JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(4), 110–116
https://doi.org/10.12911/22998993/159398
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.12.13
Accepted: 2023.02.07
Published: 2023.02.20

Assessment of Air Quality through Multiple Air Quality Index Models – A Comparative Study

Abdulmuhsin S. Shihab[1]

[1] Mosul University, Environmental Research Center, Mosul, Iraq
E-mail: mss_qzz@uomosul.edu.iq

ABSTRACT
It is important to indicate air quality level in metropolitan areas as it is harmful to public health. Air quality index (AQI) is a useful tool to convert air quality pollutants concentrations into a single number representing air quality level. There are many air quality index models in the literature to represent air quality level. Two models were selected to assess the air quality in Mosul city. The first model utilizes the highest sub-index depending on USEPA pollutants standards. The second model includes the weights of all pollutants in the model as an aggregated air quality index (AAQI) model. Air quality concentrations were collected using a fixed monitoring station located in the courtyard of the public library for a year. The results illustrate that the values of aggregated Air quality index model were higher than those of the USEPA model. Air quality category "Moderate" was dominant in winter and spring for the two models. In contrast, the category "Unhealthy for sensitive group" was dominant in summer and autumn. Furthermore, the category "Unhealthy" appeared only with aggregated model in autumn. The contribution of air pollutants in AQI can be ranked as PM_{10}, SO_2, NO_2, CO and O_3 from higher to lower. The study concluded that the AAQI is comprehensive and more workable in environmental management.

Keywords: aggregated air quality index, USEPA air quality index, PM_{10}, air quality assessment, Mosul.

INTRODUCTION

The major environmental problems facing large cities are air pollution due to increased population and anthropogenic fuel consumption in transportation and industrial activities. They are considered a serious environmental threat as they cause harm to human and environment [Kampa and Castanas, 2008]. Air pollutants differ in their risk on human according to their concentrations and types and it is difficult for the public to determine the risk of air pollution from pollutants concentration in advance, as they differ in their determinants and units. Therefore, a method is needed to determine the effect of multiple pollutants and its health risk ranking as a single number [Oakes et al., 2014]. In addition, policy-makers have recommended displaying air quality in indices to notify the public and alert them about the risk of pollution [Shah and Patel, 2021]. Air quality index (AQI) is a model used to convert the concentrations of air pollutants into a single number representing the level of air quality condition. There are many air pollution indices in the literature with different names like Air Quality Index (AQI), Air Pollution Index (API), [Bishoi et al., 2009] and Pollution Standard Index (PSI), [Eugene et al., 2007].

There are two types of AQIs according to the principal of their calculation method. The first type considers the highest sub-index as AQI after calculating the sub-indices for all pollutants depending on USEPA or local air pollutants standards. Through this type of AQI, the large amount of information is gone, while the awareness of public improved [Mirabelli et al., 2020]. In contrast, the second type of AQI involves multiple air pollutants for aggregated AQI, which try to collect the effect of multiple air pollutants. The aggregation of pollutants indices may be applied arithmetically [Kyrkilis et al., 2007; Ruggieri and Plaia, 2012] or according to pollutant weights (Hu et al.,

2015) or by complicated methods like fuzzy functions [Olvera-Garcia et al., 2016]. In addition, the health impact may be integrated in AQI to produce air quality health index (AQHI) which has been applied in Canada [Stieb et al., 2008].

The public in Mosul city as the largest city in Northern Iraq, lack what alerts residents to the state of air quality. There is a shortage in air quality studies in Mosul city. The earlier studies included dustfall and suspended particulate PM_{50} [Shihab et al., 2010; Shihab and Taha, 2014]. Besides, Shihab and Al-Jarrah [2015] studied the levels of nitrogen oxides and ozone as well as their relationship with meteorological factors. Additionally, the air quality status in Mosul city was described using USEPA air quality index [Shihab, 2021].

The present research aimed to apply two models of AQI: the first one use the highest sub-index of USEPA AQI and the second use the aggregated (AAQI) and compare between their results.

MATERIALS AND METHODS

The study was conducted in Mosul city depending on the data collected by a monitoring station located on a roadside in the courtyard of the public library. The monitoring site is located between two traffic light intersections and bordered by many buildings: Iraqi engineers union from the west, public library and housing area at the north and Courthouse of the city at the east (Fig. 1).

The site includes a Horiba type fixed monitoring station (German made). The concentrations of air pollutants monitored by the station include: O_3, NO_2, SO_2, CO, and PM_{10}. An automatic calibration of the devices in the station is conducted using span gases and zero gas. The measurements were conducted every three minutes and then the average of 30 minutes was calculated. This station belongs to the Directorate of Ninevah Environment. The surveillance operation was lasted from Feb 2013 till Jan 2014.

AQI calculations

USEPA AQI was found by equation (1) which is recommended by the USEPA [EPA, 2009].

$$\mathrm{I}_p = \frac{\mathrm{I}_{Hi} - \mathrm{I}_{Lo}}{\mathrm{BP}_{Hi} - \mathrm{BP}_{Lo}}\left(\mathrm{C}_p - \mathrm{BP}_{Lo}\right) + \mathrm{I}_{Lo} \qquad (1)$$

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 for each pollutant must be found (CO 8hr avg.), (NO_2 1hr avg.), (O_3 8hr avg.), (SO_2 1hr avg.) and (PM_{10} 24hr 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).

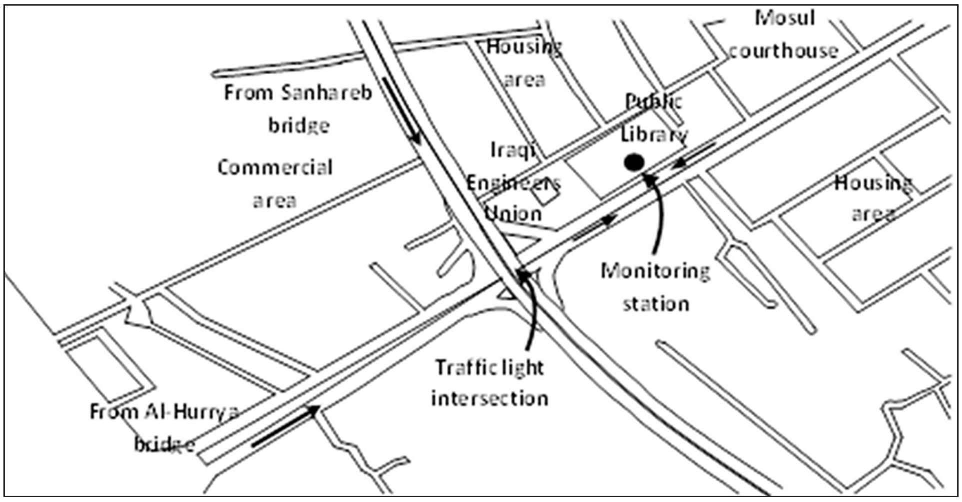

Figure 1. Location of the study site with monitoring station in Mosul city

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

The aggregated air quality index (AAQI) was calculated according to equation (3): [Ruggieri and Plaia, 2012; Zhang and Lin, 2020]

$$AAQI = \left(\sum_{i=1}^{i=n} (AQI_i)^{\rho}\right)^{1/\rho} \qquad (3)$$

where: $AAQI$ – Aggregated air quality index; AQI_i – Sub-index for single pollutant *i*, ρ – parameter in the range of 1 to ∞, $\rho = 1$; $AAQI$ – equal to the linear summation of the sub-indices of the pollutants. In the previous studies [Plaia and Ruggieri, 2011; Hu et al., 2015; Zhang and Lin, 2020], the value of ρ ranged between 2 and 3. The value of ρ was set to 2.5 in this study.

Statistical analysis

The daily AQI were analyzed statistically by calculating the descriptive statistics for each month: mean, standard deviation (SD), minimum and maximum for the USEPA-AQI and AAQI. The results of the two models were compared using paired t-test at each month. Furthermore, the distribution of AQI categories according to season was found using number and percentage for each season as well as for the two models. The significance was determined using Kruskal Wallis test. In addition, the categories of air quality for the two models were compared using Chi-squared test. The relationship between the results of the two models was found using simple regression analysis. Additionally, relationships were found between AQI as a dependent variable and the concentration of each pollutant uniquely as independent variable using simple regression analysis.

RESULTS AND DISCUSSION

Air quality index (AQI) varies along the study period from values less than 50 categorized as "Good" in March, April and May for USEPA-AQI

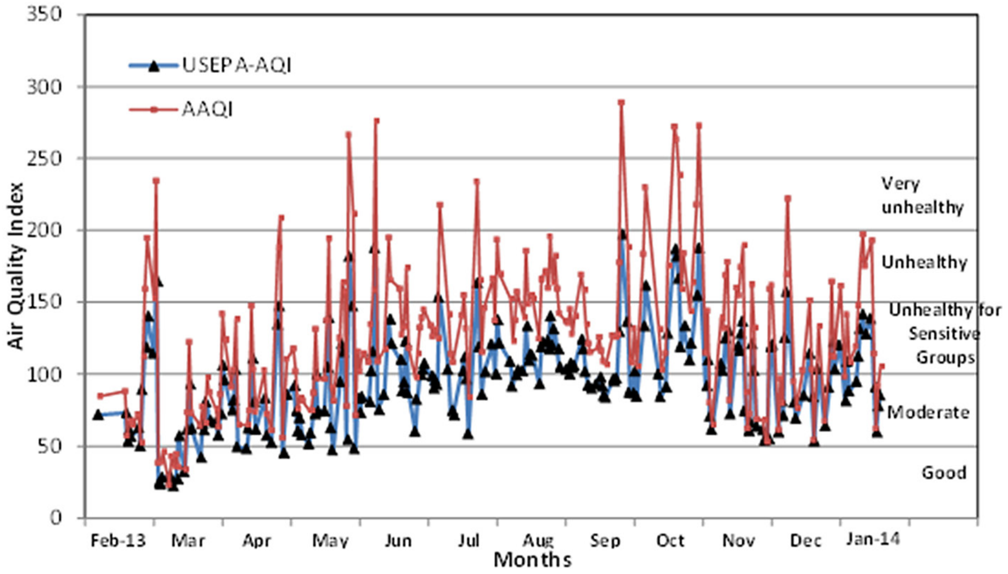

Figure 2. Variation of AQI along the study period using USEPA-AQI and AAQI

Table 1. Comparison of selected air quality levels between USEPA AQI and AAQI

AQI	USEPA AQI		AAQI		p-value
Categories	No.	%	No.	%	
>50	211	93.4	217	96.0	>0.05 N.S.*
>100	99	43.8	158	70.0	<0.001
>150	13	5.8	71	31.4	<0.001
>200	0	0.0	15	6.6	<0.001

Note: NS – not significant according to Chi-square test.

model and March only for AAQI to values less than 200 categorized as "Unhealthy" for USEPA-AQI and more than 200 categorized as "Very unhealthy" along the year for AAQI (Fig. 2). There are 15 peaks within AAQI between 201-300 categorized as "Very Unhealthy" versus zero within USEPA-AQI results. The highest number of USEPA-AQI values falls between 51 to 100 within the category "Moderate", while the highest number of AAQI values fall within the range 101 to 150 categorized as "Unhealthy for sensitive group". Additionally, the values obtained from AAQI model were higher than those obtained by USEPA model, as it includes the sub-indices of all pollutants versus one sub-indices only (maximum) for USEPA model. As the number of sub-indices included in the model increases, the value of AQI increases as well [Sahbeni et al., 2019]. On the other hand, the trend of AAQI and USEPA-AQI was comparable, which is coincided with the results of Li et al. [2018].

USEPA-AQI values were more than 100 in 99 days (43.8% of the total days) versus 168 days (70.0% of the total days) for AAQI (Table 1) and the difference between them was significant ($p<0.001$). The same results were found for USEPA-AQI of more than 150 which was recorded in 13 days (5.8%) versus 71 days (31.4%) for AAQI

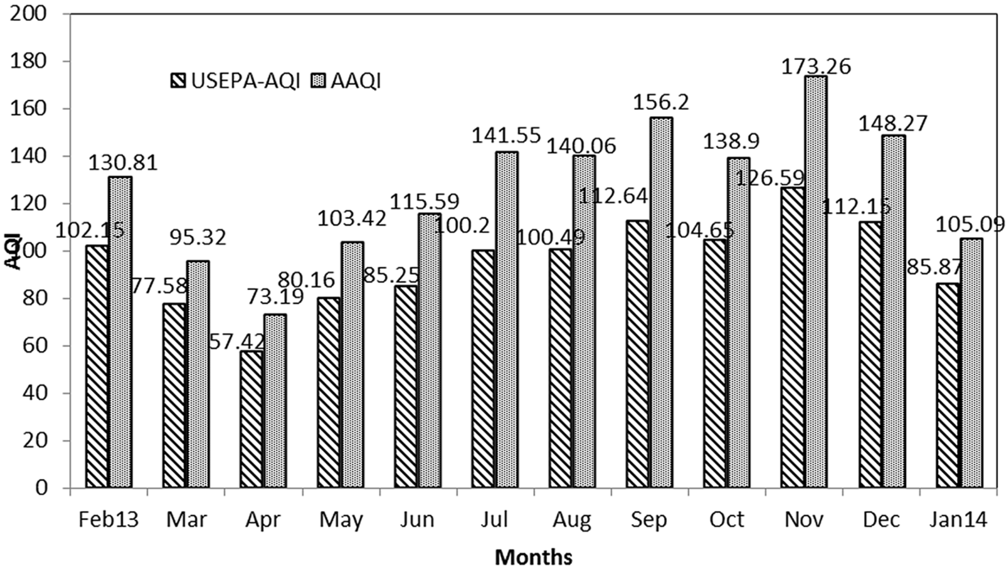

Figure 3. Monthly means for USEPA-AQI and AAQI

Table 2. Comparison between USEPA-AQI and aggregated air quality index according to month

Month	USEPA-AQI			AAQI			Significance*
	Mean	SD	Range	Mean	SD	Range	
Feb-13	102.15	23.98	59.54–141.46	130.81	39.88	62.25–197.18	<0.001
Mar	77.58	29.86	49.85–139.94	95.32	47.10	52.57–194.72	<0.001
Apr	57.42	36.01	22.50–164.36	73.19	49.95	23.09–234.40	<0.001
May	80.16	29.54	45.09–147.40	103.42	44.15	55.78–208.71	<0.001
Jun	85.25	33.25	47.08–181.93	115.59	47.91	74.80–266.61	<0.001
Jul	100.20	33.16	47.99–187.67	141.55	48.02	71.45–276.16	<0.001
Aug	100.49	24.45	58.34–163.37	140.06	34.43	84.00–233.74	<0.001
Sep	112.64	13.01	91.42–137.63	156.20	19.22	122.92–193.68	<0.001
Oct	104.65	14.91	83.75–140.27	138.90	23.82	106.55–195.56	<0.001
Nov	126.59	37.20	84.16–197.03	173.26	60.61	103.29–288.81	<0.001
Dec	112.15	31.52	61.48–187.54	148.27	51.85	64.87–272.81	<0.001
Jan-14	85.87	29.75	53.19–157.22	105.09	48.62	52.94–222.15	<0.001
Year	95.79	33.47	22.50–197.03	127.52	50.97	23.09–288.81	<0.001

Note: * using paired t-test.

with significant difference ($p<0.001$). These results indicate that the choice of AAQI model has great impact on air quality evaluation. The aggregated AQI model appears to produce higher values than USEPA-AQI or it is worse as air quality indicator. These results were also found by Zhang and Lin (2020) in China.

Furthermore, the monthly means of AAQI index were significantly higher ($p<0.001$) than USEPA-AQI at all months as the former model includes the combined effect of all pollutants (Figure 3 and Table 2). The maximum monthly USEPA-AQI mean occurred in November with 126.59 categorized "Unhealthy for sensitive groups" versus 173.26 for AAQI categorized as "Unhealthy" (Table 1). On the other hand, the minimum monthly AQI mean occurred in April for the two AQI models with 57.42 "Moderate" for USEPA-AQI and 73.19 "Moderate" also for AAQI. AAQI characterizes the exposure to all monitored pollutants, which may be more valuable to describe air quality and more feasible for environmental management (Zhang and Lin, 2020).

Some researchers consider AAQI more efficient than USEPA-AQI in urban air quality evaluation, as its values are more than USEPA-AQI and they represent the exposure to all the monitored pollutants (Shah and Patel, 2021). In case of more than one of the monitored pollutants exceeded the limits, it may be logic to use AAQI, while if some of the pollutants levels is good, it may be not acceptable for these pollutants to contribute in increasing air quality index.

A regression analysis found a strong significant positive relationship between USEPA-AQI as a dependent variable and AAQI as independent variable with a coefficient of determination (R^2) 0.976 (Figure 4). The increase in the observed values or AAQI by 1 unit will make an increase in USEPA-AQI by 0.65 unit. This relation is considered good, as it has a coefficient of determination (R^2) near 1 [Pineiro et al., 2008].

The distribution of USEPA-AQI (Table 3) shows a significant seasonal variation ($p<0.001$). Air quality categorized as "Good" was higher in spring with 21.7% versus 0.0% in autumn. In turn,

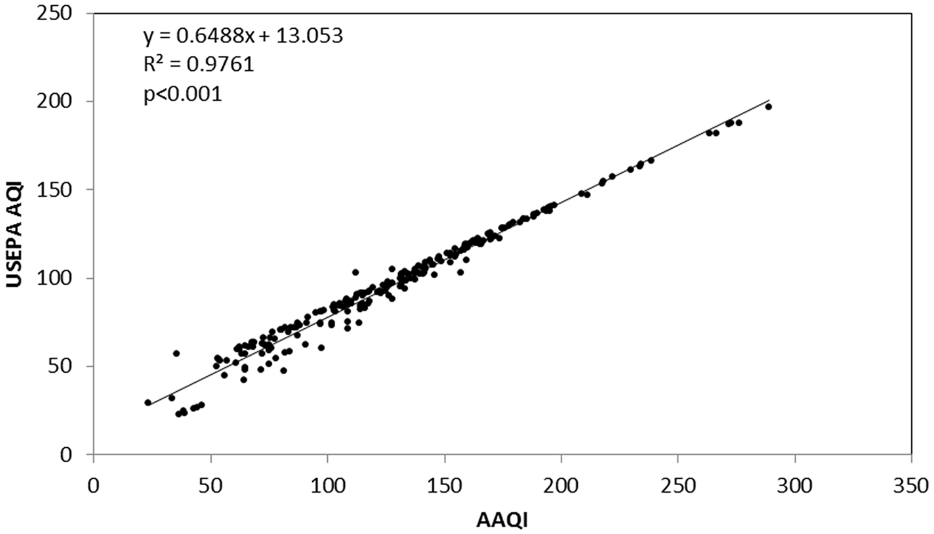

Figure 4. Regression analysis between USEPA AQI and aggregated AQI

Table 3. Distribution of USEPA AQI levels according to season

AQI Class	No. (%)				
	Winter	Spring	Summer	Autumn	Total
Good (0–50)	1(2.0)	13(21.7)	1(1.8)	0(0.0)	15(6.6)
Moderate (51–100)	30(60.0)	35(58.3)	25(43.9)	22(37.3)	112(49.6)
Unhealthy for sensitive groups (101–150)	18(36.0)	10(16.7)	28(49.1)	30(50.8)	86(38.1)
Unhealthy (151–200)	1(2.0)	2(3.3)	3(5.3)	7(11.9)	13(5.8)
Total	50(100.0)	60(100.0)	57(100.0)	59(100.0)	226(100.0)

Note: significant variation at $p<0.001$ according to Kruskal Wallis test.

the category "Moderate" occurred more in winter and spring with 60.0% and 58.3% respectively. For worse air quality category "Unhealthy for sensitive group", the higher percentage of occurrence was recorded in summer and autumn with 49.1% and 50.8% respectively. The worst category "Unhealthy" had lower percentage of occurrence ranged from 2.0% in winter to 11.9% in autumn.

For AAQI seasonal distribution, the profile of variation was deviated from the previous model. As AAQI creates higher AQI values, a shift is observed in percentage of categories towards the worst direction (Table 4). The percentage of occurrence of the category "Good" decreased from 21.7% to 15.0% in spring which was higher than other seasons. In addition, the percentage of category "Moderate" decreased to 48.3% in spring versus 58.3% for the previous model. For the category "Unhealthy for sensitive group" the higher percentages occurred in summer (54.4%) and autumn (49.2%). On the other hand, the percentage of category "Unhealthy" occurrence increased from 5.3% in summer for USEPA-AQI model to 33.3% for AAQI. Furthermore, 15 (6.6%) cases of the category "Very unhealthy" were recorded in autumn for AAQI versus 0 cases for USEPA-AQI.

The results of simple regression analysis between AQIs and the concentrations of air pollutants are shown in Table 5. PM_{10} is the most contributor to AQI variation in the studied models with a coefficient of determination (R^2) 0.993 and 0.976 for USEPA-AQI and AAQI, respectively. The increase in CO concentration has the highest effect on AQI rise as it has the highest slope among other pollutants 15.01 and 19.79 for USEPA-AQI and AAQI, respectively. Air pollutants can be ranked from higher contribution in AQI variation to lesser as PM_{10}, SO_2, NO_2, CO and O_3. This ranking is coincided with that of Li et al. [2018] in China.

CONCLUSIONS

Aggregated air quality index is comprehensive indicator of air quality and more workable

Table 4. Distribution of aggregate AQI levels according to season

AQI Class	No. (%)				
	Winter	Spring	Summer	Autumn	Total
Good (0–50)	0(0.0)	9(15.0)	0(0.0)	0(0.0)	9(4.0)
Moderate (51–100)	23(46.0)	29(48.3)	3(5.3)	4(6.8)	59(26.1)
Unhealthy for sensitive groups (101–150)	13(26.0)	14(23.3)	31(54.4)	29(49.2)	87(38.5)
Unhealthy (151–200)	13(26.0)	5(8.3)	19(33.3)	19(32.2)	56(24.8)
Very unhealthy (201–300)	1(2.0)	3(5.0)	4(7.0)	7(11.9)	15(6.6)
Total	50(100.0)	60(100.0)	57(100.0)	59(100.0)	226(100.0)

Note: significant variation at p<0.001 according to Kruskal Wallis test.

Table 5. Simple regression analysis between two AQIs as dependent variables and independent concentrations

Pollutant	Regression equation	R^2	β-weight	Significance
USEPA	AQI			
SO_2	y = 1.30x + 65.50	0.224	0.473	<0.001
NO_2	y = 0.98x + 58.99	0.179	0.423	<0.001
PM_{10}	y = 0.49x + 24.77	0.993	0.996	<0.001
CO	y = 15.01x + 76.99	0.110	0.332	<0.001
O_3	y = – 0.17x + 100.44	0.006	-0.080	>0.05*
Aggregate	AQI			
SO_2	y = 1.85x + 84.48	0.195	0.441	<0.001
NO_2	y = 1.1.42x + 74.46	0.160	0.400	<0.001
PM_{10}	y = 0.74x + 20.29	0.976	0.988	<0.001
CO	y = 19.79x + 102.76	0.083	0.287	<0.001
O_3	y = 0.054x + 126.05	0.000	-0.017	>0.05*

Note: * not significant (p-value > 0.05) according to ANOVA test.

in environmental management, as it represents many air quality pollutants. It may be more efficient than USEPA-AQI in case more than one pollutant exceeds the critical concentration.

The contribution of air pollutants in USEPA-AQI is ranked as PM_{10}, SO_2, NO_2, CO and O_3 from higher to lower. In winter and spring, air quality category "Moderate" has the highest occurrence, while the highest occurrence of the category "Unhealthy for sensitive group" was in summer and autumn for the two AQI models. There is a strong significant correlation between Aggregated AQI values and USEPA-AQI values.

Acknowledgments

The author is very grateful to Mosul University/ Environmental Research Center for funding this work and providing the facilities which helped to improve the quality of this work.

REFERENCES

1. Bishoi B., Prakash A., Jain V. 2009. A comparative study of air quality index based on factor analysis and US-EPA methods for an urban environment. Aerosol and Air Quality Research, 9, 1–17.
2. EPA (United States Environmental Protection Agency) 2009. Technical assistance document for reporting of daily air quality-the air quality index (AQI). EPA-454/B-09-001. U.S. Environmental Protection Agency, North Carolina.
3. Eugene K.C., John J., Zunckel M. 2007. A novel air pollution index based on the relative risk of daily mortality associated with short-term exposure to common air pollutants. Atmospheric Environment, 41(38), 8442–8454.
4. Hu J., Ying Q., Wang Y., Zhang H. 2015. Characterizing multi-pollutant air pollution in China: comparison of three air quality indices. Environment International, 84, 17–25.
5. Kampa M., Castanas E. 2008. Human health effects of air pollution. Environmental Pollution, 151, 362–367.
6. Kyrkilis G., Chaloulakou A., Kassomenos P.A. 2007. Development of an aggregate Air Quality Index for an urban Mediterranean agglomeration: relation to potential health effects. Environment International, 33, 670–676.
7. Li Y., Tang Y., Fan Z., Zhou H., Yang Z. 2018. Assessment and comparison of three different air quality indices in China. Environmental Engineering Research, 23(1), 21–27.
8. Mirabelli M.C., Ebelt S., Damon S.A. 2020. Air Quality Index and air quality awareness among adults in the United States. Environmental Research, 183, 109185.
9. Oakes M., Baxter L., Long T.C. 2014. Evaluating the application of multi-pollutant exposure metrics in air pollution health studies. Environment International, 69, 90–99.
10. Olvera-García M.´A., Carbajal-Hern´andez J.J., S´anchez-Fern´andez L.P., Hern´andez- Bautista I. 2016. Air quality assessment using a weighted Fuzzy Inference System. Ecological Inference, 33, 57–74.
11. Pineiro G., Perelmanb S., Guerschmanb J.P., Parueloa J.M. 2008. How to evaluate models: Observed vs. predicted or predicted vs. observed? Ecological Modelling, 216, 316–322.
12. Plaia A., Ruggieri M. 2011. Air quality indices: A review. Reviews in Environmental Science and Biotechnology, 10, 165–170.
13. Ruggieri M., Plaia A. 2012. An aggregate AQI: comparing different standardizations and introducing a variability index. Science of the Total Environment, 420, 263–272.
14. Sahbeni G., Nagy G., Gurgenidze T. 2019. Examination of Air Quality Indexes (AQIs) Role in Urban Air Quality Assessment. Asian Journal of Applied Science and Technology, 3(1), 130–142.
15. Shah D.P., Patel P. 2021. A comparison between national air quality index, India and composite air quality index for Ahmedabad, India. Environmental Challenges, 5, 100356.
16. Shihab A.S. 2021. Assessment of Ambient Air Quality of Mosul City/Iraq Via Air Quality Index. Journal of Ecological Engineering, 22(10), 241–250.
17. Shihab A.S., Al-Jarrah O.A.I. 2015. The levels of ozone and nitrogen oxides and its relationship with metrological factors. Al-Rafidain Engineering Journal, 23(4), 98–109. [in Arabic]
18. Shihab A.S., Fadhil M.N., Jumaa O.K 2010. Distribution of dustfall in selected sites in Mosul city and around it/ Iraq. Tishreen University Journal for Scientific Researches and Studies, Engineering Series, 32(6), 191–203.
19. Shihab A.S., Taha A.T. 2014. Suspended particulate levels in the left bank residential areas of Mosul city and its relation with some metrological factors. Al-Rafidain Engineering Journal, 22(3), 158–164. [in Arabic]
20. Stieb D.M., Burnett R.T., Smith-Doiron M., Brion O., Shin H.H., Economou V. 2008. A new multi-pollutant, No-threshold air quality health index based on short-term associations observed in daily time-series analyses. J. of Air & Waste Management Association, 58, 435–450.
21. Zhang X.P., Lin M.H. 2020. Comparison between two air quality index systems in study of urban air pollution in China and its socio-economic determinants. Journal of University of Chinese Academy of Sciences, 37(1), 39–50.