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A Model is Designed to Calculate the Air Quality Index in the City of Baghdad using International Standards

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ABSTRACT

The Air Quality Index (AQI) is a government tool. Employ as an indicator of air pollution levels based focusing on particulate matter and gases. It provides a unified indicator of air pollution, highlighting the detrimental effects on human health, animal well-being, and climatic patterns. This study focused on the analysis of the particle matter ($PM_{2.5}$, PM_{10}), and trace atmospheric gases (NO_2, O_3, $S0_2$, CO) for the period from 1 January 2019 to 31 December 2021 as an overall study period, including periods of particle and total lockdown during COVID-19 pandemic in the capital Baghdad. In the present study, the concentrations of six pollutant criteria, $PM_{2.5,}$ PM_{10}, NO_2, O_3, $SO_{2,}$ and CO before the lockdown and during the periods of the partial and total lockdown from March 1 to July 24, 2020, in the capital Baghdad were analyzed. The results show an overall reduction in the considered partial matter and gases by 13-64%, except the concentration of O_3 shows an increase of about 26%. The AQI enhanced by 20% in Baghdad city for the period of the partial lockdown and total lockdown during the COVID-19 pandemic if compared to its pre-lockdown period. In the second part of the present study, an empirical equation has been developed to estimate the AQI employing the particle matter ($PM_{2.5,}$ PM_{10}) and considered gases (NO_2, SO_2, O_3, CO), where shown a Correlation Coefficient and MAE, MAPE, and RMSE, with measured AQI by Mustansiriyah air pollution station about 0.93, 20.8, 11.6 and 37.3 for the first proposed equation while the second proposed equation shawls 90.91, 26.9, 19.8 and 33.12 respectively and this result refers to that the practical matter has more effective impact on AQI. Finally, this study empire that COVID-19 has drastic effects on social and economic aspects; however, the lockdown also has some positive impacts on the natural environment and air quality improvement.

Keywords: Pollution, Air Quality, Human Health, Asthma, Baghdad, Iraq.

1. Introduction

Air pollution has become the main challenge on this planet; it is caused by many sources, such as vehicles, factories, and power plants. These pollutants can cause respiratory infections, cardiovascular disease, cancer, and death. Air pollution has become a threat to health and the environment. Because it is strongly linked to weather and climate, climate change alters[1]. The factors influencing ventilation rates include wind speed, mixing depth, convection, and frontal passages. Precipitation patterns[2], chemical production, dry deposition, natural emissions, and background concentrations also have a role. Air quality is determined by the presence and concentration of pollutants[3]. Air pollution is caused by the intricate combination of particles, vapors, and gases released from both natural and human-made sources[4], as well as through photochemical transformation processes. Pollutants can cause respiratory infections, cardiovascular disease, cancer, and premature death[5]. Middle Eastern countries are vulnerable to air pollution, especially from industrialization, due to rapid economic growth and urbanization. These countries need stricter environmental regulations due Regarding the severe consequences of air pollution. Annually, air pollution claims the lives of 7 million individuals, with the majority of fatalities occurring in impoverished nations. In addition, air pollution harms crops, economies, and the environment[6]. It is possible to reduce air pollution in emerging countries by improving environmental regulations, investing in clean energy, and encouraging sustainable transportation. Global air pollution has a significant environmental impact, especially on climate change. Many experts believe that pollution causes global warming, or climate change. The average global The temperature is projected to increase by 1°C by 2025 and by 3°C by the conclusion of the 21st century, according to the Intergovernmental Panel on Climate Change European Environment Agency, 2008[7]. The composition of the atmosphere includes nitrogen, oxygen, water vapor[8], carbon dioxide, methane, nitrous oxide, and ozone[9]. in small quantities. Greenhouse gases store solar heat. A 2008 European Environment Agency report found that Earth's surface temperature is being artificially raised by 30 degrees Celsius[10]. The world's population has grown rapidly in recent centuries, along with climate change[11]. The growth of factories and businesses has increased greenhouse gas emissions. The global temperature decreased by less than 9 degrees Celsius between 1880 and 2015[12]. The European Environment Agency reported in 2008 that this temperature change was causing global warming. In 2010, human activities released approximately 46 billion metric tons of greenhouse emissions, measured as carbon monoxide-equivalent, according to the US Environmental Protection Agency 2014[13]. In 2014, the US Environmental Protection Agency announced a 35% increase compared to 1990. In 2010, energy production was responsible for 71% of global greenhouse gas emissions. Agriculture was the second-largest source of emissions, at 13% US EPA, 2014. China (30%), the United States (15%), the EU28 (9.6%), India (6.6%), the Russian Federation (5.0%), and Japan (3.6%) had the highest emissions in 2014[14]. It showed countries and regions significant trends. Leading emissions account for 54% of global emissions. China and the United States increased emissions by 0.9%. Global carbon monoxide[9], equivalent air pollution emissions have exceeded 34,000 metric ton[15]. Tonnage reached 46,000 million metric tons by 2010. The COVID-19 pandemic has reduced emissions. Emissions of carbon monoxide and ozone[9] rose by 5.4% in 2020. However, emissions of carbon dioxide[16] and other hazardous substances are expected to rise in 2021, although slightly lower than in 2019[17]. Air Quality Index (AQI) is proposed in order to estimate the health risks of breathing polluted air in the immediate vicinity, usually within hours or days with scale from 0 to 500 [18]. As air quality index rises, air pollution worsens, and public anxiety rises. The main objectives of the Air Quality Index are: daily public awareness: to inform the public about air quality. Health communication: to communicate the potential health impacts of air quality. Environmental conservation: protecting public health by raising awareness, enabling emissions reductions, and improving air quality. To predict air pollution levels and help people and governments prepare for health risks[19].

2. Data Acquisition, Methodology and Site Description

2.1 Data Acquisition

In present study two data source have been considered, first the data was acquired through the Copernicus website, where the website (https://ads.atmosphere.copernicus.eu/cdsapp#!/search?type=dataset), provides services for Earth observation through the utilization of satellite-based and non-satellite-based positional data. Copernicus serves as the Earth Observation Information Programmer for the European Union. The management of the programmer, specifically the European Commission, has been observed from the years 2003 to 2021, with the measurement units expressed in grams per cubic meter ($\mu g/m^3$). A total of 196 grid points were utilized, with a horizontal coverage resolution of 0.75° by 0.75°[20]. The second source employed in present study is a dataset that contains monthly meteorological data, which was utilized in the reanalysis process. From 2010 to 2021. The meteorological parameters encompassed where the variables include solar radiation, temperature, relative humidity, wind speed and direction. The European Centre for Medium-Range Weather Forecasts (ECMWF) is an organization that specializes in predicting weather patterns within a specific time frame [21].

2.2 Methodology

The present study was done to analyses the variations in air pollution levels in Iraq between January 1, 2019 and December 1, 2021. The measurement of the decline in particulate matter and pollutant concentrations was conducted prior to, subsequent to and throughout the time of enforced confinement. To assess the impact of the COVID-19 lockdown on air quality in Baghdad, the capital of Iraq, a city known for its high levels of pollution located in the center of the country. The aim of this article is to develop a model for evaluating the extent of pollution in the city of Baghdad[22]. This project entailed the creation of a predictive algorithm for determining the air quality index in Iraq. The model utilized a multiple linear regression equation, taking into account the presence of various pollutants and particles that have the greatest impact on air quality. Additionally, the study examined the temporal variations in air quality. Contaminants. In Iraq, events occur on a daily, monthly, and annual basis. Furthermore, this work yielded the development of two empirical equations. The initial equation encompasses particulate matter ranging from 2.5 to 10 microns in diameter, whereas the subsequent equation amalgamates the particles and gases examined in the present study. The proposed equations were assessed using statistical metrics including the correlation coefficient (r), mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean square error (RMSE), in order to attain optimal accuracy and minimize errors, this is because there exists a correlation between air pollution and Air Quality Index (AQI) is a metric used to quantify the level of air quality[23]. Air quality levels are assessed via sophisticated equipment, which subsequently creates the Air Quality Index. Consequently, the atmospheric alkalinity will rise, Ammonia gas is one of the most important molecules, as it acts as an alkaline substance in the atmosphere, as it is the only base dissolved in water and available in large proportions the Air Quality Index (AQI) is a numerical measure employed to determine the degree of air quality. Role in adjusting acidity. thereby heightening dangers to the overall health of the people.

2.3 Site Description

Iraq is situated in the eastern regions of the Middle East and North Africa. Geographically, it shares borders with Iran to the east, Turkey to the north, Syria and Jordan to the west, and Saudi Arabia and Kuwait to the south. Additionally, it is located near the Gulf in a southeastern direction. Iraq has a narrow coastal area along the Arabian Gulf, spanning around 58 km.The climate in Iraq is predominantly characterised by a subtropical and The region has a semi-arid continental climate, but the northern and northeastern hilly portions have a Mediterranean climate. Iraq is characterised by its basin-like shape, encompassing the vast Mesopotamian plain formed by the Tigris and Euphrates rivers. According to the most recent United Nations estimates, the present population of Iraq is approximately 40 million individuals. Iraq is now experiencing an annual growth rate of 2.32%. Approximately 70% of Iraq's populace resides in urban regions, with numerous expansive cities that exemplify this demographic distribution. By a significant margin, the most populous city in the country is Baghdad, the capital, boasting a population of approximately 9 million individuals[24]. Baghdad is located centrally in Iraq. The municipality of Baghdad has fourteen administrative units, with eight situated in Rusafa (to the east of the Tigris River) and six in Karkh (to the west of the Tigris River). The local government of Baghdad has an area of 4555 km2[25].shown in Fig(1). The research region possesses several advantageous qualities, including significant temperature extremes, minimal precipitation, low relative humidity, and intense sunlight[26].

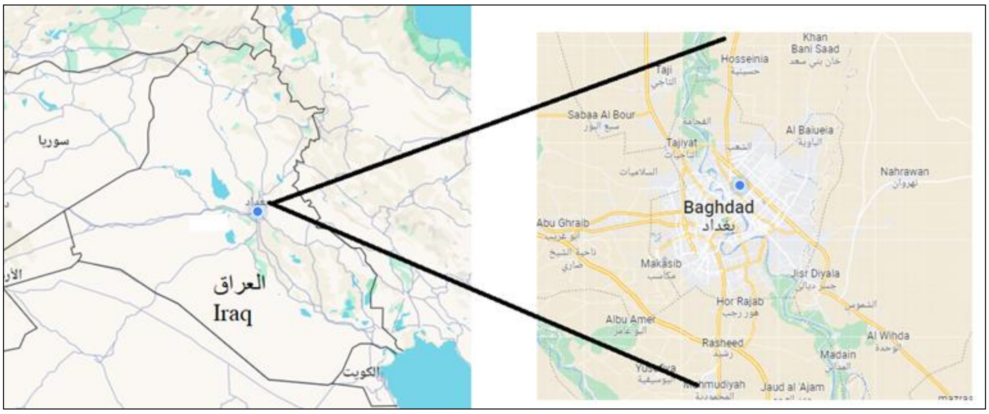

Figure 1. The Location Map of the Study Area in Baghdad, Iraq.

3. Results and Discussion

3.1 $PM_{2.5}$ Concentrations

Figure (2, a) represents the daily concentrations of $PM_{2.5}$ in (µg/m^3) units in Baghdad city for the overall period, including COVID-19 with partial and total lockdowns periods. The results showed that the average $PM_{2.5}$ concentrations was 74 µg/m^3 for the overall period of study (1 January 2019 to 31 December 2021). During the period before the COVID-19 pandemic, the average $PM_{2.5}$ concentrations was 74 µg/m^3, while the $PM_{2.5}$ mean of the two months before the pandemic (1 January–28 February 2021) was 82 µg/m^3. During the partial and total lockdown from June 15 to July 24, 2020. The average of $PM_{2.5}$ dropped to 63 µg/m^3, with a maximum and minimum of 104 and 25 µg/m^3, respectively. The daily concentrations of $PM_{2.5}$ increased to reach 79 µg/m^3, with values of (144 and 31) maximum and minimum, respectively. This obviously increased during the period (24 July to 31 December 2020) due to the fact that the mentioned period included partial and total lockdown periods. Also, the period that included the partial attendance (1 January to 31 December 2021) of the employees in government establishments augmented the particle attendance of the employers in the government establishments augmented the particle lockdown was from 5 p.m. to 6 a.m., the pm 2.5 (78 µg/m^3) with clear increases in the maximum value of 157 µg/m^3. Although these mention lockdowns (partial and total) where the transportation sector activated $PM_{2.5}$ concentrations in Baghdad city, the permitted value (25 µg/m^3) during most days through the study period established in May and summer months was due to high temperature values.

3.2 PM_{10} Concentrations

Figure (2, b) represents the daily concentrations of PM_{10} in (µg/m^3) units in Baghdad city for the overall period, including COVID-19, with partial and total lockdowns. The results showed that the average PM_{10} concentration was 116 µg/m^3 for the overall period of study (1

January 2019 to 31 December 2021). During the period before the COVID-19 pandemic, the average PM_{10} concentration was 109 µg/m^3, while the PM_{10} mean of the two months before (1 January–28 February 2021) the pandemic was 111 µg/m^3. Whereas the average of PM_{10} reduce to 96 µg/m^3 during the partial lockdown from June 15 to July 24, 2020, the average of PM_{10} was 82 µg/m^3, with a maximum and a minimum of 330 µg/m^3, respectively. The daily concentrations of PM_{10} increased to reach 95 µg/m^3 with values of 255 and 43 maximums and minimum, respectively. This obviously increased during the period (24 July to 31 December 2020) due to the fact that the mentioned period included partial and total lockdown periods. Also, the period that included the partial attendance (1 January to 31 December 2021) of the employees in government establishments augmented the particle attendance of the employers in the government establishments augmented the particle lockdown was from 5 p.m. to 6 a.m., with clear increases in the maximum value of 438 µg/m^3. Although these mention lockdowns (partial and total) where the transportation sector activated PM_{10} concentrations in Baghdad city, the permitted value (50 µg/m^3) during most days through the study period established in May and summer months was due to high temperature values.

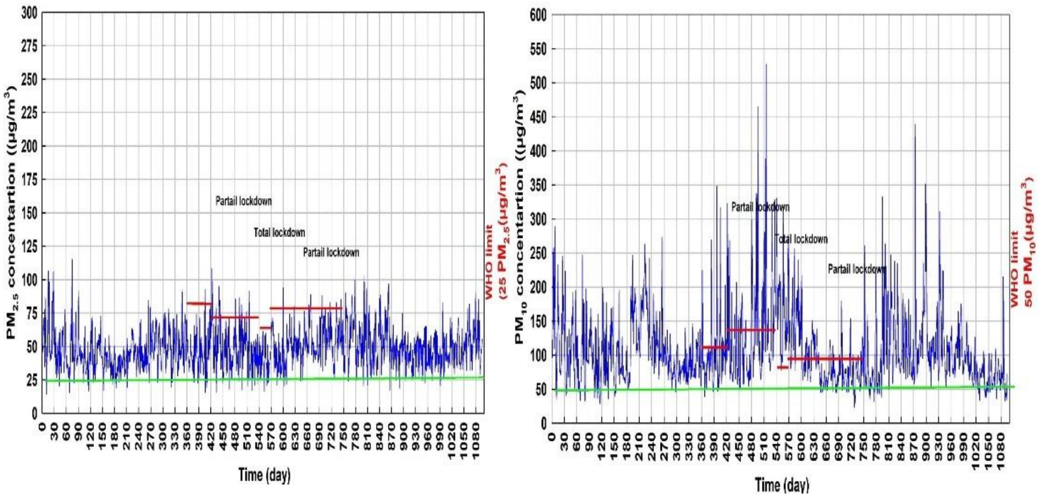

Figure 2. particle matter concentrations (µg/m_3) in Bagdad from 1Jan 2019 to 31 Dec 2021
a) $PM_{2.5}$ and b) PM_{10}

3.3 NO_2 concentration

Figure (3, a) represents the daily concentrations of NO_2 in (µg/m^3) units in Baghdad city for the overall period, including COVID-19 with partial and total lockdowns. The results showed that the average PM_{10} concentration was 34.4 µg/m^3 for the overall period of study (1 January 2019 to 31 December 2021). During the period before the COVID-19 pandemic, the average NO_2 concentration was 30.9 µg/m^3, while the NO_2 mean of the two months before (1 January–28 February 2021) of the pandemic was 59 µg/m^3. During the total lockdown from June 15 to July 24, 2020, the average of NO_2 was 21 µg/m^3, with a maximum and a minimum of 46 and 12 µg/m^3, respectively. The daily concentrations of NO_2 increased to reach 37 µg/m^3 with values of 104 and 13, respectively. This obviously increased during the period (24 July to 31 December 2020) due to the fact that the mentioned period included partial and total lockdown periods. Also, the period that includes the partial attendance (1 January to 31 December 2021) of the employees in government establishments augmented the particle attendance of the employers in the government establishments augmented the particle lockdown was from 5 p.m. to 6 a.m. for NO_2 (34.5 µg/m^3) with clear increases in the maximum value of 126.5 µg/m^3, which confirms a decrease in NO_2 concentration in Baghdad during the lockdown. From Fig. 3.3, it is noted that the daily concentrations and averages of NO_2 did not exceed the WHO limit of 200 µg/m^3 before and after lockdown.

3.4 O_3 concentration

Figure (3, b) represents the daily concentrations of O_3 in (µg/m^3) units in Baghdad city for the overall period, including COVID-19, with partial and total lockdowns. The results showed that the average of O_3 concentrations was (64 µg/m^3) for the overall period of study (1 January 2019 to 31 December 2021), while the O_3 mean of the two months before (1 January–28 February 2021) the pandemic was (65 µg/m^3). During the total lockdown from March 2 to June 15, 2020, the average of O3 was 82 µg/m^3, with a maximum and a minimum of 88 and 76 µg/m^3, respectively. The daily concentrations of O_3 were decreased to reach 73 µg/m^3 with values of 86 and 51 maximums and minimum, respectively. This decreased during the period (24 July to 31 December 2020) due to the fact that the mentioned period included partial and total lockdown periods. Also, the period that included the partial attendance (January 1 to December 31, 2021) of employees in government facilities also increased the partial attendance of employers in government facilities, as the partial curfew became from 5 p.m.to 6 a.m. for the O_3 (73 µg/m^3) with clear increases in the maximum value of (88 µg/m^3) lockdown. That confirms increase in O_3 concentration in Baghdad during the lockdown. From Fig. 3.4, it was noted that the daily concentrations and averages of O_3 did not exceed the WHO limit (100 µg/m^3) before and after lockdown. During the study period, the lockdown gave us an unintended opportunity to learn about the reasons for the sudden rise in ozone despite the decline in emissions as nitrogen oxides take over the task of absorbing active chemical radicals and preventing them from forming ground-level ozone. Therefore, a decrease in NOx levels, whether gradual as a result of pollution reduction policies or sudden as a result of lockdowns, will increase active radicals that can react with VOCs, producing more active radical chemical radicals again leading to Increased ozone levels at ground level[27]. Fine $PM_{2.5}$ particles in the air also act as a sponge that absorbs the chemical radicals responsible for worsening ground-level ozone, as ground-level ozone interacts with mixed pollutants present in the air, such as hydrocarbons and nitrogen oxides, in addition to its interaction with volatile organic compounds present in the atmosphere. Fossil fuels produce a large array of highly active chemical radicals, which in turn initiate a series of reactions with components of the atmosphere[28].

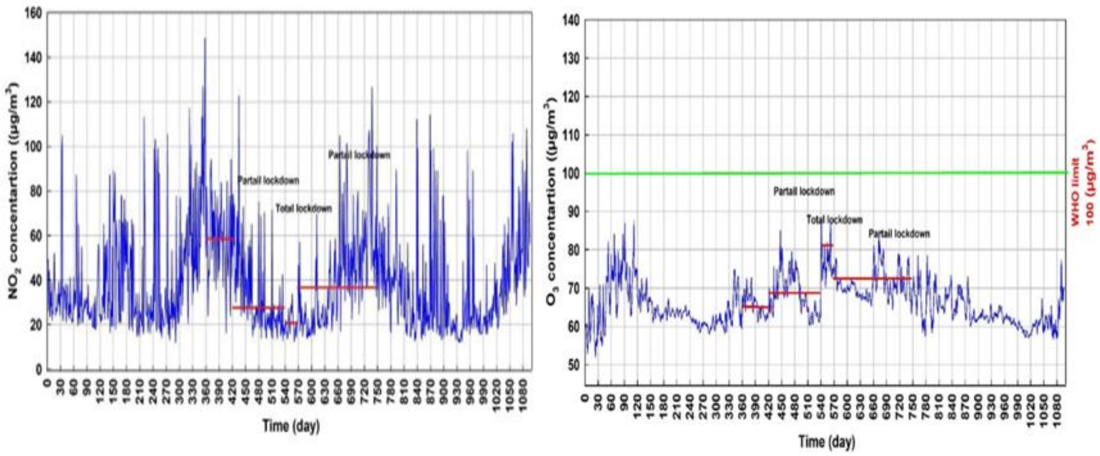

Figure 3. NO_2 and O_3 concentrations (µg/m3) in Bagdad from 1Jan 2019 to 31 Dec 2021 a) NO_2 and b) O_3.

3.5 SO_2 concentration

Figure (4, a) represents the daily concentrations of SO_2 in (μg/m^3) units in Baghdad city for the overall period, including COVID-19 with partial and total lockdowns. The results showed that the average of SO_2 concentrations was 30.35 μg/m^3 for the overall period of study (1 January 2019 to 31 December 2021), while the SO_2 mean of the two months before (1 January–28 February 2021) the pandemic was 45 μg/m^3. During the total lockdown from March 2 to June 15, 2020, the average of SO_2 was 35 μg/m^3, with a maximum and a minimum of 94 and 4.7 μg/m^3, respectively. During the total lockdown from June 15 to July 24, 2020, the average of SO_2 was 17 μg/m^3, with a maximum and a minimum of 56 and 4.3 μg/m^3, respectively. The daily concentrations of SO_2 were reduced to reach 37 μg/m^3 with values of 112 and 5.3, respectively. This decreased during the period (24 July to 31 December 2020), due to the fact that the mentioned period included partial and total lockdown periods. Also, the period that includes the partial attendance (1 January to 31 December 2021) of the employees in government establishments augmented the particle attendance of the employers in the government establishments augmented the particle lockdown was from 5 p.m. to 6 a.m., the SO_2 (37 μg/m^3) with clear increases in maximum value of (192 μg/m^3), which confirms a decrease in SO_2 concentration in Baghdad during the lockdown.

3.6 CO concentration

Figure (4, b) represents the daily concentrations of CO in (μg/m^3) units in Baghdad city for the overall period, including COVID-19 with partial and total lockdowns. The results showed that the average CO concentration was 8.95 μg/m^3 for the overall period of study (1 January 2019 to 31 December 2021). The CO mean of the two months before the pandemic (1 January–28 February 2021) was 9.3 μg/m^3. During the total lockdown from March 2 to June 15, 2020, the average CO was 9.6 μg/m^3, with a maximum and minimum of 10.9 and 7.9 μg/m^3, respectively. During the total lockdown from June 15 to July 24, 2020, the average of CO was 8.28 μg/m^3, with a maximum and a minimum of 10 and 7.4 μg/m^3, respectively. The daily concentrations of CO were reduced to reach 8.5 μg/m^3 with values of 11.5 and 7.25 maximum and minimum, respectively. This decreased during the period (24 July to 31 December 2020), due to the fact that the mentioned period included partial and total lockdown periods. Also, the period that includes the partial attendance (1 January to 31 December 2021) of the employees in government establishments augmented the particle attendance of the employers in the government establishments augmented the particle lockdown was from 5 p.m. to 6 a.m., the CO (8.9 μg/m^3) with clear increases in maximum value of (11.5 μg/m^3), which confirms a decrease in CO concentration in Baghdad during the lockdown.

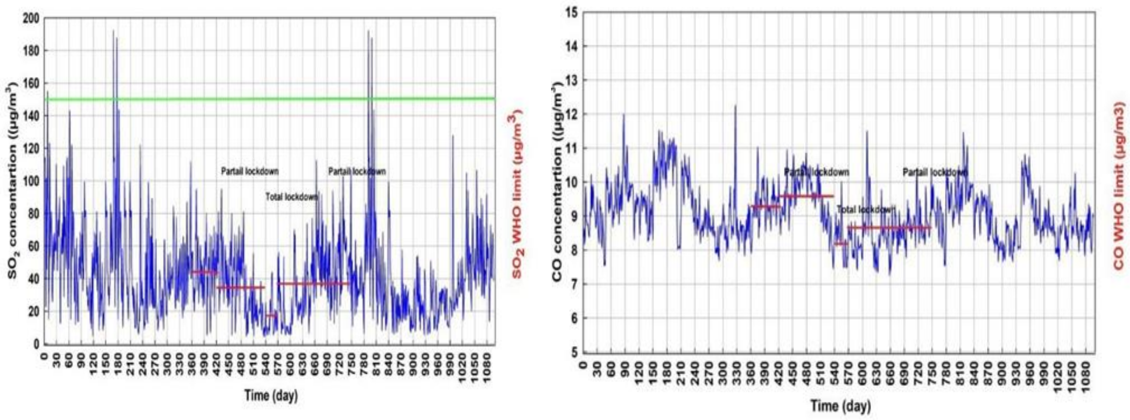

Figure 4. SO_2 and CO concentrations (µg/m3) in Bagdad from 1Jan 2019 to 31 Dec 2021 a) SO2 and b) CO.

3.7 Daily AQI in Baghdad city

The air quality index (AQI) is calculated according to the quantities of basic pollutants in the ambient atmosphere. The air quality index is classified into the concentrations of five categories, as tabulated in Table 1. The air quality index depends on the measurement of microscopic solid or liquid microscopic suspended particles in the atmosphere ($PM_{2.5}$ and PM_{10}), and the sources of particulate matter can be natural or anthropogenic as a result of their daily activities, as well as calculating the presence of other components in the air such as ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and monoxide carbon (CO), where the higher the density of pollutants in the air, the higher the air quality index (AQI). Through a general formula, the results show that air pollution in Baghdad city exceeds the standard levels, especially during peak periods. The previous studies revealed that the air quality index is directly related to human health.

Table 1. Studies revealed that the air quality index is in direct relation with human health.

AQI	**$PM_{2.5}$ (µg /m^3)**	**PM_{10} (µg/^{3})**	**CO**	**SO_2**	**NO_2**	**O_3**	**AQI Category**
0-50	0.0-12.0	0-54	0.0-4.4	0-35	0-53	0-50	**Good**
51-100	12.1-35.4	55-154	4.5-9.4	36-75	54-100	51-100	**Satisfactory**
101-200	35.5-55.4	155-254	9.5-12.4	76-185	101-360	101-168	**Moderate**
201-300	55.5-150.4	255-354	12.5-15.4	186-304	361-649	169-208	**Poor**
301-400	150.5-250.4	355-424	15.5-30.4	305-604	650-1249	209-748	**Very Poor**
$\geq$ 401	250.5-350.4	425-504	30.5-40.4	605-804	1250-1649	749-	**Severe**

This part of the present study determines the relationship between differences in the concentrations of pollutants and air quality index during a period from January 1, 2019 to December 31, 2021, where the average air quality reached (163), which represented a moderate AQI level (breathing discomfort to people with lung, heart disease, children, and older adults) during the year 2019, whereas the highest level was (343), which indicates a very poor AQI level (respiratory illness to people on prolonged exposure), and the lowest level was (50), which represents a good AQI level with a minimal impact during the first year of the study period (2019), as illustrated in Figure (5, a), While the average air quality concentration during 1-1-2020 to 1-3-2020 was (157) which represented a moderate AQI level before the COVID-19 pandemic, after the partial and total closures occurred since the emergence of the pandemic until the end of 2020, the average is (159) As shown in Figure (5, b), as for the year 2021, the average air quality values were (170), which represented a moderate AQI level during the year 2019, whereas the highest level was (410) which indicated a very poor AQI level (respiratory illness to people on prolonged exposure), and the lowest level was (54) which represented a good AQI level with a minimal impact during the first year of the study period (2019), as illustrated in Figure (5, c).

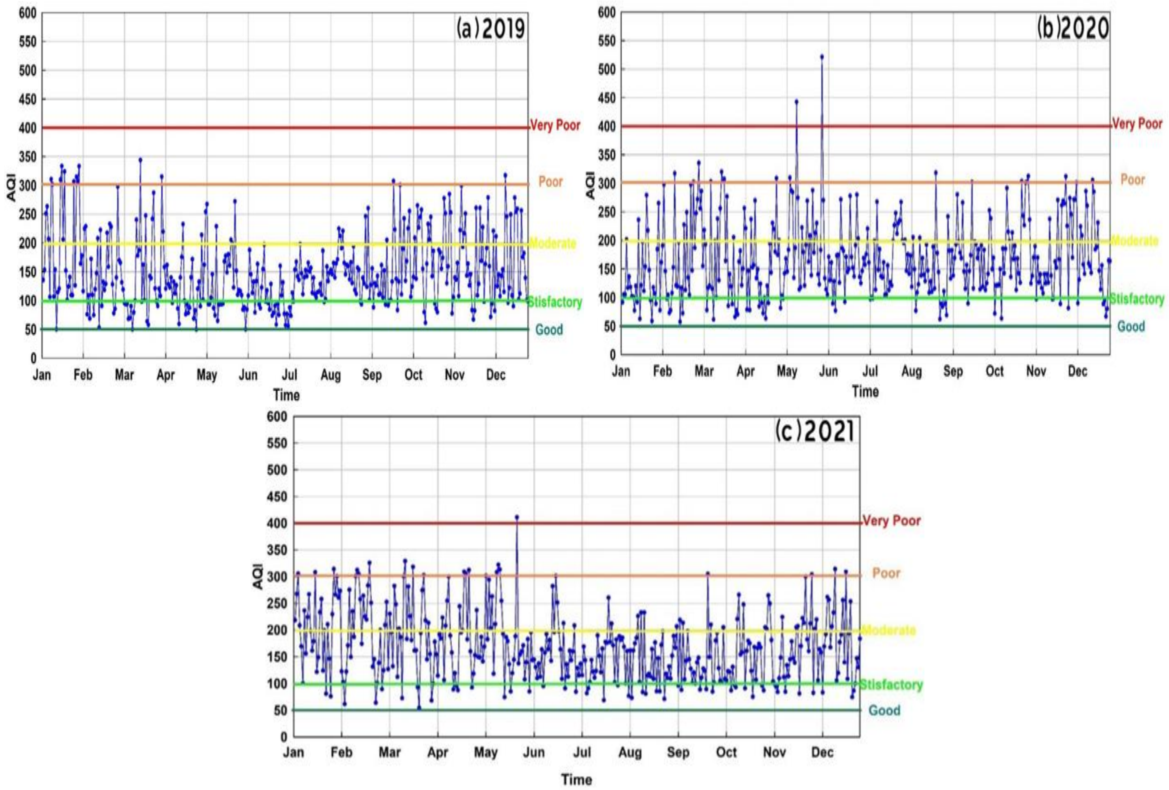

Figure 5. Air Quality Index in Baghdad from for the years (a. 2019, b. 2020, c. 2021).

3.8 Daily and monthly averages of calculated AQI in Baghdad

The present section shows that 87 days (24%) from 1-1-2019 until 31-1-2019 were classified as satisfactory. 205 days (56%) were leveled as moderate, 58 days (16%) as poor, 11days (3%) as very poor, and 4 days (1%) as good Figure (6, a). This means that people suffering from lungs, asthma, and heart disease are breathing uncomfortably on 56% of the days of the year 2019 in Baghdad, on 3% of the days, people exposed to air pollution. Generally, Baghdad is affected by air pollution, and the quality of the air in this region is generally not satisfactory, which causes many health problems and diseases. Whereas the result of the period from January 1, 2020, to January 31, 2020, 58 days (16%) were rated as satisfactory. 214 days (59%) were classified as moderately poor, 75 days (20%) as poor, and 19 (5%) as extremely poor Figure (6, b). This means that in Baghdad, people with lung disease, asthma, and heart disease suffer from breathing discomfort 59% of the year, compared to 5 percent of the time for people exposed to air pollution. Baghdad is affected by environmental pollution, and the air quality in the area is generally poor. It found that 64 days (16%) from 1/1/2021 to 1/31/2021 were rated as satisfactory. 204 days (59%) were classified as moderate, 75 days (20%) poor, and 23 days (5%) very poor Figure (6, c). This means that people with lung disease, asthma, and heart disease causes great difficulty in breathing 59% of the year in Baghdad, and people exposed to air pollution do not breathe well. In general, Baghdad is affected by air pollution, and the air quality in the area is generally not ideal, leading to many health problems and diseases. The poor air quality in general in Baghdad city caused many health problems and diseases. Air pollution is one of the most important environmental risks in Baghdad city. By reducing air pollution levels caused by strokes, heart disease, lung cancer, and chronic and acute respiratory diseases, including asthma, 209 days (19%) days from 1/1/2019 to 1/31/2021 were rated as satisfactory. 622 days (57%) were classified as moderate, 207 days (19%) were poor, and 55 days (5%) were very poor Figure (6, d). Due to the generally poor air quality in the area, many health problems and illnesses have occurred.

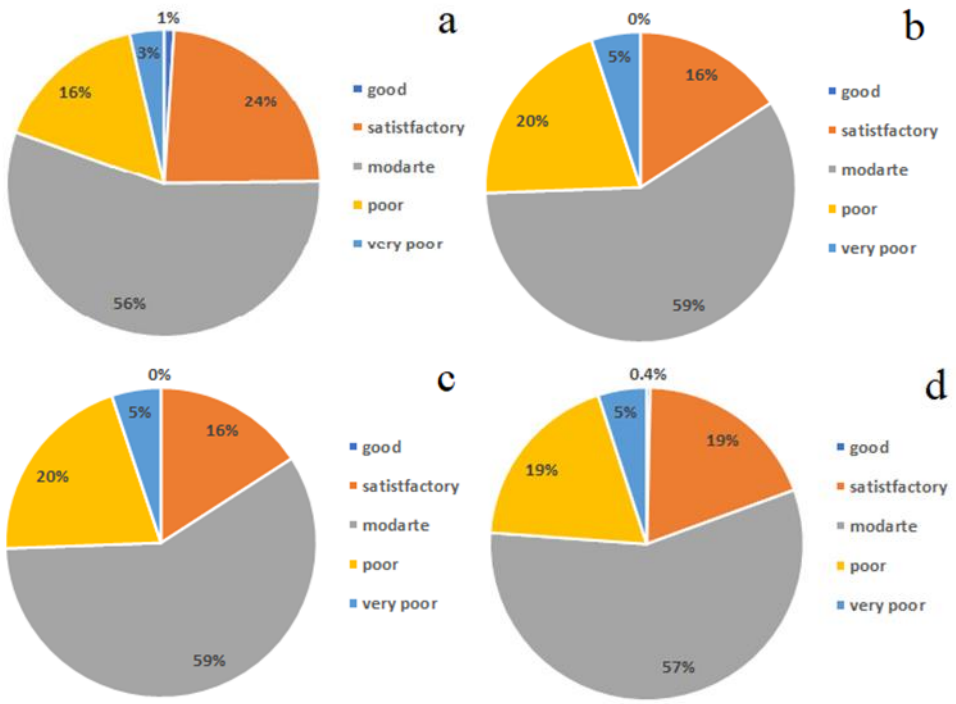

Figure 6. Air Quality Index Ratio in Baghdad from for the year a. 2019, b. 2020, c. 2021, and d. for the overall period (2019-2021).

3.9 Monthly average of calculated AQI in Baghdad

After filtering the data, the air quality index was calculated through the monthly averages for the years 2019, 2020, 2021 as shown in Figure 7, where the annual average was 148 and the highest value of the air quality index was 194 in January, whereas the lowest value was 109 in July, which represents the third level of the annual mean. which is unhealthy for sensitive groups. The air quality index showed up in the city of Baghdad during the year 2020, according to the monthly values. The average rate was 173 during the first two months of this year, preceding the partial and total closures before the emergence of the pandemic. It tends to be high in the colder seasons and decrease in the warmer seasons. This is based on the fact that the level of air pollutants rises to its highest levels in the winter, and their concentration increases with the colder season. While the average monthly average during the period of partial and total closure was reduced to 124 for the period from 3-1-2020 to 7-24-2020, which indicates a decrease in the air quality index due to transportation restrictions and a slowdown in emissions from industrial activities, but after the period of partial and total closure, when the employees began to work in official working hours, part of the production factories returned to work from the date of July 24 to the end of the year. The average monthly rate was increased to 159, as illustrated in figure 3.7. It is clear from this that the city of Baghdad is significantly affected by air pollution and suffers from health problems. According to the data of the monthly averages of the air quality index, the capital, Baghdad, ranked 13th in the most polluted city in the world in 2021. As the air quality deteriorated, the annual average reached 170, which represents a moderate level of air quality index, and the highest value was 205 within the fourth level, while the lowest value was 139.

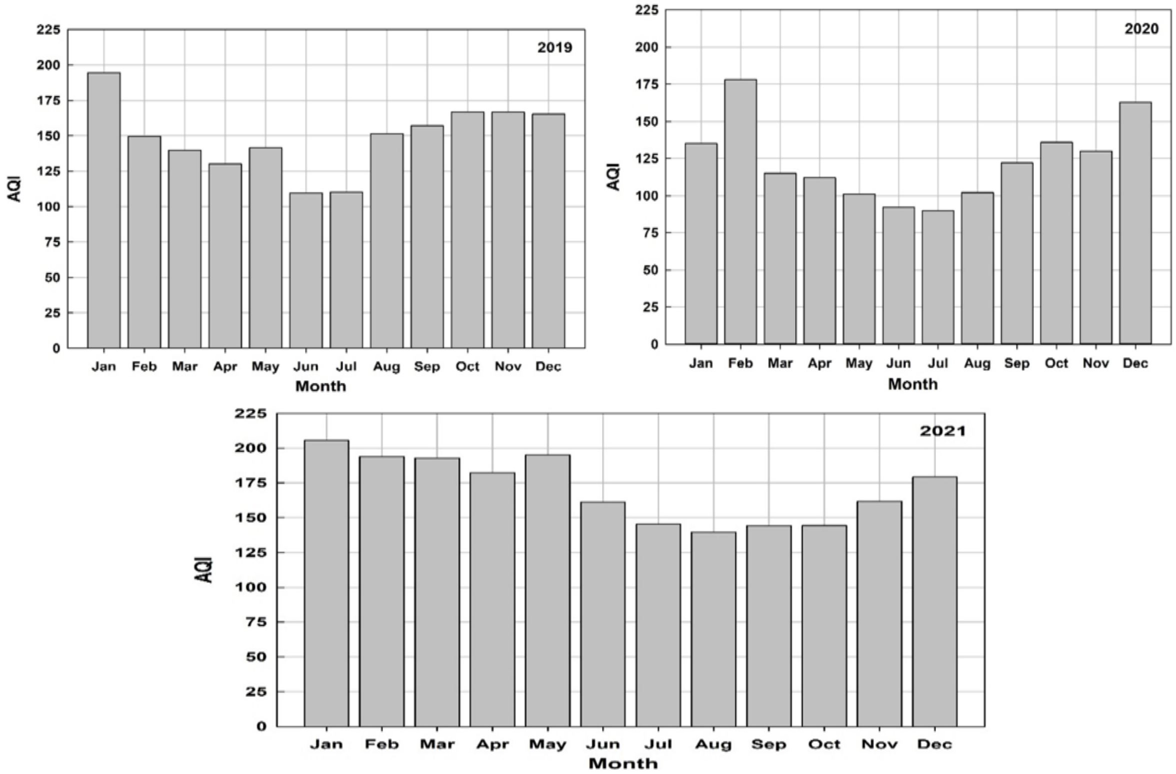

Figure 7. Monthly mean of Air Quality Index in Baghdad during 2019, 2020, and 2021.

3.10 correlation matrix in Baghdad city

The Peterson correlation matrix was used to measure the variables of air pollutants for the years 2019-2020-2021 in order to determine the correlation between the main air pollutant factors in the city of Baghdad, including PM_{10}-$PM_{2.5}$-O_3-CO-NO_2-SO_2), where it was found. The pollutant concentrations for the year 2019 were tabulated in Table (2). The concentrations of PM_{10}, $PM_{2.5}$, NO_2, and CO were the highest during the winter due to the use of gas heaters and stoves that use oil fuel, an increase in the levels of CO, an increase in the percentages of NO_2 concentrations due to electric power stations and private and industrial generators, and the lowest in the summer. Also, the boundary layer height will be decreased and increased during the winter and summer, respectively, while the concentration of O_3 reached its peak in the summer. The analysis indicates that the annual, average, and daily data indicate a significant difference between the summer and winter periods. In the winter months, $PM_{2.5}$, which comprises about 80% of PM_{10}, is closely related to NOx, indicating the importance of road traffic as a source. In the summer months, secondary particulate matter is evident, and it turns out that PM_{10} and $PM_{2.5}$ particles are weakly associated with the rest of the pollutants.

Table 2. correlation matrix between air pollutant in Baghdad city for the year 2019.

2019	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**CO**	**NO_2**	**SO_2**
PM_{10}	1					
$PM_{2.5}$	0.188	1				
O_3	0.019	0.022	1			
CO	0.030	0.012	0.137	1		
NO_2	0.072	0.035	0.059	0.079	1	
SO_2	0.082	0.083	0.041	0.021	0.507	1

The correlation matrix in Table (3) examines the analysis of the interrelationships between air pollutants in the city of Baghdad during the year 2020. The pollutants include PM_{10}, $PM_{2.5}$, O_3, CO, NO_2, and SO_2. The correlation matrix shows the interrelationship between the various pollutants among them. The presented table shows the correlation coefficients related to different pollutants. PM_{10} displays a correlation coefficient of 1 with itself, indicating perfect positive connectivity. While we found that the relationship between $PM_{2.5}$ and PM_{10} was very weak, as its coefficient reached 0.027. It turns out that the relationship between O_3 and $PM_{2.5}$ is weak by a factor of 0.19. In addition, O_3 shows a very weak relationship with other pollutants. Sulfur dioxide (SO_2) shows a modest correlation of 0.467 with ozone (O_3) and little correlation with other pollutants. It turns out that the relationship between NO_2 and PM_{10} is very weak, with a factor of 0.054. Likewise, the relationship between NO_2 and SO_2 is also very small. Sulfur dioxide (SO_2) shows a moderate correlation of 0.44 with carbon monoxide (CO), indicating a moderate association between the two pollutants. In addition, sulfur dioxide shows relatively lower associations with other pollutants. The correlation coefficients presented below provide valuable insights into the interrelationships between different air pollutants within the Baghdad city limits during 2020. It is essential to recognize that the magnitude and direction of these correlations can have implications for air quality and environmental assessments within urban areas.

Table 3. correlation matrix between air pollutant in Baghdad city for the year 2020.

2020	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**CO**	**NO_2**	**SO_2**
PM_{10}	1					
$PM_{2.5}$	0.027	1				
O_3	0.019	0.19	1			
CO	0.058	0.074	0.467	1		
NO_2	0.054	0.041	0.024	0.054	1	
SO_2	0.113	0.099	0.025	0.136	0.44	1

Table (4) shows the correlation matrix between air pollutants in Baghdad city for the year 2021 and $PM_{2.5}$ and PM_{10} concentrations ($R^2 = 0.014$). According to the data of the monthly averages of the air quality index, the capital, Baghdad, ranked 13th in the most polluted cities in the world in 2021 as the air quality deteriorated, as the correlation coefficient between PM_{10} and NO_2 became (0.115) and the correlation coefficient between the element O_3 and SO_2 was (0.177), as shown below.

Table 4. correlation matrix between air pollutant in Baghdad city for the year 2021.

2021	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**CO**	**NO_2**	**SO_2**
PM_{10}	1					
$PM_{2.5}$	0.014	1				
O_3	0.073	0.014	1			
CO	0.057	0.016	0.177	1		
NO_2	0.115	0.04	0.010	0.067	1	
SO_2	0.053	0.033	0.177	0.025	0.28	1

Table (5) shows the correlation matrix between air pollutants in Baghdad city for the overall study period (2019–2021). The strength of the correlation increases as the value of the coefficient approaches 1. If the division of the Pearson coefficient is 0, This means that there is no correlation between the comparative factors. The direct relationship means an increase in one of the factors with an increase in the related factor, while the inverse relationship means that the increase in the value of one of the factors leads to a decrease in the related factor. We note that fine particulate matter is weakly positively correlated with the 2019–2020–2021 air pollutant variables. While PM_{10} and $PM_{2.5}$ are weakly correlated between them (0.014). To determine the association between the main air pollutant factors in the city of Baghdad (PM_{10}-$PM_{2.5}$-O_3-CO-NO_2-SO_2) where the pollutant concentrations for the year 2019 in Table 2 above were found to be high and according to the percentages shown, and in the year 2020 due to the partial closure And in total, the concentrations of pollutants decreased despite the clear increase in the concentration of the ozone element in varying proportions, and this can be explained by the higher levels of solar activity during the closure period. The concentrations of pollutant the elements rose again in 2021 as shown in Table 4 according to the correlation coefficient and movement with the presence of human, industrial and commercial activities.

Table 5. correlation matrix between air pollutant in Baghdad city for the overall study period (2019-2021).

2019-2021	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**CO**	**NO_2**	**SO_2**
PM_{10}	1					
$PM_{2.5}$	0.047	1				
O_3	0.009	0.012	1			
CO	0.041	0.067	0.25	1		
NO_2	0.045	0.040	0.044	0.084	1	
SO_2	0.475	0.072	0.018	0.021	0.365	1

Table (6) shows the correlation matrix between the air quality index, meteorological elements, and air pollutants in Baghdad city for the whole study period (2019–2021). The city of Baghdad was selected to study the effect of atmospheric variables on ambient air quality in the city. The high concentration of particulate matter in the air has also reduced the amount of solar radiation that can reach the earth due to strong population growth, unplanned development, increased vehicles, dynamic construction and demolition, harmful effects on the earth, and others. Where the value of the air quality index (AQI) was found through the method of the correlation matrix and the element ($PM_{2.5}$) is (0.830), where strong positive correlation The meteorological parameters chosen for the study were solar radiation, relative humidity, temperature, wind speed, and direction. The study shows a significant weak relationship between each variable of the meteorological indicators and the air quality index, which was carried out separately.

Table 6. correlation matrix between AQI and air pollutant and meteorological elements in Baghdad city for the overall study period (2019-2021).

2019-2021	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**CO**	**NO_2**	**SO_2**	**SR**	**Temp**	**RH**	**WS**	**WD**
AQI	0.203	0.830	0.013	0.031	0.025	0.045	0.021	0.087	0.015	0.064	0.0156

Table (7) Correlation matrix between AQI and air pollutants and meteorological elements in Baghdad city for the overall study period (2019) The results showed that the air quality index for the year 2019 is directly affected by the $PM_{2.5}$ elements through the data in Table 7, where the correlation value was 0.737, which represents a relatively strong correlation.

Table 7. correlation matrix between AQI and air pollutant and meteorological elements in Baghdad city for the overall study period (2019).

2019	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**CO**	**NO_2**	**SO_2**	**SR**	**Temp**	**RH**	**WS**	**WD**
AQI	0.286	0.737	0.035	0.047	0.019	0.058	0.037	0.098	0.045	0.061	0.0257

Table (8) Matrix of correlation between the air quality index, meteorological elements, and air pollutants in the city of Baghdad for the total study period for the year 2020 The Peterson matrix correlation was used to calculate the relationships among air pollutants and meteorological parameters. The results indicated that the correlation coefficient confirms the results mentioned above in the table. The AQI index in Baghdad city illustrated the lowest values during the period of partial and total closure. According to the previously mentioned, the air quality index showed the lowest daily concentrations of air pollutants, which led to an overall improvement in air quality due to the citizens' commitment to the guidelines, the reduction of the use of public transportation, the closure of universities and schools, and restrictions imposed on the movement of employees. These professional precautions contributed greatly to the decrease in air pollutants and gas emissions in the city of Baghdad.

Table 8. correlation matrix between AQI and air pollutant and meteorological elements in Baghdad city for the overall study period (2020).

2020	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**CO**	**NO_2**	**SO_2**	**SR**	**Temp**	**RH**	**WS**	**WD**
AQI	0.030	0.020	0.096	0.046	0.066	0.053	0.043	0.070	0.073	0.018	0.008

Table 9, Correlation matrix among the air quality index, meteorological elements, and air pollutants in Baghdad city for the total study period (2021) Location-to-site air quality varies greatly daily, even with constant daily emissions due to meteorological standards. The air quality in the region is greatly affected by the atmospheric parameters mentioned below. The results showed that the correlation coefficient between the air quality index and the meteorological variables had a weak relationship with the concentrations of pollutants (PM_{10}-$PM_{2.5}$-O_3-CO-NO_2-SO_2), according to the table below, and a weak relationship with meteorological parameters.

Table 9. correlation matrix between AQI and air pollutant and meteorological elements in Baghdad city for the overall study period (2021).

2021	**PM_{10}**	**$PM_{2.5}$**	**O_3**	**CO**	**NO_2**	**SO_2**	**SR**	**Temp**	**RH**	**WS**	**WD**
AQI	0.031	0.07	0.011	0.014	0.011	0.096	0.083	0.043	0.059	0.018	0.011

3.11 Air quality index forecasting for Baghdad city

Air quality Model estimations provide two purposes. First, they confirm what scientists already know about the processes in the atmosphere that affect how air quality varies over time. They also assist authorities in monitoring the quality of the air to which the inhabitants and the natural environment are exposed. For the protection of public health and the environment, atmospheric and climate sciences are revealed. Authorities are able to minimize or mitigate short-term pollution peaks because of the knowledge provided by the predictive models. These methods primarily consist of restricting pollutant emissions through restrictions on traffic (automotive, maritime, and airport), industrial activities (goods manufacturing, energy production, etc.), or home activities (particularly heating). Forecasting models also make it possible to conduct permanent monitoring, which can serve as a guide for public policy regarding the planning of land use to take into account and enhance air quality. Pollutants are being considered in the planning stages of new construction projects. Predictive models can be a helpful resource for weighing potential outcomes from a number of different scenarios. In the present part of this research work, multi-linear regression methods have been utilized in order to create two empirical equations. The first involves particulate matter with a tow size of 2.5 and 10 microns, whereas the second empirical equation depends on the concertation of the gases considered in the present study. These proposed equations have been evaluated using the statistical indicators, which include r, MAE, MAPE, and RMSE, as tabulated in Table 10, where equation 1 is superior to equation 2 according to the employed statistical indicators, which showed the highest r (0.95) and lowest MAE, MAPE, and RMSE (27.5, 13.5, and 34.38), respectively, and this indicates that particulate matters are more effective on AQI than considered gas concentrations in the preset thesis, as show as Figure 8.

$$AQI = -41.13 + 3.41PM2.5 + 0.337PM10 \quad (1)$$

$$AQI = 3.011 + 3.33PM2.5 + 0.357PM10 - 4.237CO - 0.153O3 + 0.0199NO2 + 0.183SO2 \quad (2)$$

Table 10. summery evaluation of the empirical proposed equations according the statistical indicators.

Mathematical expression	**r**	**MAE**	**MAPE**	**RMSE**
Equation (1)	0.95	27.5	13.5	34.38
Equation (2)	0.89	29.6	23.4	35.5

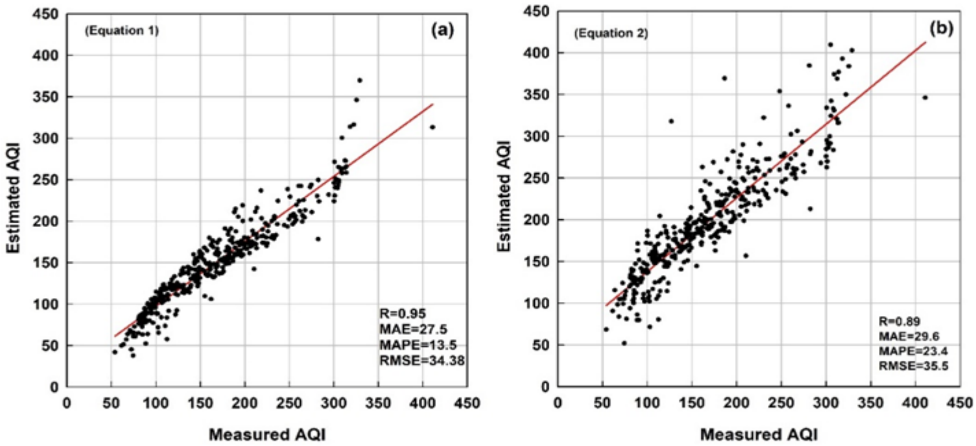

Figure 8. Scatter plot of the measured and estimated AQI using empirical equations.

3.12 Evaluation of the Air Quality Index

In final part of this chapter, we have to make some comparisons between the AQI measured by the air pollution station installed above the roof of the Atmospheric science department /Mustansiriyah University and the AQI estimated by the developed equations (1 and 2) for the available AQI during the last six months includes the period from march to Augusts 2023. Figure 9 show the results of these comparisons between the AQI measured by the air pollution station installed above the roof of the Atmospheric science department /Mustansiriyah University and the AQI estimated by the developed equations (1) and (2) respectively. It is seen that measured and estimated values of daily AQI are comparable and relatively matching according to the statistical analyses for these comparisons were carried out as tabulated in Table 11.

Table 11. summery evaluation of the empirical proposed equations and Mustansiriyah air pollution station data according the statistical indicators.

Mathematical expression	r	MAE	MAPE	RMSE
Equation (1)	0.93	20.8	11.6	37.30
Equation (2)	0.91	26.9	19.8	33.12

The correspondence between estimated and measured AQI is also illustrated by the scatter plots in Figure 10 (a, b). It can be seen from this figure that the estimated values are in good agreement with the measured values, and the correlation coefficients are significant at 0.01 levels and have a value of (0.93 and 0.91), respectively. Finally, from the results and presented measured and estimated values of AQI for the two proposed equations (1, 2), in order to estimate AQI, other regions or locations in Iraq can be considered based on particulate matter and available concentrations of CO, O_3, NO_2, and SO_2.

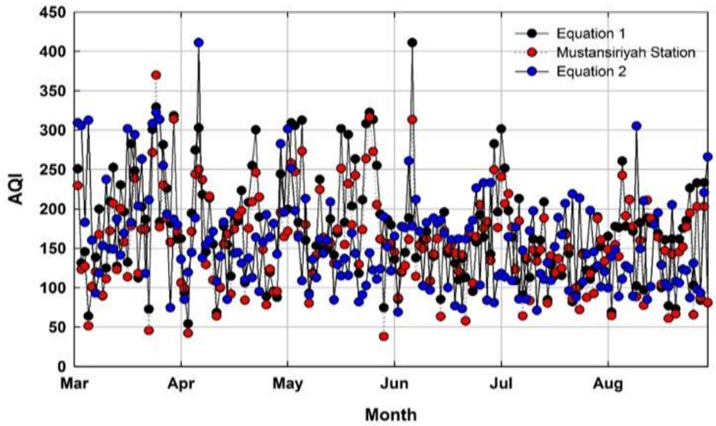

Figure 9. Scatter plot of the measured & estimated AQI using empirical equations.

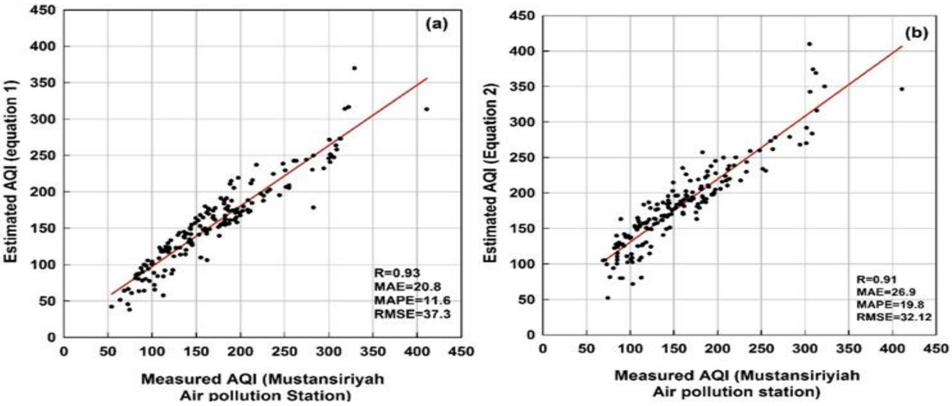

Figure 10. Scatter plot of the measured (Mustansiriyah air pollution station) and estimated AQI using empirical equations.

3.13 Air Quality Index Calculator Application

In order to facilitate present research work with datasets and automatic extraction of the results, an application was designed for this purpose. Programmed by employing Ms. Access ver.16 software. The present application with a via a simple interface as shown in Figure 11 which provides the capability to estimate the AQI. The present application provides two procedures the first based on tow data input includes (PM_{10} and $PM_{2.5}$) as shown in fig (3.10), whereas the second procedure employ six data set inputs includes (PM_{10} and $PM_{2.5}$, NO_2, O_3, SO_2 and CO). data processing operations carried out thought two equations that have been developed by multiply linear regression algorithms.

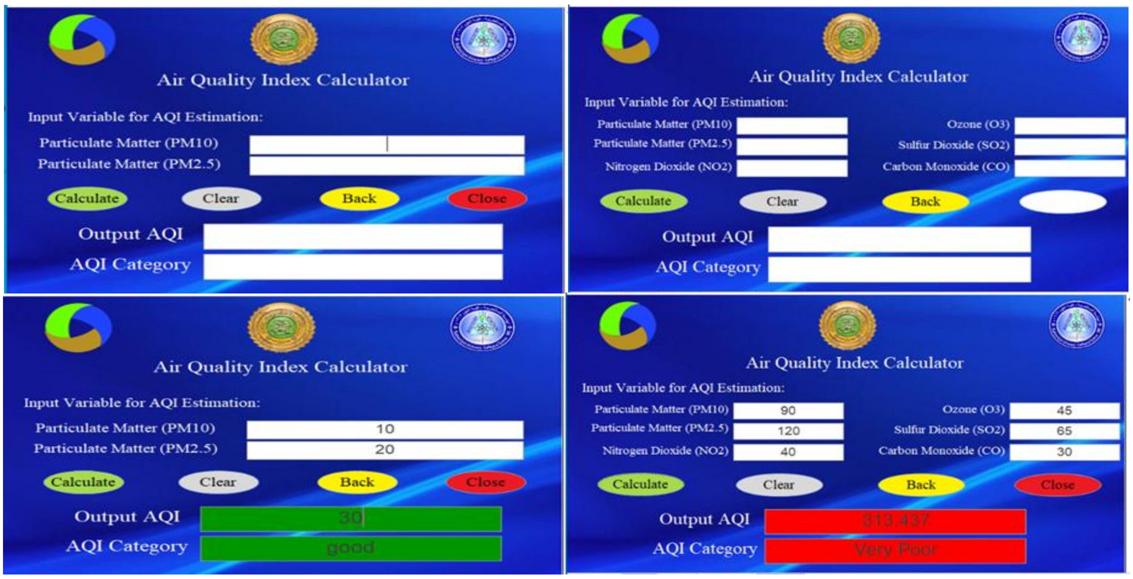

Figure 11. AQI calculator application basic interface, first and second input procedure interfaces, output interfaces.

4. Conclusions

The study presents two empirical formulas for quantifying the Air Quality Index (AQI), emphasizing the importance of particulate matter in influencing air quality. The primary determinant of the first equation is the concentration of particulate matter, specifically $PM_{2.5}$ and PM_{10}. However, the second equation incorporates other gases, including CO, O_3, NO_2, and SO_2. Based on a statistical study of both equations, it has been shown that the first equation exhibits superior performance in terms of correlation (r), average absolute error (MAE), average percentage error (MAPE), and root mean square error (RMSE) when compared to the second equation. The results of the study indicate that particulate matter, specifically $PM_{2.5}$ and PM_{10}, exerts a more significant influence on the Air Quality Index (AQI) compared to the concentrations of the gases under consideration, namely carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). Equation 1 has a stronger correlation and lower error metrics due to its focus on particulate particles. Statistical Assessment: In order to assess the efficacy of the empirical equations, this study used statistical markers such as the correlation coefficient (r), mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean square error (RMSE). Equation (1) has superior performance over Equation (2) in predicting AQI due to its higher correlation coefficient (0.95) and lower error metrics (MAE, MAPE, and RMSE). The practical implementation of the concept is of significant importance. The findings of the study may have potential implications for the management and regulation of air quality. Equation (1) can serve as a reliable method for estimating the air quality index by considering particulate matter concentrations. This can potentially enhance the effectiveness of air quality monitoring efforts, owing to its superior predictive capacity. During the period spanning from March to August 2023, a comparative analysis was conducted between the air quality index (AQI) derived from your formulated equations and the AQI data obtained from the Air Pollution Station. Equations (1) and (2) had correlation coefficients over 0.90 and displayed error measures of relatively diminutive magnitude, suggesting a strong concordance with the observed values. In summary, this study provides valuable insights into the air quality of Baghdad city from 2019 to 2021. This study showcases the capacity to accurately predict the air quality index through the utilization of empirical equations. It underscores the importance of particulate matter, particularly PM2.5, in influencing the air quality within the specified region. The aforementioned findings possess potential utility in the regulation and surveillance of air quality in Baghdad, as well as in other locations experiencing similar air quality challenges.

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