shows the distribution of black carbon concentrations measured in the study area of Basra Province during the Spring. The lowest value was 3.3 μg.m^{-3} in the Majnoon oil field, representing the blue colour, and the highest value was 7.05 µg.m^{-3} in Altuba Degassing Station, representing the red colour.

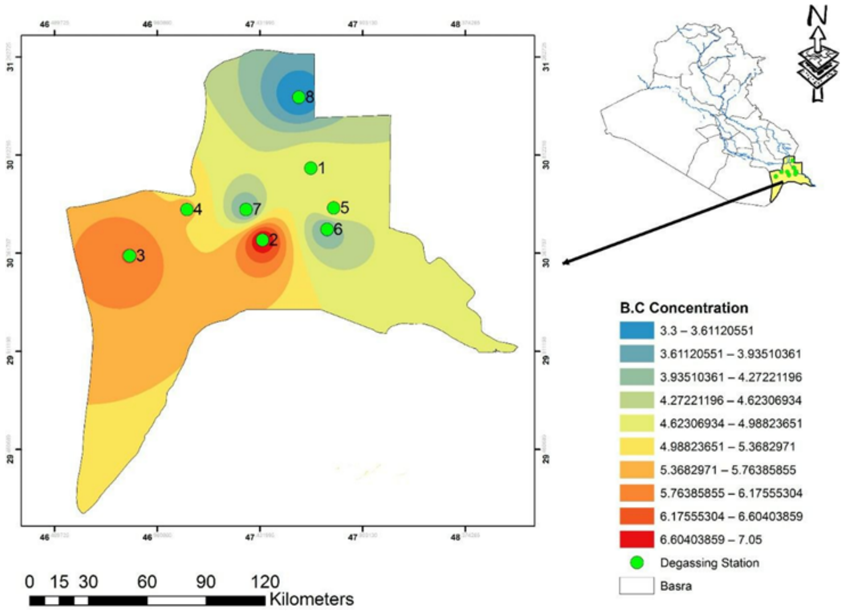

Fig. 3. Concentration of Black Carbon in Basra province measured in μg.m-3 during Spring

The results indicated a significant variation in concentrations between the two seasons for the three stations (Nahran Omar, Altuba, and North Rumaila). Concentrations were higher in Winter than in Spring. This may be due to the higher wind speed and temperatures in Spring than in Winter. Figure 4 shows the wind speed and direction of the study area during Winter respectively.

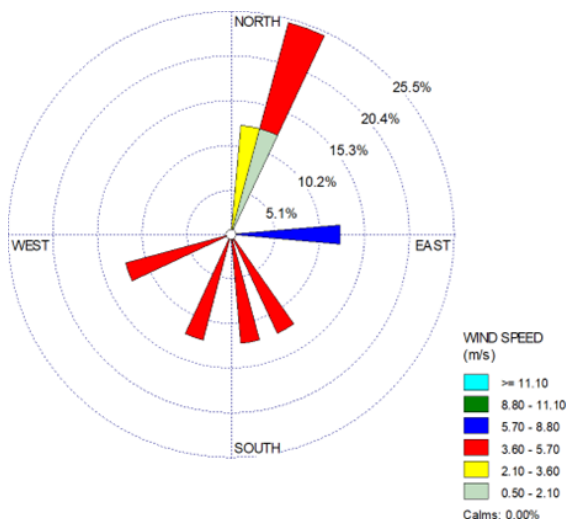

Fig. 4. Wind Rose Diagram Representing Winter Wind Patterns During the Study Period

Figure 5 shows the wind speed and direction in the study area during Spring respectively. This result agreed with that of [35], who concluded that BC was higher in Winter than in Spring. Higher BC concentrations were detected in Winter than in Spring, indicating that in addition to seasonal changes in emissions, meteorological conditions may have influenced BC concentrations during the Winter season.

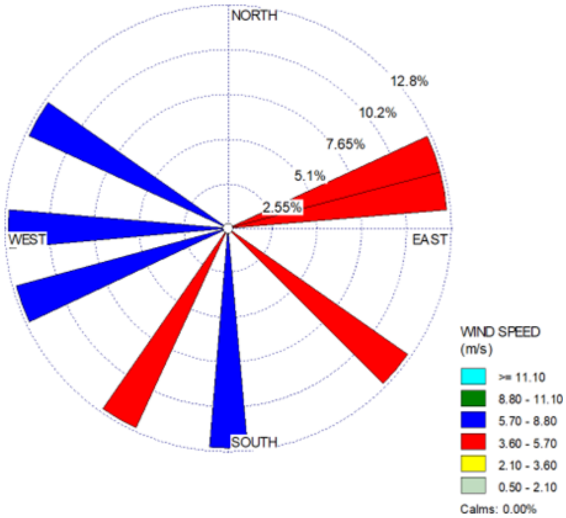

Fig. 5. Wind Rose Diagram Representing Spring Wind Patterns During the Study Period

To evaluate the effects of meteorological parameters on the mass concentration of BC, a correlation analysis of BC mass concentrations and wind speed ($m.s^{-1}$), and temperature (°C) was performed. The study showed a negative correlation between BC and temperature (r = -0.66). An inverse correlation was shown in Winter (r = -0.73) when the temperature was 18.07°C. An inverse correlation was also shown in Spring (r = -0.52) when the temperature was 20.22°C. The study also showed an inverse correlation (r = -0.11) between BC and wind speed.

The results indicated no significant variation in black carbon concentrations between the seasons. The average concentration of BC in winter was 5.66 ±1.49, and in spring was 4.94 ±1.28. Figure 6 shows the ratio of black carbon concentrations measured during the winter and spring seasons to the total emissions during winter and spring. The average winter concentration reached 53%, which is 6% higher than the average spring concentration. Spring concentrations accounted for 47% of the total emissions.

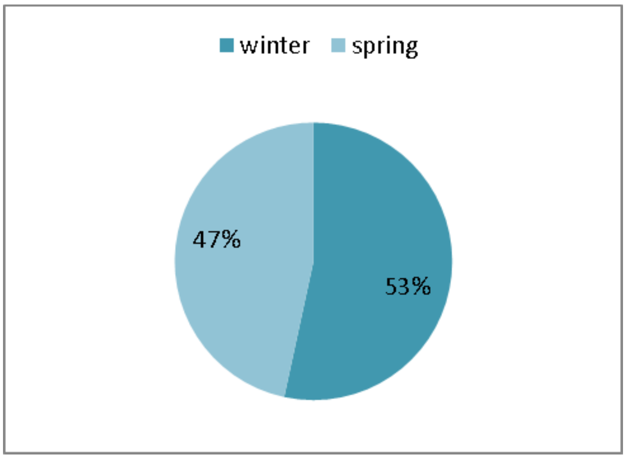

Fig. 6: Comparative Ratios of Black Carbon Concentrations between Winter and Spring

These results contradicted the findings of [36], which showed that BC concentrations were highest in winter and lowest in summer.

All sites in Winter and Spring had concentrations higher than the recommended exposure limit (REL) by NIOSH (1 $\mu g.m^{-3}$) [37]. In winter, the BC concentration in the Artawi oilfield was approximately eight times higher than the REL. The concentration of BC in Altuba Degassing Station during spring was seven times higher than the REL, as shown in Figure 7.

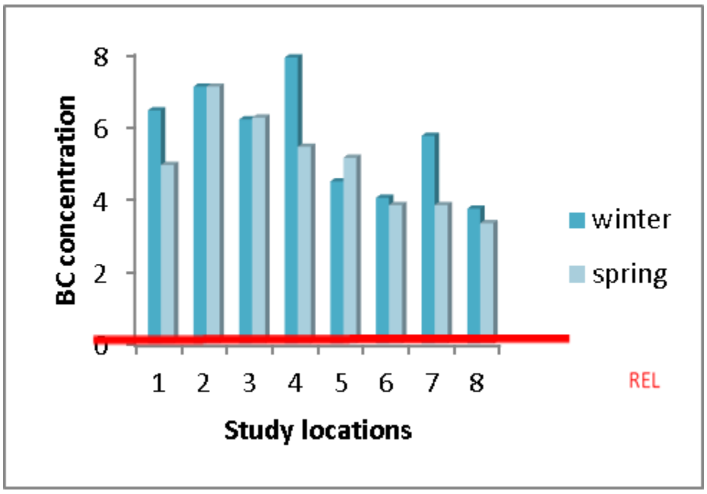

Fig. 7. Comparison of Black Carbon Concentrations in the Study Area with Reference Exposure Levels

It has been established that black carbon (BC) is crucial for the climate. It affects cloud formation, and atmospheric instability, and temperature profiles taken from [31]. Therefore, it is crucial to understand the concentrations of BC and its sources. This area organized BC monitoring from fossil fuels 880 nm. The approach used was the approach to analyse data collected from various locations in the province of Basra demonstrated the value of this method for tracking BC.

4. Conclusions

The study found that industrialized areas exhibit a markedly higher prevalence of Black Carbon (BC), primarily due to the incomplete combustion processes prevalent in oilfields and power plants within the surveyed regions. Consequently, the concentrations of BC in these areas surpass the Recommended Exposure Limits (REL), posing potential health and environmental risks. Additionally, an inverse correlation between wind speed and BC concentration was identified, contributing to significant seasonal fluctuations. Specifically, BC concentrations were observed to be higher during the winter months as compared to the spring, indicating the impact of meteorological conditions on pollutant dispersion and accumulation.

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