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Assessment of Ambient Air Quality of Mosul City/Iraq Via Air Quality Index

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ABSTRACT

The research aimed to assess air quality in Mosul city (Iraq) using air quality index (AQI). The data were collected at six monitoring sites using two stations, one fixed and the other is mobile type. The concentrations of CO, NO_2, O_3, SO_2 and PM_{10} were measured. The daily AQI were calculated for each site and classified to AQI categories according to USEPA approach. The dominant AQI category at the public library site fluctuated between "Moderate" to "Unhealthy for Sensitive Groups". AQI undergoes seasonal variation with lower value at March. The results showed that PM_{10} is the main contributor for AQI determination in Mosul city with 93.8%. CO has no contribution to Mosul AQI. SO_2, O_3 and NO_2 have little contribution to Mosul AQI with 0.8%, 2.7% and 2.7% respectively. The annual mean of AQI in the public library site/ Mosul city is 96 in the category "Moderate. The worst site was Mosul municipality (old location) with a dominant category "Unhealthy for Sensitive Groups".

Keywords: AQI, Mosul city, air quality, PM10, ozone, NO_2, SO_2, CO

INTRODUCT ION

Air pollution is an environmental threat associated with urban areas around the world. Epidemiological studies have linked between higher ambient levels of air pollutants and adverse health effects, such as respiratory, cardiovascular disease, coronary heart disease and mortality [Brook et al., 2012; Hoek et al., 2013; Achilleos et al., 2017]. Additionally, air pollution continues to present one of the world's biggest health hazards to people everywhere, contributing to about 7 million premature deaths annually [WHO 2020].

Numerous pollutants are monitored by each station and daily or hourly concentrations are collected in urban areas. As a results, air monitoring stations provide a large mass of data. Therefore, the presentation of these data to the population and their interpretation by public agencies is a difficult task. In addition, air quality is exhibited in different manners using different interpretation criteria, which is usually not clear. Therefore, a need is arise to make an index of air quality with respect to its effects on human health. A daily air quality index (AQI) has been suggested by Environmental Protection Agency (EPA) [1999] and the procedure was later updated and defined in terms of main air pollutants: Carbon monoxide (CO), Nitrogen dioxide (NO_2), Ozone (O_3), particulate matter (PM) and Silver dioxide (SO_2) [EPA, 1999; EPA, 2009].

Air Quality Index (AQI) is a valuable tool to indicate the levels of daily air pollutants from a public health point of view. It is an alert to the public in terms of health impact. AQI values varies from "0" to "500" and its value is proportional to the concentrations of the pollutants in the air. Thus, greater AQI indicates more serious health complications. The overall range is subdivided into six ranges to which six categories of air quality is relate (Table 1).

Many researchers had calculated AQI established by USEPA to analyze the daily air quality [Choi et al., 2015; Verma et al., 2016]. Mosul city as the largest population community in Northern Iraq, suffers from lack of air quality studies. This town includes 317000 vehicle and 3147 electrical generators. The importance of conducting this

Table 1. Categories of air based on air quality index [EPA 2009]

Air quality index range	Air quality condition	Color code
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for sensitive groups	Orange
151-200	Unhealthy	Red
201-300	Very unhealthy	Purple
>300	Serious	Maroon

study arises, as it will identify the category of air quality with respect to its effects on human health and presented in a clear manner. Air pollution has been studied in Mosul city. The earlier studies focused on dustfall and suspended particulate distribution of PM_{50} [Shihab et al., 2010; Shihab and Taha, 2014]. After that, Al-Jarrah [2015] conducted a study to identify the levels of pollutants concentrations within the largest population community in Northern Iraq, Mosul city. Furthermore, Shihab and Al-Jarrah [2015] investigated the levels of ozone and nitrogen oxides including their relationships with metrological factors. In Iraq, Mohamed et al. [2016] studied AQI in Kirkuk city/ Iraq, while Shehabalden and Azeez [2017] studied AQI in Basra province/ Iraq.

The objective of this research to use air quality index in analyzing air quality parameters in Mosul city for the first time.

MATERIALS AND METHODS

Study site

Mosul is a major city in Northern Iraq, serving as the capital of Nineveh Governorate. Approximately 400 km north of Baghdad, with an area of 180 km^2 and a population of 2,443,861 [Iraqi Ministry of Planning 2021]. Mosul lies on both the left bank (East side) and the right bank (West side) of the Tigris river. Mosul city has a semi-arid climate with extremely hot, prolonged, dry summer, mild autumn and spring and moderately wet cool winter. The dominant wind direction in the study area is NW with 17.2% calm conditions [Al-Jarrah 2015].

Air quality monitoring sites

The study includes six monitoring sites in Mosul city. Four sites at the left bank of the city: "Public Library", "Mosul Technical Institute", "Al-Shifaa Hospital" and "Mosul Yogurt Factory" and two sites at the right bank of the city: "Mosul Municipality (old location)" and "Directorate of Youth and Sport" (Figure 1). Two monitoring stations were used to collect concentrations of air quality pollutants. One station is stationary type Horiba (German made) at the public library site along the study period, while the other station is mobile type Teledyne (American made). The mobile station was moved among the sites except the public library site along the study period. These stations belongs to Ninavah Environment Directorate.

The concentrations of CO, NO_2, O_3, SO_2 and PM_{10} were measured. The devices in the station are calibrated automatically using span gases and zero gas. The measurements were conducted every three minutes and then the average of 30

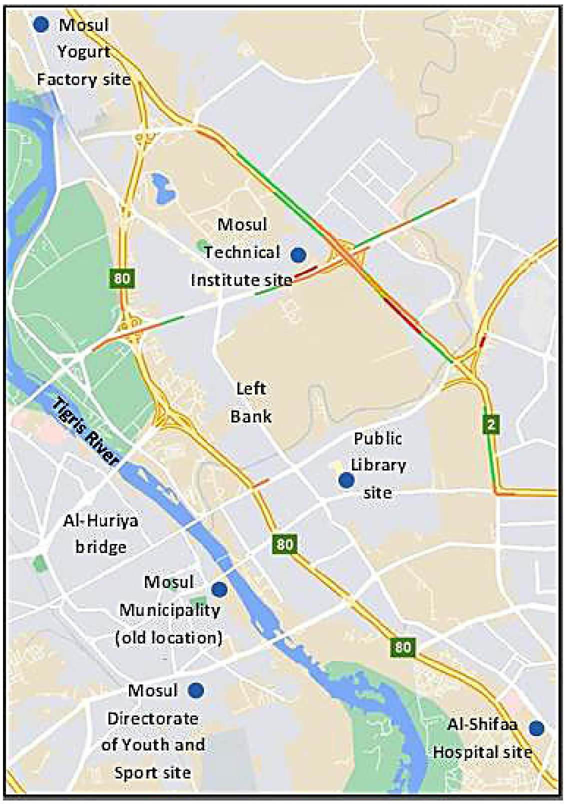

Figure 1. Air quality monitoring sites distributed on Mosul city map

minutes was calculated. The surveillance operation was continued from Feb 2013 till Jan 2014.

Air quality index

Air quality index (AQI) was calculated by using equation (1) which proposed by the USEPA (EPA, 2009).

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo} \quad (1)$$

where: I_p – the index of pollutant p,
C_p – the rounded concentration of pollutant p,
BP_{Hi} – the break point that is greater than or equal to C_p,
BP_{Lo} – the break point that is less than or equal to C_p,
I_{Hi} – the AQI value corresponding to BP_{Hi}
I_{Lo} – the AQI value corresponding to BP_{Lo}

The daily moving average according to the break point values must be calculated (CO 8 hr avg.), (NO_2 1 hr avg.), (O_3 8 hr avg.), (SO_2 1 hr avg.) and (PM_{10} 24 hr avg.) to be used in the calculation of AQI.

The value of the highest sub-indices AQI is considered the AQI of the site (eq. 2).

$$AQI = Max\left(I_{CO}, I_{NO_2}, I_{O_3}, I_{SO_2}, I_{PM_{10}}\right) \quad (2)$$

Statistical analysis

The daily AQI were analyzed statistically by calculating the descriptive statistics for each month: mean, median, minimum and maximum. The frequency and percentage of AQI categories were found for the studied sites. A comparison of AQI was conducted between the public library site and other sites using unpaired t-test.

RESULTS AND DISCUSSION

The trend of AQI in Mosul city at the public library site shows a decrease or an improvement in March 2013, followed by a gradual increase till September, AQI exhibited a decrease (Figure 2). In October and November, a slight increase occurred, followed by a decline in November and December and an increase in January 2014 (Winter). The decrease is due to the low concentration of PM_{10} with the growth of green cover in March, while the start of rainfall season in November and December improved AQI in this period. The pollutants sub-indices (Figure 3) illustrate clearly the prevalence of PM_{10} in deteriorating AQI among other pollutants along the study period. The main contributor to PM_{10} is the diesel vehicles like buses and trucks as this site is located at two way road-side. The improvement in AQI was also noticed at March in Baghdad city, the capital of Iraq [Hashim et al. 2021].

Table 2 shows that August is the most polluted month with 24 unhealthy days (AQI>100) all for PM_{10}. On the other hand, March recorded the lowest polluted month with 3 unhealthy days only for PM_{10}.

The monthly frequencies of AQI categories, for public library site where high vehicular traffic is present, are shown in Figure 4. The monthly frequency of the category “Good” varied between 0% to 45%. For the category “Moderate”, it fluctuated from 22.2% to 71.4%. The category

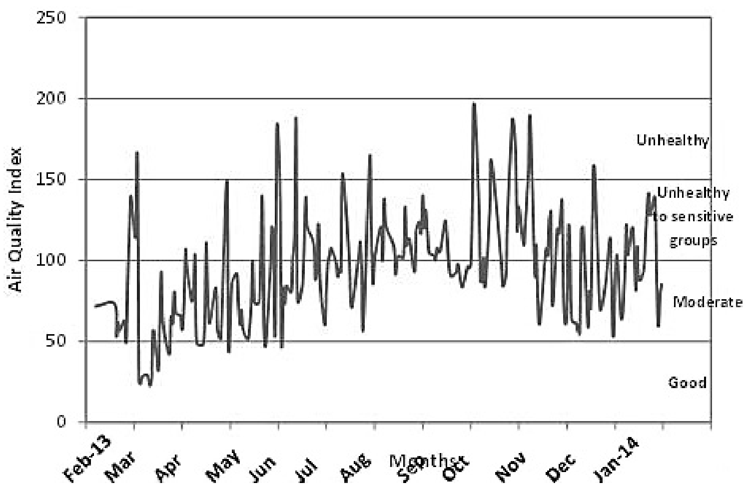

Figure 2. AQI along the study period in the public library site

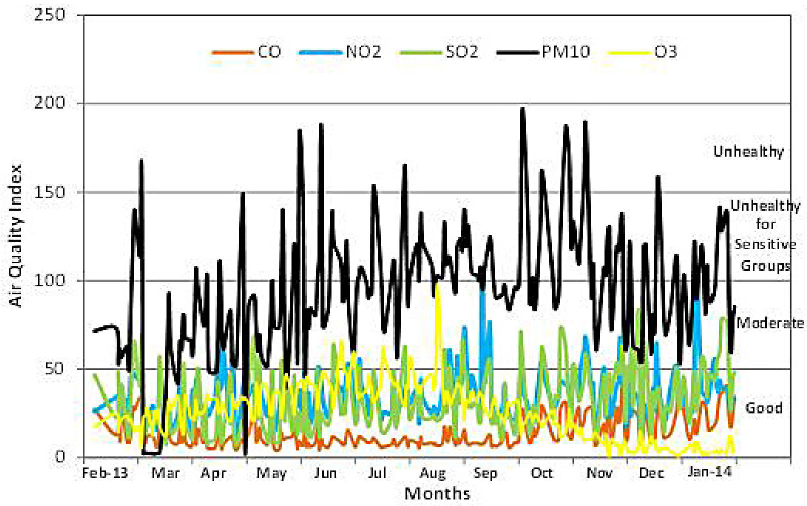

Figure 3. Daily variation of pollutants sub-indices along the study period in the public library site

Table 2. The number of unhealthy days (AQI >100) according to type of pollutant and month along the study period

Month	CO	NO_2	SO_2	O_3	PM_{10}	Total
Feb-13	0	0	0	0	6	6
Mar	0	0	0	0	3	3
Apr	0	0	0	0	8	8
May	0	0	0	0	7	7
Jun	0	0	0	0	13	13
Jul	0	0	0	0	14	14
Aug	0	0	0	0	24	24
Sep	0	1	0	0	15	16
Oct	0	0	0	0	20	20
Nov	0	0	0	0	22	22
Dec	0	0	0	0	10	10
Jan-14	0	2	0	0	14	16
Total	0	3	0	0	156	159

"Unhealthy for sensitive groups" varied between 5.0% to 77.8%, while the category "Unhealthy" varied between 0.0% to 28.6%. It seems that the dominance fluctuated between the categories "Moderate" and "Unhealthy for sensitive groups". These results justify the effect of vehicular traffic and the wind in this location.

For the mobile station located in Mosul yogurt factory site North of Mosul city at February and March, the category of AQI "Good" ranged between 42.1% to 46.7%. The category "Moderate" varied between 42.1% to 53.3%. On the other hand, the categories "Unhealthy for sensitive groups" and "Unhealthy" varied from 0% to 10.5% and 0.0% to 5.3% respectively. It looks like the dominance shared between the categories "Good" and "Moderate" (Figure 5).

In Al-Shifaa Hospital site, South Mosul city, the category "Good" varied between 0.0% to 16.7% (Figure 5). On the other hand, the category "Moderate" fluctuated from 5.3% to 61.1%. The frequency of AQI category "Unhealthy for sensitive groups" ranged between 22.2% to 42.1%. The other categories of AQI: "Unhealthy", "Very Unhealthy" and "Hazardous" all appear in this site with frequency percentages 0–31.6%, 0–15.8% and 0–5.3% respectively with unclear dominance for any category, while these results showed that air quality in this site was poor.

For the results of air quality at Mosul Technical Institute site (Figure 5), the frequencies of category "Good" varied between 20.0–31.5% versus 42.1–75.0% for "Moderate". Furthermore, the category "Unhealthy" has a frequency of 5.0%. The other categories were not found. The dominance was for the category "Moderate" in this site at April and May. For Mosul Municipality (old location) site, the category "Good" appears only in December with a frequency of 5% (Figure 6). The categories "Moderate", Unhealthy for sensitive

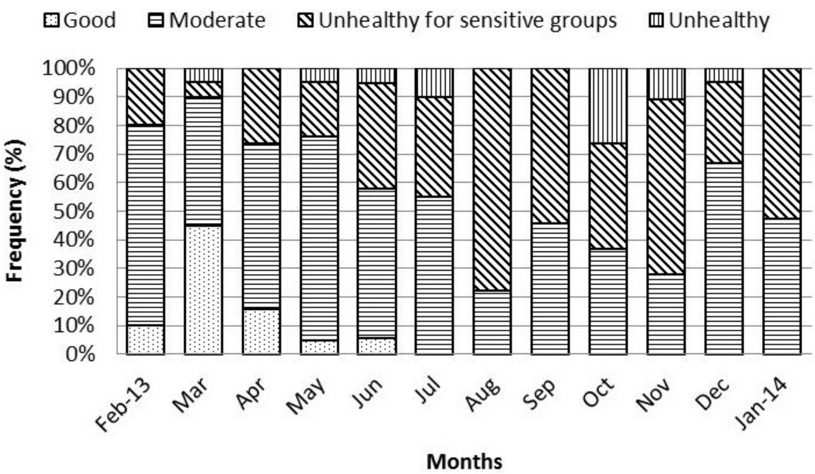

Figure 4. Monthly frequencies of AQI categories in public library site

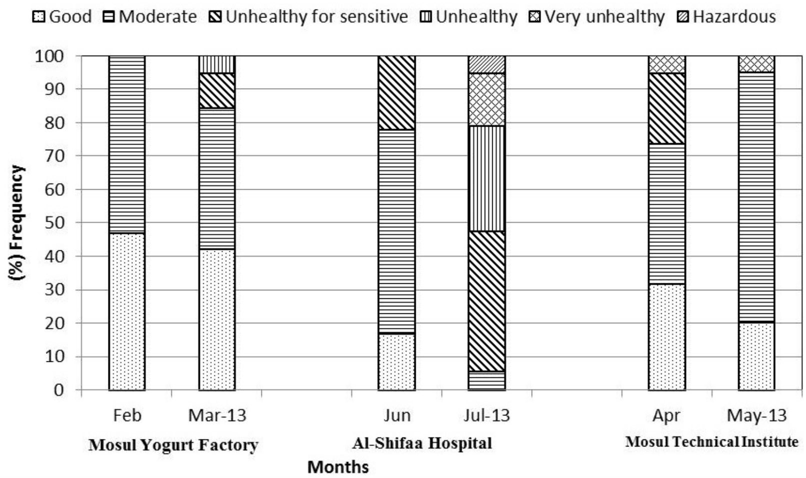

Figure 5. The monthly frequencies of AQI categories in the sites Mosul yogurt factory, Al-Shifaa hospital and Mosul technical institute

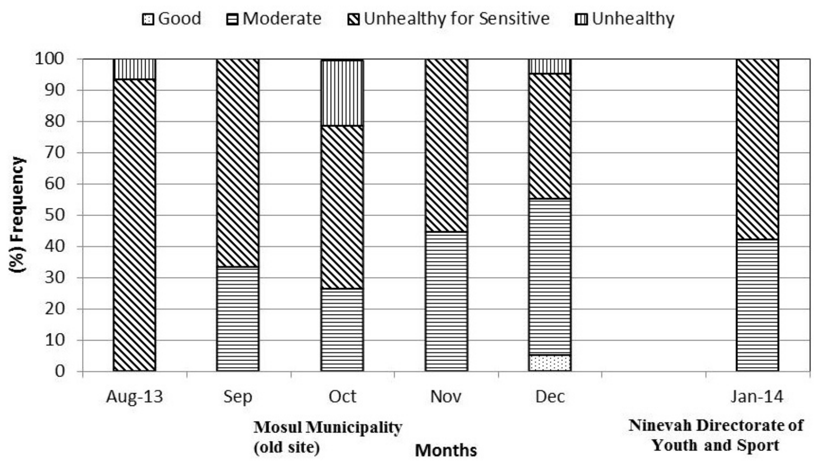

Figure 6. The monthly frequencies of AQI categories in the sites Mosul municipality (old site) and Ninevah directorate of youth and sport

groups” and “Unhealthy” occurred at frequencies 0–50.0%, 40.0–93.3% and 0–21.1% respectively. The results recognize the category “Unhealthy for sensitive group” as dominant for the site with the worse air quality among other sites.

For the Directorate of youth and sport site at the right side of Mosul city, AQI categories distributed between “Moderate” with 42.1% and “Unhealthy for sensitive groups” with 57.9% at January 2014 (Figure 6). From the results of AQI in the studied sites, it appears that the category "Moderate" is more dominant. Additionally, the category "Unhealthy for sensitive groups" was dominant at Mosul municipality (old location) site. A comparison of these results with other studies, like a study conducted in Catania/ Italy for municipal sites, the dominance was for the category "Good" [Lanzafame et al. 2015]. A study at Kirkuk city rich with oil showed that air quality index falls in the category "Unhealthy" due to NO_2 concentration [Mohamed et al. 2016]. In South Iraq/ Basra province, the category "Unhealthy for sensitive groups" was dominant due to high concentration of total suspended particulates [Shehabaldain and Azeez 2017]. In Bahrain, a study found air quality dominant in the category "Moderate" in January, while the dominance changed to "Unhealthy for sensitive groups" in August as PM_{10} showed high concentration [Jassim and Coskuner 2017].

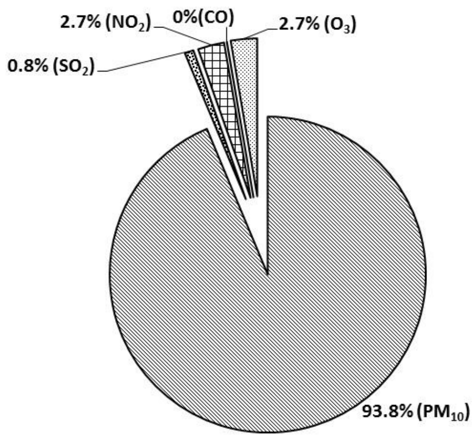

Figure 7. Distribution of air pollutants according to their annual contribution to air quality index for public library station Feb-13 to Jan-14

The annual contribution percentages of pollutants in AQI show that the deterioration of air quality in Mosul city is mainly belongs to high concentration of PM_{10} with 93.8% (Figure 7). CO has no contribution to AQI, while SO_2, O_3 and NO_2 has little contribution to AQI at 0.8%, 2.7% and 2.7% respectively. There is no interest in creating the green areas and take care of them in addition to the effect of diesel vehicles especially buses. In Saudi Arabia, Al-Harbi et al. [2014] found that 71% of time Riyadh city air is of "Good" category, while 74% of the remaining 29% is caused by PM_{10}. In India/ Kodinar Gujrat, a study of AQI found air quality in the categories from "Moderate" to "Unhealthy for sensitive groups" due to the high concentration of PM_{10} [Chaurasia et al. 2013].

Figure 8 presents the contribution of the pollutants in determining AQI as percentage in the public library site. With respect to winter months (December to February), PM_{10} is dominant and accounts for 98.2% of AQI determination on average. These results corresponds to the findings of Al-Awadhi [2019] in Kuwait who found PM_{10} to be the more contributor to AQI and to Motesaddi et al. [2017] in Tehran who found the same results. In spring (March to May), PM_{10} still dominant with a lesser percentage, which contributed 81.6% to AQI determination followed by O_3 which accounts for 8.3% of AQI determination. The possible appearing of O_3 contribution may be due to the longer duration of solar radiation and temperature increase in spring [Chuturkova 2015]. In summer months (June to August), PM_{10} prevailing the contribution of other pollutants especially O_3, which accounts for an average of 98.2% of AQI determination. This may be due to

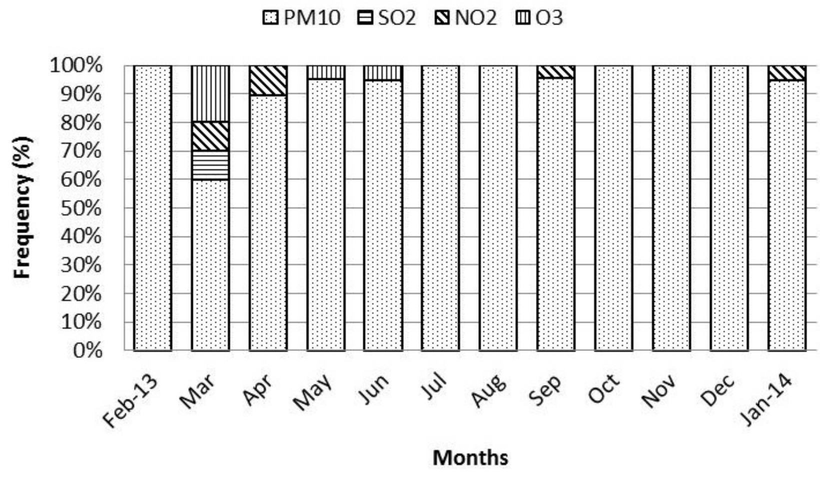

Figure 8. Percentage of pollutants contribution in determining AQI value

the lack of green spaces around the town and to diesel vehicles. In autumn (September to November), PM_{10} still the dominant contributor to AQI determination with 98.5%. It appears that the effect of green spaces lack with high PM_{10} overcomes the other air quality pollutants.

Descriptive statistics of AQI for the studied sites in Mosul city according to site and month are shown in Table 3. For the fixed station at the public library, there is a significant difference among the monthly AQI values ($p<0.001$). AQI has a minimum mean value of 57.4 in March. After that, AQI showed an increasing trend and reached its maximum value of 126.6 in October. Later for the remaining months, it fluctuates between fall and rise (Table 3).

For AQI according to season, the results revealed a distinct seasonal variation of AQI with the mean ranked in an increasing order as spring (74.3) < winter (90.4) < summer (104.3) < (114.0) indicating that air quality in the public library site is much worse in autumn and summer, but relatively better in spring. The annual average of AQI in Mosul city at public library site is 96.0. It is lesser than AQI in Baghdad city which recorded mean AQI of 120 [Hashim et al. 2021].

A comparison between public library site and mobile station sites AQI, showed different results according to site and month (Table 3). AQI shows significant increase ($p<0.01$) in public library site compared with Yogurt factory site in February and with Mosul Technical Institute site in May. On the other hand, AQI in the sites Al-Shifaa Hospital site and Mosul Municipality (old location) site showed a significant increase than AQI in Public Library site at July and August respectively. The other comparisons with Public Library site shows non-significant difference. This may be due to the effect of wind direction as each site has different wind direction which increase the pollutants concentration.

The data of sub-index in the public library site was categorized into above 50 and above 100 for each pollutant (Table 4). PM_{10} exhibits the highest percentage of data above 50 (92.92%) followed by SO_2 (18.14%). This means that air quality at 92.92% of the year will be at "Moderate" category or worse. For sub-air quality index above 100, PM_{10} also shows the highest percentage (44.70%) followed by NO_2 (10.89%). This means that air quality at 44.70% of the year will be at "Unhealthy for sensitive groups" category or worse. These results indicates PM_{10} as the main control of AQI index in Mosul city.

When the results are distributed according to pollution categories and pollutant type (Tables 5–10), the concentrations of CO fall in the category "Good" with 100% in all the studied sites. NO_2 concentrations fall in the categories "Good", "Moderate" and "Unhealthy for sensitive groups"

Table 3. Comparison of AQI between public library site and mobile station sites

Date	Fixed station at Mosul Public Library#			Mobile station at difference sites			Significance
	Mean	Median	Range	Mean	Median	Range	
Feb-13	77.6	67.2	49.9- 139.9	52.3[1]	51.2	30.8- 99.5	0.006
Mar-13	57.4	59.0	22.5- 164.4	65.2[1]	60.5	27.2- 179.1	>0.05*
Apr-13	80.2	74.8	45.1- 147.4	82.2[2]	69.4	30.6- 242.7	>0.05*
May-13	85.3	74.2	47.1- 181.9	62.5[2]	56.7	43.2- 110.7	0.005
Jun-13	100.2	88.2	48.0- 187.7	80.0[3]	75.4	37.6- 134.9	>0.05*
Jul-13	100.5	99.0	58.3- 163.4	176.5[3]	158.0	87.2- 448.5	<0.001
Aug-13	112.6	113.3	91.4- 137.6	130.8[4]	124.3	102.9-174.2	<0.001
Sep-13	104.7	102.3	83.8- 140.3	108.3[4]	108.0	84.3- 141.9	>0.05*
Oct-13	126.6	128.3	84.2- 197.0	121.9[4]	118.7	86.5- 163.9	>0.05*
Nov-13	112.2	113.1	61.5- 187.5	102.2[4]	103.1	58.4- 139.9	>0.05*
Dec-13	85.9	80.4	53.2- 157.2	98.9[4]	98.0	42.1- 153.5	>0.05*
Jan-14	102.2	103.0	59.5- 141.5	100.7[5]	109.4	50.8- 143.9	>0.05*

[1] Yogurt factory site, [2] Mosul Technical Institute site, [3] Al-Shifaa Hospital site, [4] Mosul Municipality (old location) site, [5] Directorate of Youth and Sport site. * No significant difference. # Significant difference among monthly AQI by ANOVA test $p<0.001$.

Table 4. Percentage of AQI exceeding 50 and 100 according to pollutant type for the study period in public Library site

Percentage of AQI	CO 8hr	NO_2 1hr	O_3 8hr	SO_2 1hr	PM_{10} 24hr
% of AQI exceed 50	0.00	11.50	3.10	18.14	92.92
% of AQI exceed 100	0.00	10.89	0.00	0.00	44.70

according to site. It was in the categories: "Good" with a percentage between 78.8–100%, "Moderate" with a percentage between 0.0–15.8% and "Unhealthy for sensitive groups" between 0.0–5.3%. The highest percentage of the category "Good" for NO_2 was recorded in the sites Al-Shifaa Hospital site and Mosul Technical Institute at a value of 100%, while the highest percentages for "Moderate" and "Unhealthy for sensitive groups" categories were recorded in the directorate of youth and sports" site with 15.8% and 5.3% respectively.

Ozone falls in "Good" category at percentage between 83.8–100% according to site, with highest percentage of 100% recorded at the sites

Table 5. Percentage of Sub-indices of AQI according to the categories in the public Library site

Pollution Categories	CO 8hr	NO_2 1hr	O_3 8hr	SO_2 1hr	PM_{10} 24hr
Good	100.0	88.9	96.9	96.9	7.1
Moderate	0	10.2	3.1	18.1	50.0
Unhealthy for sensitive group	0	0.9	0	0	37.1
Unhealthy	0	0	0	0	5.8
Very Unhealthy	0	0	0	0	0
Hazardous	0	0	0	0	0

Table 6. Percentage of Sub- indices of AQI according to the categories in the Mosul Municipality (old location) site

Pollution Categories	CO 8hr	NO_2 1hr	O_3 8hr	SO_2 1hr	PM_{10} 24hr
Good	100.0	92.5	98.9	58.1	2.2
Moderate	0	6.4	1.1	38.7	32.2
Unhealthy for sensitive group	0	1.1	0	2.1	60.2
Unhealthy	0	0	0	1.1	5.4
Very Unhealthy	0	0	0	0	0
Hazardous	0	0	0	0	0

Table 7. Percentage of Sub- indices of AQI according to the categories in the Yogurt factory site

Pollution Categories	CO 8hr	NO_2 1hr	O_3 8hr	SO_2 1hr	PM_{10} 24hr
Good	100.0	94.1	100.0	100.0	47.1
Moderate	0	5.9	0	0	44.1
Unhealthy for sensitive group	0	0	0	0	5.9
Unhealthy	0	0	0	0	2.9
Very Unhealthy	0	0	0	0	0
Hazardous	0	0	0	0	0

Table 8. Percentage of Sub-AQI according to the categories in the Al-Shifaa hospital site

Pollution Categories	CO 8hr	NO_2 1hr	O_3 8hr	SO_2 1hr	PM_{10} 24hr
Good	100.0	100.0	83.8	91.9	8.1
Moderate	0	0	16.2	8.1	32.4
Unhealthy for sensitive group	0	0	0	0	32.5
Unhealthy	0	0	0	0	16.2
Very Unhealthy	0	0	0	0	8.1
Hazardous	0	0	0	0	2.7

Table 9. Percentage of Sub- indices of AQI according to the categories in the Technical institute/Mosul site

Pollution Categories	CO 8hr	NO_2 1hr	O_3 8hr	SO_2 1hr	PM_{10} 24hr
Good	100.0	100.0	94.9	100.0	30.8
Moderate	0	0	5.1	0	53.8
Unhealthy for sensitive group	0	0	0	0	12.8
Unhealthy	0	0	0	0	0.0
Very Unhealthy	0	0	0	0	2.6
Hazardous	0	0	0	0	0

Table 10. Percentage of Sub- indices of AQI according to the categories in the Sports and Youth Directorate site

Pollution Categories	CO 8hr	NO_2 1hr	O_3 8hr	SO_2 1hr	PM_{10} 24hr
Good	100.0	78.9	100.0	73.7	0.0
Moderate	0	15.8	0	15.8	47.4
Unhealthy for sensitive group	0	5.3	0	10.5	52.6
Unhealthy	0	0	0	0	0
Very Unhealthy	0	0	0	0	0
Hazardous	0	0	0	0	0

Directorate of youth and sport and Yogurt factory. While, O_3 falls in "Moderate" category at a maximum percentage of 16.2% in the site Al-Shifaa Hospital. Sulfur dioxide falls with category "Good" at percentages 58.1–100% in the studied sites. The highest percentage of 100% was recorded in two sites: Yogurt factory and Mosul technical institute. On the other hand, the minimum percentage of category "Good" of 58.1% was recorded in Mosul municipality (old location) site. In addition, SO_2 falls in the categories "Moderate" and "Unhealthy for sensitive groups". The highest percentage of "Moderate" was recorded in the Mosul municipality (old location) site with 38.7% and 10.5% for "Unhealthy for sensitive groups" at Directorate of youth and sports site.

PM_{10} records the lowest percentage of "Good" category in the studied sites among other pollutants. It ranged between 0.0% at Directorate of youth and sports to 47.1% at Yogurt factory site. For "Moderate" category, Technical institute site recorded the maximum percentage of 53.8%. All the categories of air pollution were recorded in the Al-Shifaa hospital site from "Good" at 8.1% to "Hazardous" at 2.7%.

CONCLUSIONS

AQI undergoes seasonal variations along the year. The lower values of AQI was recorded in March, while the higher values of AQI was recorded in October. AQIs values along the year was distributed mainly in the categories "Moderate" and "Unhealthy for sensitive group", while few values fall in the categories "Good" and "Unhealthy". The dominance category varied from "Good" to "Moderate" at yogurt factory site, "Moderate" to "Unhealthy for sensitive group" in public library site, "Moderate" at Mosul technical institute, and "Unhealthy for sensitive group" at Mosul municipality (old location) site. PM_{10} was the main contributor for AQI determination in Mosul city.

Ozone, Carbon monoxide and NO_2 had very little contribution to air pollution in Mosul city. The mean annual AQI in Mosul city was 96.0 in the category "Moderate". The sub-indices of AQI for PM_{10} falls in the "Moderate" category then "Unhealthy for sensitive group", while other pollutants falls in the category "Good".

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