

The Impact of Human Activities on Air Pollution in the Fallujah City, Al-Anbar Province – West Iraq

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Abstract: Air pollutant field study and laboratory sample analyses revealed that most of the air pollutants in Fallujah City come from various human activities. These activities: Factories, Bakeries, Private electric generators, etc represent the major sources of gaseous and particulate pollutants. Those emissions have affected the air quality of the air in study areas. This research aimed to identify air pollutant concentrations, and their effects, and develop immediate solutions to reduce their health and environmental impacts.

Air pollutant measurements were taken for four sites, with each site having generators and bakeries, another five sites representing industrial activities, and another site representing the residential areas. These measurements which included total suspended particles (TSP), PM10, PM2.5, nitrogen dioxide (NO₂), sulphate dioxide (SO₂), methane (CH₄) and (CO) were conducted in the winter and summer seasons. The plaster and asphalt factories and industrial district locations recorded the highest concentrations of particle pollutants (TSP, PM10, and PM2.5) and gases (NO₂, SO₂, CH₄, and CO). It was also observed that there was an increase in the concentrations of total suspended particles, in addition to some gases measured at the sites of bread ovens and private electric generators, especially in the summer. Most of the sites recorded values higher than the local environmental allowable limits.

The high concentrations of air pollutants measured at the study sites are due to the increased demand for electrical energy and the use of private electrical generators to compensate for the lack of electrical energy emitted by high air pollutants. In addition to the emissions of cement, plaster, and asphalt factories and the large quantities of suspended particles they release into the atmosphere resulting from crushing operations and loading operations for raw materials, in addition to the polluting gases they release resulting from the use of black oil, as well as the use of black oil as fuel in the bakeries, which leads to an increase in pollutant concentrations will, therefore, negatively affect air quality.

Key words: Human activities, air pollution, bakeries, plaster and asphalt factories, private electrical generators, Fallujah City.

Introduction

Human activities have led to hazardous environmental exploitation, especially in urban areas, due to the numerous demands and competition between different activities (Al-QarraLucy, 2014). The increase in pollution, particularly air pollution, has resulted in

the release of numerous gases, including dioxide, into the atmosphere. Studies reveal that various gases, particulate matter, total suspended particles, and heavy metals can cause human infections, including cancer, heart disease, and respiratory disorders (AL-QarraLucy, 2017). Air pollution is a global concern as it impacts not only the air but also soil and water (Tohma, 2009).

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Urban air pollution, primarily caused by combustion activities from automobiles and industrial processes, poses a significant environmental and human health risk (Sultan, 2005).

Studies on pollutants' types, distribution, concentrations, and spread dynamics in urban areas have utilised satellite images, monitoring, and surveillance stations, along with mathematical models for daily and seasonal measures (Du et al., 2013).

Iraq's air quality has worsened due to increased electric power plants, crude oil-fueled ones, excessive use of generators, decreased electricity supply, increased transport, and uncontrolled fossil fuel use, releasing large pollutants into the atmosphere (Al-Kasser, 2018). Urban air pollution is caused by various anthropogenic sources, including mobility practices, waste management, fossil fuel burning, industrial development, energy production, plastic combustion, incomplete combustion, motor vehicles, and activities causing dust and suspended particles (Kang et al., 2022).

Since 2003, Fallujah has been grappling with air pollution, which has been further exacerbated by the recent ISIS invasion of the Anbar Governorate. The Iraqi Ministry of Environment was prevented from conducting surveys in the Anbar Governorate, specifically in Fallujah, thereby extending the effect.

As a result, environmental monitoring has been neglected, which calls for addressing this issue, which pertains to the population's health and environmental aspects.

This research aims to identify air pollutant concentrations, and their effects, and develop immediate solutions to reduce their health and environmental impacts.

Materials and Methods

Study Area

The investigated region was in the Fallujah District of the Anbar Governorate, which encompasses the Saqlawiyah district (Hassan, 2013). The study region is surrounded by Baghdad Governorate to the north, Salah

al-Din to the east, Ramadi to the west, and Fallujah District to the south (Salman & Muhammad, 2013). The study area is located in the Saqlawiyah district, consisting of eight districts and 23 residential areas, with coordinates of 43.47°- 44.50° to the east and 33.45°- 33.21° to the north (Figure 1).

In 2022, the city's population was about 418,038 people divided between rural and urban areas. Most people lived in old neighbourhoods like Al-Jumhuriya, Al-Resala, Al-Golan, and Al-Mu'tasim, while new neighbourhoods like Al-Amin, Al-Mansour, Al-Salam, Al-Jami'ah, Second Al-Jami'ah, and Rasheed were formed (Mehanna, 2022). Industrial sector shops and workshops primarily focus on auto repair and maintenance due to government electrical plant failures, population growth, and increased energy demand. Table 1 refers to the number of electrical generators in the study area.

Gas oil production increases with generator capacity, with winter generating 30-40 litres per hour for 250 KVA and 12-16 litres per hour for 150 KVA, and doubles in summer due to longer operating hours. Generator owners combine fuel components, resulting in poor-quality fuel and pollutants like lead, carbon dioxide, particulates, and noncarbonated gases, in informal mobile factories in Karma, Saqlawiyah, Tharthar, and Samarra. Table 2 makes it evident that poor quality and extended operating hours, particularly during the summer, contributed to the average amount of pollutants released into the air for both the winter and summer seasons, as well as for all elements, exceedingly locally permissible environmental limits. This has a significant negative impact on public health and poses a risk to individuals with respiratory illnesses.

Air Pollutant Measurements

Four sites were measured, each with generators and bakeries, five representing industrial activities, and one representing residential areas, Table 2. These measurements which included (Total Suspended Particles (TSP), PM10, PM2.5, nitrogen dioxide (NO₂), sulphate dioxide (SO₂), and methane (CH₄) were

Table 1: Number of electrical generators, their production capacity, and quantity of fuel used for the year 2022

No. of Generators	1	1	3	10	30	61	82	7	93	1	2	3	22	130
Production capacity (KVA)	130	135	450	500	400	313	350	200	300	175	60	125	150	250
Fuel used 10 L/ 1 KVA)	1300	1350	4500	5000	4000	3130	3500	2000	3000	1750	600	1250	1500	2500

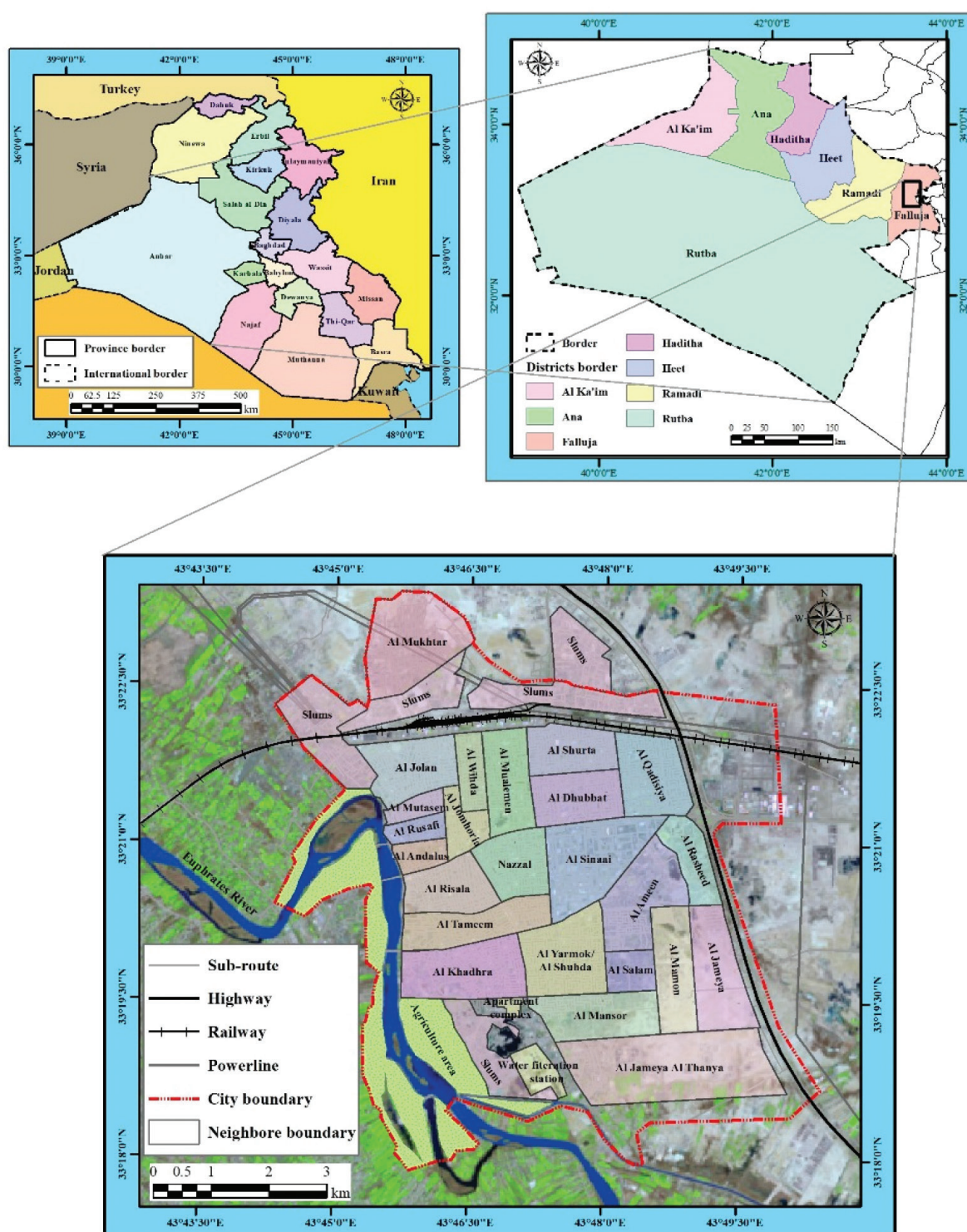


Figure 1: Location of Fallujah city in respect to Al-Anbar Province (Ref. Worked by the researcher based on: The General Authority for Surveying, scale 1:500,000, and Fallujah Municipality Directorate, Projects Division.

conducted in the winter and summer seasons, using portable measuring devices (Low volume sampler, PM2.5, PM10, and gas analyser).

Results and Discussion

Table 4 shows the averages of some air pollutant concentrations in the study area in the summer and

Table 2: Devices used to measure gases and total suspended particles

<i>Devices used in the field study</i>	<i>The device name</i>
	GPS
	Gasmeter Technologies FTIR
	AEROCET 531

winter of 2022. At 2.41 ppm, NO₂ was the highest concentration ever measured in the Teachers District generator during the summer. Regarding SO₂, the generator in the Nazal district had the greatest concentration, measuring 0.72 ppm throughout the winter. CH₄ gas was found to have the highest reading in both the generator in the teachers' neighbourhood and the generator in the Nazzal neighbourhood. In the summer, it reached a concentration of 2.28 ppm, which was higher than the reading in the winter, when it reached 2.03 ppm for the generator in the teachers' neighbourhood and 2.02 ppm for the generator in the Nazzal neighbourhood. While al-Shorta district generator recorded the highest reading of carbon monoxide gas in the summer, reaching 67 ppm, which exceeded the local environmental limits for all generator sites and for the winter and summer seasons, which amounted to 35 ppm. Regarding PM_{2.5} particles, the teacher's neighbourhood generator's greatest reading was 84 µg/m³ during the winter, while the highest reading 497 µg/m³ for PM₁₀ particles recorded during the summer. The police district generator recorded the highest concentration in summer, reaching 7619.7 µg/m³, most concentrations surpassed the local environmental limits in all generator sites.

Table 3: Measurements sites in study area

<i>Symbol</i>	<i>Coordinate</i>	<i>Measurement site</i>
Factories		
F1	3692755.8 / N 393051.78 / E	Fallujah Black Cement
F2	3692998.3 / N 390377.54 / E	Plaster factory
F3	3690610.3 / N 387801.43 / E	Dairy factory
F4	3692505.4 / N 391816.06 / E	Asphalt plant
F5	3690623.1 / N 383323.61 / E	Industrial district
B	3692145.9 / N 389671.87 / E	The border area between the residential area and the factories area
Generators		
S1	3690648.5 / N 386949.52 / E	Nazzal district
S2	3688590.8 / N 386195.84 / E	Green district
S3	3692656.4 / N 387544.09 / E	Police district
S4	3692377.6 / N 386316.02 / E	Teachers district
Bakeries		
A1	3691749 / N 385787.55 / E	Al-Amin
A2	3691922.6 / N 387509.35 / E	Al-Mashhadani
A3	3691987.6 / N 388114.96 / E	Al- Sultan
A4	3690681.4 / N 385075.2 / E	Al- Andalus

Bakeries are yet another source of pollution in residential settings. The majority of Fallujah's families experienced improvements, leading to a total of 281 bakeries, divided into 185 pastry bakeries, and a workforce of 10 employees. Regarding the bakeries, there were 96 of them, and 6 employees were working there. Bakeries in the research area, operating on black oil, release high concentrations of pollutants, causing adverse effects on the population, Table 5.

Table 4: Averages of air pollutant concentrations in the study area in 2022

<i>Iraqi Limits, 2018</i>	<i>July</i>				<i>January</i>				<i>Pollutants</i>
	<i>S4</i>	<i>S3</i>	<i>S2</i>	<i>S1</i>	<i>S4</i>	<i>S3</i>	<i>S2</i>	<i>S1</i>	
(0.1) ppm/ hour	2.41	2.39	2.17	2.21	0.36	0.28	0.66	0.2	NO ₂
(0.15) ppm/hour	0.50	0.53	0.52	0.52	0.66	0.69	0.65	0.72	SO ₂
(0.24) ppm /3 hours	2.28	2.26	2.24	2.28	2.02	2.03	2.03	2.03	CH ₄
(35) ppm /1 hours	63	67	64	66	61	65	61	63	CO
(25)µg/m ³ /24 hours	81	83	78	75	84	70	29	38	PM2.5
(100) µg/m ³ / 24 hours	497	345	148	333	148	129	224	177	PM10
(350)µg/m ³ / 24 hours	2965.1	7619.7	3951.8	6743.8	528.4	371.5	438.2	368.1	TSP

Table 5: Average of some air pollutants emitted from the bakeries for two seasons in 2022

<i>Iraqi Limits, 2018</i>	<i>July</i>				<i>January</i>				<i>Pollutants</i>
	<i>A4</i>	<i>A3</i>	<i>A2</i>	<i>A1</i>	<i>A4</i>	<i>A3</i>	<i>A2</i>	<i>A1</i>	
(0.1) ppm/ hour	1.66	1.69	1.52	1.67	2.03	1.98	1.97	2.08	NO ₂
(0.15) ppm/hour	1.53	1.26	1.25	1.41	1.14	1.05	0.93	1.14	SO ₂
(0.24) ppm /3 hours	2.26	2.35	2.30	2.22	2.17	2.21	2.27	2.22	CH ₄
(35) ppm /1 hours	47	48	49	52	44	45	46	47	CO
(25)µg/m ³ /24 hours	108	106	104	108	122	127	123	118	PM2.5
(100) µg/m ³ / 24 hours	341	362	350	340	960	869	867	1155	PM10
(350)µg/m ³ / 24 hours	4595.1	4573.1	4483.4	4479.9	1682.6	1743.4	1777.8	1586.2	TSP

In terms of NO₂ gas, Al-Amin Bakery had the highest reading for the winter, coming in at 2.08 ppm. It was discovered that Al-Andalus Bakery had the highest readings for SO₂ gas in the summer and winter, respectively, coming in at 1.14 and 1.53 ppm. In terms of CH₄ gas, the summertime value at Al-Sultan Bakery was the highest, coming in at 2.35 ppm. As for carbon monoxide gas, the highest reading was recorded in the Samoon Al-Amin furnaces, reaching 47 ppm and 52 ppm for the winter and summer seasons, respectively. In terms of PM2.5 particles, the highest reading was recorded for the winter season at Al-Sultan Bakery, coming in at 127 µg/m³, and for the winter season at Al-Amin Bakery, it was 1.555 µg/m³ for PM10 particles. In terms of TSP, the highest reading was recorded for the summer season at Al-Andalus Bakery, coming in at 4595.2 µg/m³. For every bakery, the readings exceeded the 350 µg/m³ municipal environmental limit.

Industrial activity is a significant service sector in Fallujah city, attracting workers to the area (Bandar, 2009). The manufacturing process and chimney exhaust of these gases contribute to their high pollution levels in the air (Naser, 2013). Fallujah's Industrial zone, one of Iraq's largest, boasts a diverse array of industries and workshops, fostering a diverse range of industrial

activities. Constriction factories produce various items like blocks, tiles, stickers, and alabaster, while food factories produce flour, dairy products, juice, vinegar, and more. In addition, there are further dye production, auto repair shops, lathe shops, paper tissue manufacturers, and animal feed factories—most of which received environmental permits before 2003. Government operations are located both inside Fallujah, as evidenced by a medical CO₂ filling plant, and outside the city, encircled by factories. Many factories, including those for block, cassette, asphalt, paint, lime, flange, glass gelatinisation, old oil purification, ice and flour factories, general and mixed companies for glass and refractories, black and white cement factories, and what's left of the plaster factories, cold storages, thermistor factories, and others, are located in each of the provinces of Al-Kifa, Al-Jaghifi, Al-Nasaf, and Al-Hassa (Table 6).

The Environmental Protection and Improvement Law No. (27)/(2009), states that no government activity is permitted to have an environmental impact (Jassim, 2011). This was made evident by the evaluation of the Legal Division in the Fallujah environment. Among the most environmentally harmful industries in construction are those that produce cement, plaster, and asphalt. This

is because these industries release a lot of suspended particles into the atmosphere as a result of crushing and loading raw materials (Al-QaraLucy, 2022), and they also release a lot of pollutants from using black oil, such as carbon dioxide, sulphur dioxide, and nitrogen oxides, among other gases.

It is noted from Table 7 that industrial pollutants affect the increase in the concentrations of nitrogen dioxide gas in the asphalt plant for the summer season, which amounted to 1.32 ppm, in contrast to the reading recorded for the same plant in the winter season, as the recorded reading decreased to 1.20 ppm. As for the second gas Sulphur oxide and methane gas, the highest value was recorded in the Industrial District, reaching 1.82 ppm of sulphur dioxide and 2.39 ppm of methane gas for the winter season of the plaster factory.

While the Fallujah Black Cement Factory recorded the highest value for the winter season at 262 $\mu\text{g}/\text{m}^3$, the Plaster Factory recorded the highest value for the summer season at (64) $\mu\text{g}/\text{m}^3$, and the Fallujah Black Cement Factory recorded the lowest value for the

winter season at (40) $\mu\text{g}/\text{m}^3$. PM10 particles recorded the highest value for the plaster plant for the winter season, reaching (1873) $\mu\text{g}/\text{m}^3$. The Fallujah Black Cement Factory and the Gypsum Factory recorded the highest concentrations reaching 58 ppm and 57 ppm of carbon monoxide gas, respectively, during the summer. PM2.5 particles were all above the environmental limitations of 25 $\text{m}^3/\mu\text{g}$. They found the highest value for total suspended particles (TSP). At the same location, the plaster factory's value peaked in the summer at 5323 $\mu\text{g}/\text{m}^3$, while its winter value was 8352.4 $\mu\text{g}/\text{m}^3$. Because these labs are located two kilometers from the start of Fallujah's residential zone and three kilometers from the city center, their positions violate the environmental requirements for lab signs, In addition to not being surrounded by greenbelts to reduce the city's air pollution. Most factories suffer from problems in treatment plants (Filters), this is evident in the asphalt factory, as the factory floor was black due to the lack of filters.

Table 6: Number of work force in factories in Fallujah City 2022

<i>Molasses, jams, and paste factory</i>	<i>Juice factory</i>	<i>Nuts factory</i>	<i>Dairy factory</i>	<i>Block factory</i>	<i>Plaster factory</i>	<i>Asphalt plant</i>	<i>White Cement</i>	<i>Fallujah Black Cement</i>	<i>Type of factory</i>
3	1	3	5	44	3	10	1	1	No.
15	10	10	10	12	25	25	250	200	No. of the workers
kerosene fuel	kerosene fuel	kerosene fuel	kerosene fuel	kerosene fuel	Black oil	Black oil	Black oil	Black oil	Type of fuel used

Table 7: Average air pollutants of industrial zone and border between the residential zone and factories for February and July 2022 in Fallujah

<i>Iraqi Limits, 2018</i>	<i>July</i>						<i>January</i>						<i>Pollutants</i>
	<i>B</i>	<i>F5</i>	<i>F4</i>	<i>F3</i>	<i>F2</i>	<i>F1</i>	<i>B</i>	<i>F5</i>	<i>F4</i>	<i>F3</i>	<i>F2</i>	<i>F1</i>	
(0.1) ppm/ hour	0.16	1.21	1.32	1.18	0.78	0.89	0.10	0.71	1.20	0.51	1.17	1.26	NO ₂
(0.15) ppm/hour	0.26	1.82	0.42	0.51	0.76	1.02	0.88	0.36	0.43	0.36	0.58	1.26	SO ₂
(0.24) ppm /3 hours	2.07	2.26	1.98	2.18	1.96	1.84	2.11	2.06	2.30	1.98	2.39	2.28	CH ₄
(35) ppm /1 hours	89	34	51	40	57	58	87	31	41	38	48	52	CO
(25) $\mu\text{g}/\text{m}^3$ /24 hours	113	49	34	50	64	40	103	232	154	91	212	262	PM2.5
(100) $\mu\text{g}/\text{m}^3$ / 24 hours	353	198	195	144	275	485	299	1581	1213	167	1873	1041	PM10
(350) $\mu\text{g}/\text{m}^3$ / 24 hours	987.6	917.2	1241.3	429.2	5323	5133	335.8	2391.0	1781.1	506.0	8352.4	1838.1	TSP

The border area, which is the area between the end of the industrial area and the beginning of the residential neighbourhood, recorded a clear increase in air pollutant concentrations for all elements except for Total Suspended Particles (TSP) for the winter season, which was within the local environmental limits.

Methane and sulphur dioxide, concentrations were recorded at their highest levels during the winter, coming up at 2.11 and 0.88 ppm, respectively. Among the determinants was the total suspended particle count, which came in at 335.8 $\mu\text{g}/\text{m}^3$, the lowest reading this season, the summer season recorded the highest values for most components, with nitrogen dioxide reaching 0.16 ppm. It reached 89 ppm for carbon monoxide in the border area between the factories and the residential area during the summer and particulate matter (PM_{2.5}, PM₁₀) for each of them 113, 353 $\mu\text{g}/\text{m}^3$. The allowable environmental limit is 350 $\mu\text{g}/\text{m}^3$, and we discovered that the total suspended minutes documented for the same season is 987.6 $\mu\text{g}/\text{m}^3$.

Conclusions

1. Although the necessary laws and regulations were put in place to maintain air quality, their implementation was not sufficient, and more stringent measures are needed to maintain air quality.
2. Factories that produce cement, plaster, and asphalt are among the sectors of the construction industry that have the most impact on the ecosystem. This is because it releases a lot of suspended particles into the atmosphere resulting from crushing, grinding, and loading of raw materials and construction, in addition to harmful gases resulting from burning black oil.
3. Because the factories are located three kilometers from the city center and two kilometers from the start of the residential zone in Fallujah, they violate environmental regulations.
4. The poor fuel quality that was used in the private electrical generators, and the increased operating hours, particularly during summer, led to the average concentrations of some air pollutants emitted during the two seasons (winter and summer) exceeding the permissible environmental limits. Where the police district recorded high concentrations of TSP at 7619.7 $\mu\text{g}/\text{m}^3$, while the local environmental limit at 350 $\mu\text{g}/\text{m}^3$. This has a significant negative impact on human health and puts the injured in danger,

especially those suffering from respiratory diseases.

5. In the summer season, the highest readings for most elements were high in the border area between the residential area and the industrial area, as the Nitrogen dioxide (NO₂) at 0.16 ppm, and particulate matter (PM_{2.5}, PM₁₀, and TSP) were 113, 353, and 8352.4 $\mu\text{g}/\text{m}^3$ respectively, these concentrations exceeded significantly of the permissible limits.
6. While al-Shorta district generator recorded the highest reading of carbon monoxide gas in the summer, reaching 67 ppm, which exceeded the local environmental limits for all generator sites and for the winter and summer seasons, which amounted to 35 ppm.
7. In the winter and summer seasons, the NO₂, SO₂, CH₄ and CO, in addition to the PM_{2.5} concentrations were highest in the bakeries, which were larger than the allowed limits of the local environment. The use of black oil or poor-quality fuel in bakeries is the main reason for the emission of air pollutants in high concentrations.
8. Through the results of the research, we conclude that improving the quality of fuel, reducing the use of private electric generators, and redistributing factories that pollute the environment at a distance of no less than 5 kilometers from residential areas according to environmental legislation established for this purpose, and not using black oil in bakeries will reduce its negative effects on air quality and citizen health.

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