Assessing Health Impact of Air Pollutants in Five Iraqi Cities Using AirQ+ Model

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Abstract. Concentration of air pollutants CO, NO₂, SO₂, O₃, PM10, PM2.5 in four Iraqi cities (Al-Najaf, Al-Muthanna, Maysan, Kirkuk) and PM2.5 in Baghdad city were monitored and analysed for the period September 1, 2019 to August 31, 2020. The results showed that the daily mean concentration of CO, NO₂ for the four cities are well below the WHO air quality standard. In general, PM2.5 and PM10 concentrations are the factors that govern the air quality index in Iraqi cities under consideration. It is clear that, for all the cities under consideration, the daily AQI is mostly “Moderate” and to a less extent “Unhealthy for sensitive groups”. However, there are 53 days for Al-Muthanna (mainly due to PM10) and 58 days for Baghdad (due to PM2.5 alone) in which the AQI is “Unhealthy”. Moreover, there are another 53 days for Al-Muthanna in which the AQI is “Hazardous”. So, the air quality in Al-Muthanna and Baghdad can be considered lower than that in other cities. Indeed, this is attributed to dust storms in Al-Muthanna and high population of Baghdad city and consequently higher air pollutants emissions due to their industrial, transportation and electric generation activities. AirQ+ software was used to assess public health consequences of long term exposure to PM2.5 in terms of relative risk (RR). RR of acute lower respiratory disease, chronic obstructive pulmonary, mortality by lung cancer, ischemic heart disease, mortality by stroke for the five cities were assessed. RR of mortality by lung cancer due to exposure to PM2.5 in Baghdad is the highest among the cities under consideration. RR₉₅ = 1.25 (95% CI = 1.14 – 1.4).

Keywords. Air pollution, Air quality index, AirQ+, PM2.5

1. Introduction
Clean air is considered a basic requirement of human health and well-being. However, air pollution continues to pose a significant threat to health worldwide. According to an assessment by the World Health Organization (WHO) concerning the burden of disease, including heart or lung disease and respiratory damage due to air pollution, more than 2 million premature deaths each year are attributed to the effects of urban outdoor air pollution and indoor air pollution. More than half of this disease burden is borne by the populations of developing countries.[1] Moreover, air pollutants can cause environmental effects such as smog, acid rain, radiation, ozone depletion, and property damage.[2,3] The sources of air pollution are the emissions from motor vehicles, industrial processes, power generation, the household combustion of solid fuel…etc.. The precise chemical and physical features of ambient air pollution, which comprise a myriad of individual chemical constituents, vary around the
world due to differences in the sources of pollution, climate, and meteorology. However, normally, the mixtures of ambient air pollution invariably contain specific chemicals known to be carcinogenic to humans.[4] All over the world, common ambient air pollutants include particulate matter (PM10 and PM2.5), ozone, carbon monoxide, sulphur dioxide and oxides of nitrogen.[5] Particulate matter represents a good index for other air pollutants. Its impact on public health is more effective than other pollutants. Normally, particulate matter consists of solid and liquid particles. Chemically it is composed of sodium chloride, nitrate, sulfate, ammonia, black carbon, organic compounds, dust and water. Regarding health effect, two particulate matter categories are considered: PM10 particles with a diameter of 10 microns or less, and PM2.5 with a diameter of 2.5 microns or less. PM2.5 has much adverse health effects since they can penetrate deeply inside the lungs, and reach the blood circulation system. In general, long term exposure to air with low particles concentration may cause many cardiovascular and respiratory diseases, such as lung cancer.[6,7] Exposure to ambient fine particles (PM2.5) was recently estimated in 2010 to have contributed to 3.2 million premature deaths worldwide due to, largely, cardiovascular disease, and 223,000 deaths from lung cancer. More than half of the lung cancer deaths attributable to ambient PM2.5 are in China and other East Asian countries.[4] PM2.5 is emitted from natural and anthropogenic sources. In urban areas, PM2.5 is normally associated with local emissions from automobile exhausts. This is not only the most important source of urban PM2.5, but also the main source of secondary particles in the atmosphere through chemical transformation (gas-to-particles).[8] In Iraq, both transportation and electric power generation (especially local generators) sectors contribute to air pollution significantly, causing high environmental problems.[9] Moreover, the continual burning of oil field co-produces natural gas resulting in high levels of emissions which are linked to the deterioration of air quality in Iraq. The worsening of air quality is also linked to the use of low quality fuel in transportation, power generation and the industrial sectors; emissions from industrial facilities; dust storms; open burning of waste and the increase of illegal logging. Baghdad is regarded as the second largest city in the Middle East. It suffers from severe air quality degradation due to the high levels of the atmospheric particulate matter (PM). In fact, there is a limited information regarding the sources of PM in this city. Accordingly, the lack of information hinders the development of control strategies that would reduce air pollution.[10, 11] To report the daily air quality, Air Quality Index (AQI) was used. It indicates how clean or unhealthy the air is, as well as the possible health effects that should be be considered during a few hours or days of breathing polluted air. Usually, criteria air pollutants are considered when calculating AQI. They include ground level O3, PM2.5, PM10, CO, NO2 and SO2. For each of these pollutants, WHO and EPA have developed air quality standards to protect public health.[12] AQI is a piecewise linear function of the pollutant concentration. If multiple pollutants are measured at a monitoring site, then the largest or "dominant" AQI value is reported for the location. To assess the impact of exposure to air pollutants on public health, WHO has developed the AirQ+ model. Many studies have used this model to assess the risk that resulted from exposure to particulate matter in different cities, such as Cairo, Makkah and Athens. The output results of such studies hugely affect the policy making and urban planning.[13,14,15]. The aim of this study is to analyze the variation of air pollutants CO, NO2, SO2, O3, PM10 and PM2.5 concentrations in five Iraqi cities for a period of one year, from September 1, 2019 to August 31, 2020, and to assess their public health consequences using AirQ+ software in terms of relative risk.

2. Materials and methods

2.1. Study area

The study area of the present paper covers five Iraqi cities: Al-Najaf, Al-Muthanna, Maysan, Kirkuk and the Capital Baghdad as shown in Figure 1. Their projected populations as of 2019 were 1510338, 835797, 1141966, 1639953 and 8340711, respectively.[16] Regarding Al-Najaf and Al-Muthanna, the most important emission source of air pollution is dust storms. Oil production industry is the main source of air pollution in Maysan and Kirkuk. Emissions from electric power generation, Al-Dura oil refinery and motor vehicles are the main sources of air pollution in Baghdad.
2.2. AirQ+ software

In this model, evaluation is carried out by using AirQ+ software (WHO regional office for Europe) based on the Relative Risk (RR) estimation that reflects the magnitude of an association between exposure and disease. RR indicates the likelihood of developing the disease in the exposed group, PDE, relative to those who are not exposed, PDU. This likelihood is equal to PDE/PDU. Relative Risks due to air pollution are modeled with the function,

$$RR = \exp(\beta(x-x_0))$$  \hspace{1cm} (1)

Where; $X$ is the pollutant concentration ($\mu g/m^3$), and $X_0$ is the cut-off or counterfactual, for example the background concentration or the lowest achievable value is ($\mu g/m^3$). In the log-linear model, $\beta$ denotes the change in the RR for a one-unit change in concentration $X$.[17] It should be mentioned that the use of RR, obtained from AirQ+ model and developed for Europe in regions other than Europe, may increase the prediction error of the model. However, it provides the decision makers and officials with useful information concerning the impact of air pollutants in the study in order to minimize the health effects by applying necessary management.[18]

2.3. Air pollution data monitoring

In this study necessary daily mean of air pollutants concentrations for the period September 1, 2019 to August 31, 2020 were obtained from Air Matters- the Global Air Quality Service Provider.[19] These data are based on hourly mean (24 hr/day) air quality measurements done by ground stations.

3. Results and discussion

3.1. Concentration of different pollutants

Figure 2 shows the variation of CO daily mean concentration for different Iraqi cities under consideration. It is clear that the concentration of CO for all these cities did not exceed 380 $\mu g/m^3$, for all days, which is very well below the WHO air quality standard (35 mg/m3, 1 hour mean, 7 mg/m3, 24 hour mean).[20] Thus maximum and minimum annual mean concentrations were observed in Kirkuk (197.93 $\mu g/m^3$) and Al-Muthanna (126.12 $\mu g/m^3$), respectively as in Table (1). This can be attributed to the existence of emissions from oil production industry in Kirkuk and the absence of a major industrial emission source in Al-Muthanna. Higher concentrations were observed during late autumn and winter seasons which may be attributed to more fuel consumption for indoor heating.
Figure 2. CO daily mean concentration variation with time for different Iraqi cities.

Figure 3 shows the variation of NO2 daily mean concentration for different Iraqi cities under consideration. It is clear that the concentration of NO2 for all these cities did not exceed 80 µg/m3, for all days, which is well below the WHO air quality standard (200 µg/m3, 1 hour mean and 40 µg/m3 annual mean).[1] In general, maximum and minimum annual mean concentrations were observed in Al-Najaf (17.22 µg/m3) and Al-Muthanna (4.47 µg/m3), respectively as in Table (1). Higher concentrations were observed during late autumn and winter seasons. They may be attributed to fuel consumption by electric power plants during this period.

Figure 3. NO2 daily mean concentration variation with time for different Iraqi cities.

Figure 4 shows the variation of SO2 daily mean concentration for different Iraqi cities under consideration. It is clear that the concentration of SO2 for all cities did not exceed 235 µg/m3 which is higher the WHO air quality standard (20 µg/m3, 24 hour mean and 500 µg/m3, 10 min mean) for all days.[1] However, it is lower than EPA air quality standard [75 ppb (196.5 µg/m3), 1 hour mean and 500 ppb (1,310 µg/m3), 3 hour mean except for 12 Nov 2019 in Al-Najaf.[2] In general, maximum and minimum annual mean concentrations were observed in Al-Najaf (31.5 µg/m3) and Maysan (8.64 µg/m3), respectively as in Table (1). Higher concentrations were observed during late autumn and winter seasons. They may be attributed to more fuel consumption for indoor heating.

Figure 4. SO2 daily mean concentration variation with time for different Iraqi cities.

Figure 5 shows the variation of O3 daily mean concentration for different Iraqi cities under consideration. It is clear that the concentration of O3 for all cities did not exceed 104 µg/m3 which is below the WHO air quality standard (100 µg/m3, 8 hour [2] except 11 days in Al-Najaf, 16 days in Al-Muthanna, 86 in Maysan and 28 days in Kirkuk. In general, maximum and minimum annual mean concentrations were observed in Maysan (81.09 µg/m3) and Kirkuk (65.55 µg/m3), respectively as in Table (1). A clear sinusoidal trend is shown in Figure 5 with peak occurrence in summer, and minimum occurs in winter. This trend is the result of the variation of sun light intensity during seasons, taking
into consideration that O3 is generated naturally from the reaction of volatile organics compounds with NO2 in air in presence of sun light.

![Figure 5. O3 daily mean concentration variation with time for different Iraqi cities.](image)

Regarding particulate matter PM10, Figure 6 shows the variation of PM10 daily mean concentration for different Iraqi cities under consideration. It is clear that the concentration of PM10 for all cities exceeded the WHO air quality standard (50 µg/m³, 24 hour mean and 20 µg/m³, annual mean).[2] However, it is lower than EPA air quality standard (150 µg/m³, 24 hour mean) except 107 days in Al-Najaf, 202 days in Al-Mathanna, 45 days in Maysan and 128 days in Kirkuk throughout the study period (mostly occurred during spring season) as in Table (1).

![Figure 6. PM10 daily mean concentration variation with time for different Iraqi cities.](image)

Figure 7 shows the variation of PM2.5 daily mean concentration for different Iraqi cities under consideration. It is clear that the concentration of PM2.5 for all cities exceeded the WHO air quality standard (25 µg/m³, 24 hour mean and 10 µg/m³ annual mean) [2] and also exceeded EPA air quality standard (35 µg/m³, 24 hour mean and 12 µg/m³ annual) for 102 days in Al-Najaf, 120 days in Al-Mathanna, 100 days in Maysan, 112 days in Kirkuk and 188 days in Baghdad throughout the study period (mostly occurred during winter season).

![Figure 7. PM2.5 daily mean concentration variation with time for different Iraqi cities.](image)

Table 1 summarizes the mean values of different pollutants concentration over the period of twelve months under study and number of days in which these concentrations exceeded their air quality standard value. It is clear that PM10 & PM2.5 are the most frequently pollutant exceeded its air quality standard value in comparison with other pollutants. However, it should be noted that PM2.5 has much more adverse effects on public health than PM10. In Baghdad PM2.5 concentration exceeded (35 µg/m³) for 188 days during the study period. So, PM10 and PM2.5 concentration are the lonely factors governing the air quality index in the cities under consideration. Figure 8 shows the
daily mean PM2.5 concentration frequency distribution. It is clear from this figure that, excluding Baghdad, the peak values of the frequency distribution occurred at 30 µg/m³. For Baghdad the peak value occurred at 40 µg/m³ which is higher than PM2.5 air quality standard. It seems that the lognormal distribution is the most appropriate tool to represent the PM2.5 distribution.

Table 1. The annual mean values of pollutants concentration over the study period (µg/m³) / number of days exceeding the air quality standard values for different Iraqi cities.

| City       | AQI | PM2.5 | PM10 | SO2  | NO2   | O3    | CO    |
|------------|-----|-------|------|------|-------|-------|-------|
| Al-Najaf   | 99.45 | 32.19/102 | 128.91/107 | 31.50/1 | 17.22/0 | 65.81/11 | 186.45/0 |
| Al-Muthanna| 154.96 | 33.25/120 | 219.70/202 | 13.09/0 | 4.47/0  | 75.19/16 | 126.12/0 |
| Maysan     | 94.40  | 31.95/100 | 102.88/45  | 8.64/0  | 4.61/0  | 81.09/86 | 163.69/0 |
| Kirkuk     | 105.93 | 32.41/112 | 146.99/128 | 8.87/0  | 12.40/0 | 65.55/28 | 197.93/0 |
| Baghdad    | 109.79 | 41.20/188 | |

Table 2 shows the frequency distribution of AQI categories for different Iraqi cities. It is clear that for all the cities under consideration, the AQI is mostly “Moderate” and to a less extent “Unhealthy for sensitive groups”. However, there are 53 days for Al-Muthanna (mainly due to PM10) and 58 days for Baghdad (due to PM2.5 alone) in which the AQI is “Unhealthy”. Moreover, there are another 53 days for Al-Muthanna in which the AQI is “Hazardous”. So, the air quality in Al-Muthanna and Baghdad can be considered lower than that in other cities which can be attributed to dust storms in Al-Muthanna and high population of Baghdad and consequently higher air pollutants emissions due to their industrial, transportation and electric generation activities.

Figure 8. PM2.5 daily mean concentration frequency distribution for different Iraqi cities.
Table 2. Frequency distribution (days) of different categories of AQI for different Iraqi cities.

|                | Al-Najaf | Al-Muthana | Maysan | Kirkuk | Baghdad |
|----------------|----------|------------|--------|--------|---------|
| Good           | 2        | 6          | 0      | 2      | 4       |
| Moderate       | 237      | 160        | 261    | 218    | 168     |
| Unhealthy for sensitive groups | 101      | 83         | 93     | 108    | 134     |
| Unhealthy      | 21       | 53         | 12     | 31     | 58      |
| Very unhealthy | 2        | 12         | 0      | 2      | 1       |
| Hazardous      | 3        | 53         | 0      | 5      | 1       |

The correlation coefficient between time series of daily AQI for different Iraqi cities is shown in Table 3. Relatively good correlation exists between AQI in Al-Najaf and Al-Muthanna which can be attributed to the geographic location of the two cities adjacent to the Iraqi western desert and consequently the domination of dust storms as the main source of air pollution with particulate matter.

Table 3. Correlation coefficient between AQI’s for different Iraqi cities.

|                | Al-Najaf | Al-Muthana | Maysan | Kirkuk | Baghdad |
|----------------|----------|------------|--------|--------|---------|
| Al-Najaf       | 1        | 0.81976    | 0.13871| 0.16856| 0.37866 |
| Al-Muthana     | 1        |            | -0.13184| -0.01199| 0.12242 |
| Maysan         | 1        | 0.51446    |        |        |         |
| Kirkuk         | 1        | 0.34845    |        |        |         |
| Baghdad        | 1        |            |        |        |         |

3.2. Assessing health impact of PM2.5

By using AirQ+ software, the long term exposure relative risk (RR) due to PM2.5 at different Iraqi cities under consideration was obtained. The mean value of PM2.5 concentration over the study period (Table 1) was used. Default values for β and Xo in Eq.(1) were used as given by the AirQ+ software. Figure 9 presents the RR due to acute lower respiratory disease (ALRI) for Children (0-5 years) as predicted by the AirQ+ software for different Iraqi cities. Due to the exposure to relatively high PM2.5 mean concentration in Baghdad city, there is relatively high RR. For Baghdad, RRALRI = 1.4 (95% CI=1.27-1.57), where CI is confidence interval, while for Maysan for example, RRALRI = 1.33 (95% CI = 1.15 – 1.55).

![Figure 9](image)

Figure 9. Relative risk of mortality due to ALRI for children (0–5 years).

Regarding attribute cases of chronic obstructive pulmonary (COPD) for Adults (30+ years) due to PM2.5 exposure, Figure 10 shows that for Baghdad, RRCPD = 1.37 (95% CI = 1.18 – 1.64) and for Maysan, RRCPD = 1.31 (95% CI = 1.15 – 1.55).
Figure 10. Relative risk of mortality due to COPD for adults (30+ years).

Figure 11 shows the RR of mortality due to lung cancer (LC) for Adults (30+ years) as a result of the exposure to PM2.5 for different Iraqi cities. RR in Baghdad is the highest among the cities under consideration. For Baghdad, RRLC = 1.25 (95% CI = 1.14 – 1.4), while the lowest RR is for Maysan, RRLC = 1.2 (95% CI = 1.11 – 1.32).

Figure 11. Relative risk of mortality due to LC for adults (30+ years).

Regarding attribute cases of ischemic heart disease (IHD) for Adults (25+ years) due to PM2.5 exposure, Figure 12 shows that for Baghdad, RRIHD = 1.6 (95% CI = 1.26 – 2.09) and the lowest is for Maysan, RRIHD = 1.54 (95% CI = 1.23 – 1.96).

Figure 12. Relative risk of mortality due to IHD for adults (25+ years).
Figure 13 shows the RR of mortality due to stroke for Adults (30+ years) as a result of exposure to PM2.5 for different Iraqi cities. RR in Baghdad is the highest among the cities under consideration. For Baghdad, \(\text{RR}_{\text{Stroke}} = 1.42\) (95% CI = 1.16 – 1.79), while the lowest is for Maysan, \(\text{RR}_{\text{Stroke}} = 1.37\) (95% CI = 1.13 – 1.68).

![Figure 13. Relative risk of mortality due to stroke for adults (30+ years).](image)

4. Conclusion and recommendations

4.1. Conclusions

The results of this study reveal the following:

- PM10 and PM2.5 are the most frequently air pollutants exceeding their air quality standard value in comparison with other pollutants.
- PM10 and PM2.5 concentrations are the main factors governing the air quality index in Iraqi cities under consideration.
- It should be noted that PM2.5 has much more adverse effects on public health than PM10. In Baghdad, PM2.5 concentration exceeded (35 \(\mu g/m^3\)) for 188 days during the study period.
- It is clear that for all the cities under consideration, the AQI is mostly “Moderate” and to a less extent “Unhealthy for sensitive groups”.
- There are 53 days for Al-Muthanna (mainly due to PM10) and 58 days for Baghdad (due to PM2.5 alone) in which the AQI is “Unhealthy”. Moreover, there are another 53 days for Al-Muthanna in which the AQI is “Hazardous”.
- The air quality in Al-Muthanna and Baghdad can be considered lower than that in other cities which can be attributed to dust storms in Al-Muthanna and high population of Baghdad. Consequently, the higher air pollutants emissions are due to their industrial, transportation and electric generation activities.
- AirQ+ software was used for the RR estimation as it reflects the magnitude of the association between exposure and disease.
- RR of mortality by LC due to the exposure to PM2.5 in Baghdad is the highest among the cities under consideration. For Baghdad, \(\text{RR}_{\text{LC}} = 1.25\) (95% CI = 1.14 – 1.4). However, the lowest RR is for Maysan, \(\text{RR}_{\text{LC}} = 1.2\) (95% CI = 1.11 – 1.32). These values of RR are significant, and measures should be taken by decision makers to reduces air pollution.

4.2. Recommendations

- Measures should be taken to reduce the exposure to PM10, resulting from dust storms for all the cities under consideration and especially Al-Muthanna by implementing green belts strategy.
• Measures should be taken to reduce the exposure to PM2.5 resulting from all sources for all the cities under consideration and especially Baghdad by:
  
  - Implementing better transport sector strategy that reduces the number of vehicles by considering public transport instead of private cars.
  - Using natural gas instead of low grade oil as fuel in electric power generation plants.
  - Reducing the number and the collective capacity of the small scale private electric power generation units by depending on central electric generation power plants.
  - Controlling the pollutants emitted from oil production and refining industry especially in Kirkuk and Mysan.

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