International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.06 pp 552-559, 2016

Air Quality Index for Makkah City, Saudi Arabia: Recommended Breakpoints and Bands

Abdel Hameed A. Awad*, Alia A. Shakour, Yasser H. Ibraheim, Nasser Abdel-Latif

Department of Air Pollution, National Research Centre, Dokki, Giza, Egypt

Abstract: The purpose of this paper is to suggest an air quality index (AQI) for Makkah city, Saudi Arabia. AQI provides public with timely and easily understandable information on how clean or polluted the air is? AQI is divided into ranges; each range is assigned a descriptor and a color code. The breakpoints and bands (sub-indices) were selected basing on actual trends of ambient air pollutant concentrations, the national standard, WHO-guidelines and our scientific judgment. The index value of 50 was based on the annual air pollutant of the Saudi Arabia standards. The index value of 100 was based on the numerical value of the short-term standard (1 h- 24 hrs) for each pollutant. AQI is developed for criteria air pollutants (health related pollutants) including: particulate matter less than 10 µm in size (PM_{10}), ozone (O_3), sulphur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2). The suggested AQI was divided into 6 bands indicating different level of health concerns: 1) 0-50 (good), 2) 51-100 (moderate), 3) 101-150 (unhealthy for sensitive groups), 4) 151-200 (unhealthy), 5) 201-300 (very unhealthy), and 6) 301-500 (hazardous). The selection of breakpoints not dependend on epidemiological or meta-analysis studies, as no data are available on the relastionships between air pollution and health effects in Saudi Arabia. The paper provides a proposal to develop an AQI for Makkah city and its importance for air quality management and protection of human health.
Keywords: Makkah city, AQI, proposal, breakpoints, bands.

Introduction

Air pollution is a serious environmental problem around the world[1,2]. In many cities, outdoor air pollution exceed the World Health Organization (WHO) guidelines[3]. Air pollutant concentration is related to emission rate, atmospheric chemistry, and meteorological and topographical factors. Air pollutant concentrations vary with the time and location, and various monitoring programs have been undertaken to measure air quality of criteria pollutants, PM_{10}, SO_2, NO_2, O_3 and CO[4].

Air pollution damages human and environmental health[5,6]. Long-term exposure (years) or short term exposure (several days) are associated with adverse health effects ranged from respiratory symptoms to cancer and mortality [7,8,9].

A great efforts have been made by developed and developing countries to improve air quality, use of cleaner fuel, reduce emission, and set up air quality regulations[10]. The WHO air quality guidelines are designed to guide in reducing adverse health impacts of air pollution. However, a wide gap still exists between physical and chemical characteristics of air pollutants and medical practitioners, and the awareness of air quality is not sufficient for public[11].

The public needs simply and easily understandable information on air quality. AQI is a tool used to report information on real-time levels of outdoor air pollution in the short term, tells how clean or polluted air is? and what are associated health effects?[12,13]. The AQI is aimed to advise sensitive groups (elderly, children, and people with respiratory or cardiovascular problems to avoid outdoor exertion[14], guid policy makers to reduce emissions[15], send an understandable message to public about air quality and its related health effects[16], and provide advance information on air quality (can be forecasted)[17].

How is AQI developed?

Generally some factors are needed to establish an AQI, including 1) list of criteria pollutants; 2) averaging exposure periods (1 hr- 24hrs); 3) the actual measured data using continuous monitoring stations, 4) health endpoints, 5) exposure–response relationships, epidemiological and meta-analysis studies, and 6) a method to calculate the AQI. The short exposure times/periods (1h- 24 hrs) are applied for criteria air pollutants. Air pollutants with acute health effectsare SO_2, NO_2, O_3 and CO, however air pollutants with chronic effects are PM_{10} and SO_2[18]. The piecewise linear function "segmented linear function" is mainly used to convert the actual air pollutant concentration to AQI[19].

Worldwide, AQI is divided into ranges; each range is assigned a descriptor and a color code. The higher value of the index refers to a higher level of air pollution[12]. The selection of breakpoints is based on the national ambient air quality standards/ or regulations, and epidemiological, meta-analysis, and time-series studies, that indicate adverse health effects of a specific air pollutant[20,21,22].

Air quality indices with different breakpoints and bands have been reported in literature[23]. Setting of breakpoints between bands may be an arbitrary process, because any air pollutant is regionally distributed and influenced by local sources, geographical factors and meteorologicalconditions.

International-AQIs

AQIs have been employed by many of developed and developing countries to provide information on the levels of air pollutants, recommended counteractions, and health advice regarding priorities of each country. AQI was introduced by the US Environmental Protection Agency and previously called pollutant standard index (PSI) in 1976[19]. The AQI categories, pollutants, and health breakpoints for some countries including: USA, Kuwait, India and UK are shown in Tables 1, 2, 3 and 4, respectively.

Table 1. Breakpoints for the US- AQI

	Averaging period	Unit	Good	Moderate	Unhealthy for sensitive group	Unhealthy	Very unhealthy	Hazardous
Index			0-50	51-100	101-150	151-200	201-300	301-500
PM_{10}	24-hour*	µg/m^3	0–54	55–154	155–254	255–354	355–504	505–604
SO_2	24-hour	µg/m^3	0.0–90.4	93.1–383	385.7–595.8	598.5–808.6	1729-3298.4	3325–5426
O_3	8-hour	µg/m^3	0.0–128	130–168	170–208	210–248	250–748	810–1208
NO_2	24-hour	µg/m^3	*	*	*	*	1222–2331.2	2350–3835.2
CO	8-hour	mg/m^3	0.0–4.4	4.5–9.4	9.5–12.4	12.5–15.4	15.5–40.4	40.5–50.4

*Mean concentration

Table 2. Breakpoints for Kuwait AQI

	Averaging period	Unit	Good	Moderate	Unhealthy for sensitive group	Unhealthy	Very unhealthy	Hazardous
Index			0-50	51-100	101-150	151-200	201-300	301-500
PM_{10}	24-hour	µg/m^3	0–90	90.1–350	350.1–431.3	431.4–512.3	512.6–675	675.1–1000
SO_2	24-hour	µg/m^3	0.0–79.8	82.4–159.6	162.2–484.1	486.7–808.6	811.3-1606.6	1609.3–2670.6
O_3	8-hour	µg/m^3	0.0–60	{62-120	122–184	186–248	250–748	750–1208}
NO_2	24-hour	µg/m^3	0-56.4	{75.2-94	112.8-564	582.8-1034	1052.8-1955.2	1974-3835.2
CO	8-hour	mg/m^3	0.0–4	4.1–8	8.1–11.7}	11.8–15.4}	{15.5–30.4	{30.5–50.4

Table 3. Breakpoint concentrations for India AQI

	Averaging period	Unit	Good	Moderate	Poor	Very poor	Severe
Index			0-100	101-200	201-300	301-400	401-500
PM_{10}	24-hour	µg/m^3	(0–100) {0–100}	(101–150) {101–150}	(151–350) {151–350}	(351–420) {>351}	(>420)
SO_2	24-hour	µg/m^3	(0.0–80)	(81–367)	(368–786)	(787–1572)	>1572
O_3	8-hour	µg/m^3	(0.0–157) {0.0–50}	(158–196) {51-98}	(197–235) {99–118}	(236–784) {>119}	(>784)
NO_2	24-hour	µg/m^3	(0-80) {0-42}	(81-180) {43-94}	(181-564) {95-295}	(565-1272) {>296}	>1272
CO	8-hour	mg/m^3	(0.0–2) {0.0–1.7}	(2.1–12) {1.8–10.3}	(12.1–17) {10.4–14.7}	(17.1–35) {>14.8}	>35

(Breakpoints as proposed by Sharma et al[24]), {Breakpoints as proposed by AQI-EPA[13]}

Table 4. Breakpoints for UK-AQI

Pollutant	Averaging period	Unit	Low	Moderate	High	Very high
Index			1-3	4-6	7-9	10
PM_{10}	24-hour	µg/m^3	0–49	50–74	76–99	100 or more
SO_2	15 minute	µg/m^3	0.0–265	266–531	532–1063	1064 or more
O_3	Running-8-hourly	µg/m^3	0.0–80	81–160	161–240	241 or more
NO_2	1-hour	µg/m^3	0-200	201-400	401-600	601 or more
CO	Removed from the index					

Air quality of Saudi Arabia

In Saudi Arabia, the environmental law was implemented in 2001 in order to assess air quality and take steps to improve and controll air pollution. Air quality management is currently concerned with employing air quality regulations for: SO_2, PM_{10}, O_3, NO_2 and CO[25]. Air pollution in Saudi Arabia is influenced by topography, meteorology, fast urbanization, and industrialization[26]. The Saudi Arabia have experienced large amount of suspended dust[27], as a result of the nature of the arid environment and frequent occurrence of dust storms. Table 5 shows air quality regulations/ quidelines have been established by the WHO; UK; US-EPA; Kuwait; India, and Saudi Arabia, differ from country to country and organization to another.

In Riyadh city, the capital city, air pollution problem is attributed to refineries, power plants, and transport sector. The concentrations of SO_2 and O_3 reached 23.8 µg/m^3 and 53.4 µg/m^3, respectively[28]. The concentrations of O_3, CO, and PM_{10} showed upward trends, however SO_2 and H_2S exhibited downward trends and PM_{10} concentrations reached ~ 1000 µg/m^3 corresponds to dust storms, over the the period between 1999-2004 (Fig. 1)[27]. The average concentrations of PM_{10} (1-Y), O_3 (1-hr) and SO_2 (1-hr), respectively exceeded theair quality standards: 85 µg/m^3, 235 µg/m^3, and 730 µg/m^3 (Table 5), in Jeddah and Riyadh cities, Saudi Arabia, during the period within 2000-2004[29].

Table 5. Air quality regulations (µg/m^3) of WHO; UK; US-EPA; Kuwait; India and Saudi Arabia

	SO_2			NO_2			PM_{10}			Ozone	
Region/country	**1-Y**	**24-h**	**1-h**	**1-Y**	**24-h**	**1-h**	**1-Y**	**24-h**	**1-h**	**8-h**	**1-h**
WHO (2006)	20	-	500 (10 min)	40	-	200	20	50	-	100	-
UK-EUROPE	20	125	350	40	-	200	40	50	-	120	-
US-EPA	80	365	1300 (3hrs)	100	-	-	50	150	-	157	235
India											
- Sensitive areas	15	30	-	15	30	-	50	75	-	-	-
- Residential and rural areas	60	80	-	60	80	-	60	100	-	-	-
- Industrial areas	80	120	-	80	120	-	120	150	-	-	-
Kuwait	-	20	75	40	-	200	90	150	-	-	100
Saudi Arabia	85	360	730	-	-	660	80	340	-	157	235

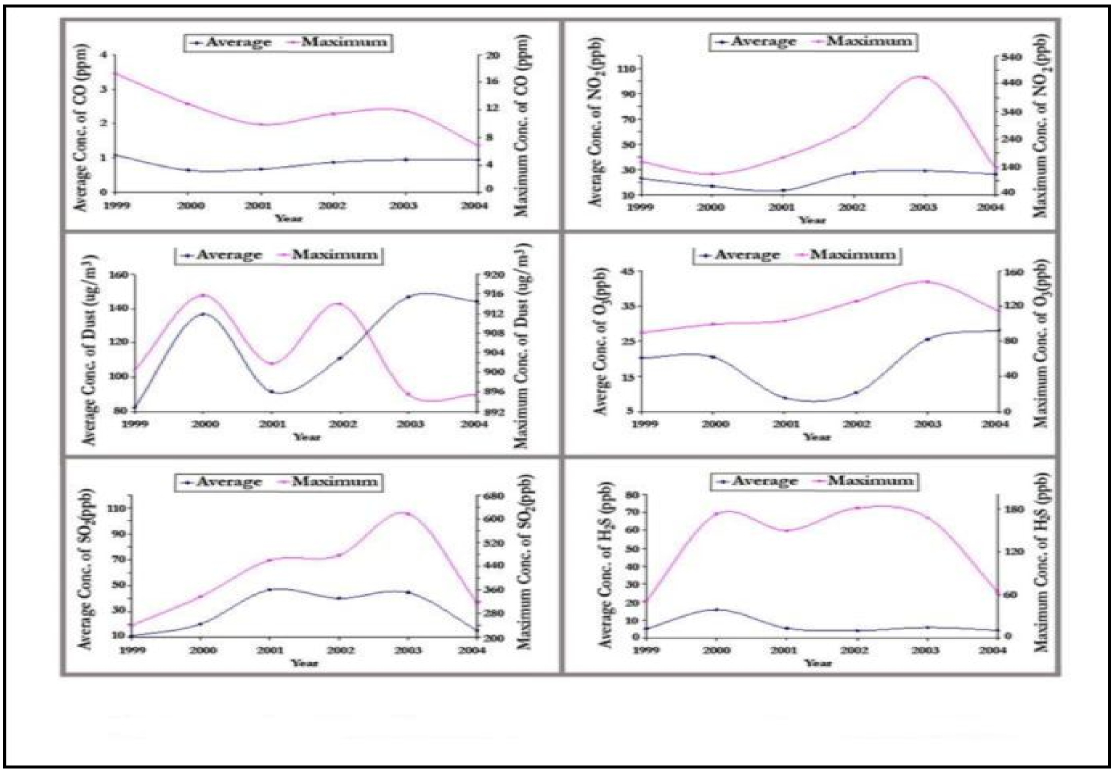

Fig. 1. The annual average and maximum hourly air pollutant concentrations in Riyadh city

Makkah city, the holy city, is a densely populated city and remains busy along over the year, as millions of people visit it every year to perform pilgrimage. The daily average concentrations of air pollutants during the period between 1997- 2012 are shown in Table 6, as well as the time plots of air pollutants are presented in figure 2[30]. It is clear that, CO showed downward concentration trend, but PM_{10}, SO_2, NO_2, and O_3 showed upward concentration trends. The negative trend of CO confirms the improvement of exhaust emissions from road traffic. In Makkah city, SO_2 showed upward trend which is opposite to the trend was found in Riyadh city by AlHarbi and his coauthors[27]. This may be attributed to heavy traffic and extensive human activities in daytime and nighttime along over the year, as large amounts of people visit Makkah every year. The concentrations of traffic related gaseous air pollutants such as NOx, CO, and SO_2 were below the air quality standards[31], however PM_{10} and O_3 concentrations sometimes exceeded the air quality standards[32].

Table 6. A summary of daily average concentrations (µg/m³) of air pollutants over the period of 1997 – 2012 in Makkah city

Metric	PM_{10} µg/m³	SO_2 µg/m³	CO mg/m³	O_3 µg/m³	NO_2 µg/m³
[1]q 0	0.00	0.00	0.00	0.00	0.00
q 0.1	54.00	2.62	0.37	13.73	43.24
q 0.2	66.00	7.85	0.57	27.47	52.64
q 0.3	77.00	13.08	0.73	35.32	60.16
q 0.4	87.00	15.70	0.87	41.20	65.80
q 0.5	96.00	18.31	0.98	45.13	73.32
q 0.6	108.00	20.93	1.10	51.01	78.96
q0.7	124.00	23.54	1.23	56.90	86.48
q 0.8	145.58	28.78	1.43	68.67	94.00
q 0.9	192.98	38.73	1.83	84.37	109.04
q 1	821.00	690.62	48.31	979.04	607.24
Mean	112.83	20.69	1.14	49.26	80.10
%Data capture	88	79	95	96	95

[1]q stands for quantile, where q 0 represent minimum, q 0.5 represent median and q 1 represents maximum concentration. Furthermore, q 0.1 is equivalent to percentile 10 and q 0.2 is equivalent to percentile 20 and so on.

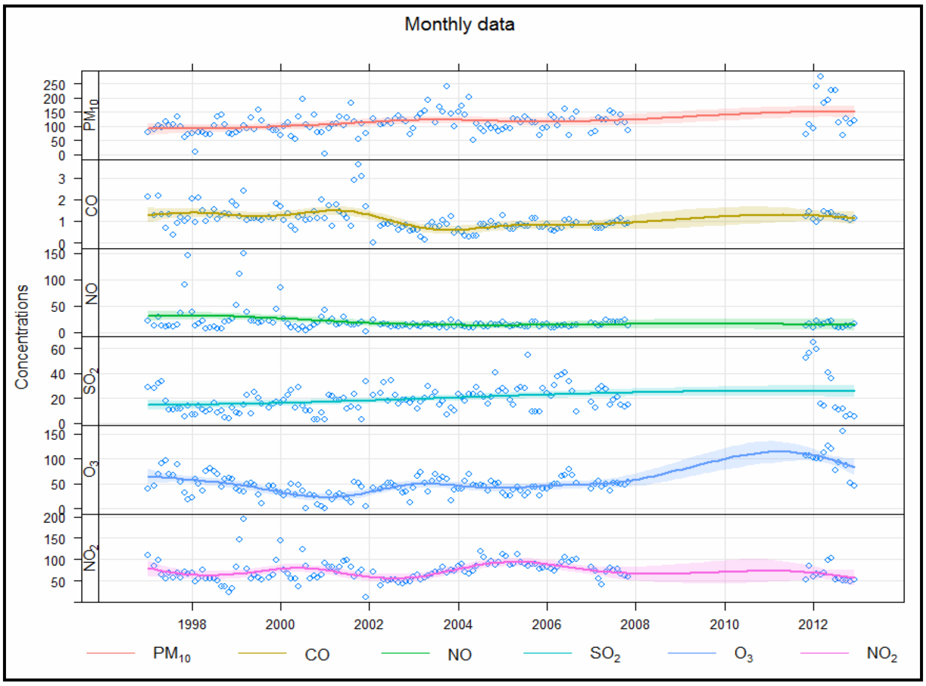

Fig. 2. Time plots of various air pollutants with smooth trend lines in Makkah city

Developing of an AQI for Makkah city

The propsed AQI was recommended for criteria air pollutants [($PM1_0$ (24-h average), NO_2 (1 h-average), SO_2 (24 h-average), O_3 (8 h-average) and CO (8 h-average)], these average time periods are included in the Saudi Arabia air quality standards (Table 5). The breakpoints between each index value were defined for each air pollutant. The recommended AQI is divided into 6 bands (subindices) follows the US-EPA- AQI as: good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy and hazardous (Table 7)[17].

Based on the actual measured ambient air pollutant concentrations, as well as the national standard and health impact, the sub-index was calculated for each pollutant. The index value of 50 was based on the annual air pollutant in the Saudi Arabia standards, however the index value of 100 was associated with the numerical value of the short-term standard (1 h- 24 hrs) for each pollutant. The breakpoints of the index band namely "unhealthy for sensitive groups" were based on the interim target – 1 (IT1) of the WHO guideline for NO_2[33] and the national standards of the Saudi Arabia for PM_{10}, SO_2, O_3 and CO air pollutants (Table 5).

In this recommended AQI, the breakpoints of higher bands namely "very unhealthy and hazardous" were selected basing on the serious health effects and increasing proportion of population experienced health effects according to the rational of WHO guidelines[33] and the 99th percentiles of air pollutant concentrations that were recorded in the last 15 years in Makkah city (Table 5)[30].

AQIs vary depending on the national standards and priorities of each country. In the present study, employing of breakpoints for PM_{10} was experienced some difficulties, for example, the breakpoint of PM_{10} between the low and moderate bands in the UK–AQI is 49 µg/m^3 and between good and moderate bands in the US-EPA-AQI is 54 µg/m^3. The rproposed breakpoint between the low and moderate bands was 100 µg/m^3, double of the USEPA and UK values, and relatively similar to the AQI for Kuwait (90 µg/m^3), due to high background of partuclate matter in the arid environment. Regarding NO_2, the index band "unhealthy for sensitive group" was selected basing on the experimental studies of people with asthma and chronic obstructive pulmonary diseases, who are more susceptible to the acute effects of NO_2[10]. The values ranged within 375-565 µg/m^3 are the lowest observed levels for health effects[10]; i.e. NO_2 can only generate AQI ≥ 200 µg/m^3.

Table 7. The recommended AQI category, air pollutants and health breakpoints for Makkah city

Band	Index	Air pollutant*				
		PM_{10} 24-hour- µg/m^3	SO_2 24-hour µg/m^3	O_3 8-hour µg/m^3	NO_2 1-hour µg/m^3	CO 8-hour mg/m^3
Good	0 - 50	0 - 100	0 - 85	0 - 100	0 - 100	0 - 4
Moderate	51 - 100	101 - 340	86 - 360	101 - 157	101 - 200	4.1 - 10
Unhealthy for sensitive group	101 - 150	341 - 431	361 - 585	158- 240	201 - 564	11 - 13
Unhealthy	151 - 200	432 - 512	596 - 808	241 - 400	565- 1034	14 - 17
Very unhealthy	201 - 300	513 - 675	809 - 1606	401- 800	1035 - 1955	18 - 35
Hazardous	301 - 500	676 - 1000	1607 - 2138	> 800	> 1955	>35

*Mean concentration

Discussion and Conclusion

AQI provides public with understandable information on air quality and helps decision makers to manage air quality. AQIs are similar in concept and targets but may be differed in implementation. The proposed index bands and breakpoints were based on a part on the scientific judgment, and the international air quality indices. Two steps were involved in developing the AQI: 1) formation of bands for the criteria pollutants ranged between good (0-50), to hazardous (301-500), and 2) set up breakpoints for each index band depending on air pollutant trends, the national standard of Saudi Arabia, and the guidelines of the WHO. The selection of breakpoints for PM_{10} was difficult, as the national standard is 340 µg/m^3, ~7 times higher than the

WHO guideline (50 µg/m^3). The Saudi Arabia's air quality regulations should be revised on the basis of air pollution trends and WHO guidelines.

Acknowledgment

This study was funded by the National Research Centre, Cairo, Egypt and the Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research, Umm Al-Qura University, Makkah, Saudi Arabia.

References

1. Curtis, L., Rea, W., Smith-Willis, P., Fenyves, E., and Pan, Y., Adverse health effects of outdoor air pollutants, Environment International, 2006, 32, 815-830.
2. Kistan, A, Sakaya sheela L., haminum Ansari A., Comparison of air quality in Sipcot at Walajha town and Sipcot at Narasingapuram-Ranipet, Vellore District, Tamil Nadu, India, International Journal of ChemTech Research, 2015, 8 (4),1916-1922.
3. UNEP, Year Book emerging issues update, Air Pollution: World's Worst Environmental Health Risk, 2014. Available at: http://www.unep.org/yearbook/2014/PDF/chapt7.pdf (Accessed in April, 2016).
4. US-EPA, Air Quality Index (AQI): A Guide to air quality and your health. *US EPA, December 2011*. Retrieved 8 August, 2012.
5. WHO, Air quality guidelines for Europe, 2nd Ed, WHO Regional Publications, Europe Series No 91, 2000a, World Health Organization Regional Publication Office for Europe, Copenhagen.
6. Koken, P.J., Piver, W.T., Ye, F., Elixhauser, A., Olsen, L.M., Portier, C.J., Temperature, air pollution, and hospitalization for cardiovascular diseases among elderly people in Denver, Environ Health Perspect, 2003, 111, 1312–1317.
7. Brook, R.D., Rajagopalan, S., Pope, C.A.III., Brook, J.R., Bhatnagar, A., Diez-Roux, A. and et al., Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association, Circulation, 2010, 121, 2331–2378.
8. Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., Amann, M. and et al., A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010, *Lancet, 2012*, 15 (380)*,* 2224-*2260.*
9. Wise, J., Nitrogen dioxide is linked to 5900 deaths a year in London, report says, BMJ, 2015, 17, 351.
10. WHO, Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005, Summary of risk assessment, World health organization, 1211 Geneva 27, Switzerland, 2006.
11. Beig, G., Ghude, S.G., Deshpande, A., Scientific evaluation of air quality standards and defining air quality index for India. Research report NO r-127, 2010, Indian Institute of tropical meteorology- Pune-411008- India, Ministry of Earth Science, Gov. of India.
12. AQI-EPA., Air quality guide for ozone. 2008. Available http://www.airnow.gov /index.cfm? action= pubs.aqiguideozone (Accessed in Aprilt, 2015).
13. Murena, F., Measuring air quality over large urban areas: development and application of an air pollution index at the urban area of Naples, Atmos. Environ., 2004, 38, 6195-6202.
14. Air Quality Index, American Lung Association. American Lung Association. Retrieved 20 August 2015.
15. Spare the Air, *Summer Spare the Air*. Retrieved 20 August 2015.
16. FAQ, Use of masks and availability of masks, Retrieved 20 August 2015.
17. US-EPA, *Air Quality index: a guide to air quality and your health*, Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, 2008.
18. WHO, Guidelines for air quality. Geneva, World Health organization, WHO/SDE/OEH/00.02, 2000b.
19. US-EPA., Federal register- Air quality index reporting: proposed rules, 1998, 63 (236).
20. COMEAP. The Quantification of the Effects of Air Pollution on Health in the United Kingdom. Department of Health. HMSO, London, 1998. Available: http://www.comeap.org.uk/documents/reports.html
21. Liang, W.M., Wei, H.Y. and Kuo, H.W., Association between daily mortality from respiratory and cardiovascular diseases and air pollution in Taiwan. Environment Research*,* 2009, 109, 51–58.

22. Strickland, M.J., Darrow, L.A., Klein, M., Flanders, W.D., Sarnat, J.A., Waller, L.A., Sarnat, S.E., Mulholland, J.A. and Tolbert, P.E., Short-term associations between ambient air pollutants and pediatric asthma emergency department visits, Am J Respir Crit Care Med., 2010, 182, (3), 307–316.
23. Prathipa V., Sahaya Raja A., Air quality assessment and air quality index of Dindigul town (Tamil Nadu), India– A case study, International Journal of PharmTech Research, 2015, 8 (6), 45-55.
24. Sharma, M., Pandey, R., Maheswari, M., Sengupta, B., Shukla, B.P. and Mishra, A., Air quality index and its interpretation for the city of Delhi. Clean Air. International Journal on Energy for a Clean Environment, 2003, 4, 83-98.
25. PME, Presidency of Meteorology and Environment, Kingdom of Saudi Arabia National Environmental Standard, Available at: http://www.pme.gov.sa/en/En_EnvStand19.pdf (Accessed in March, 2016).
26. Khodeir, M., Shamy, M., Alghamdi, M., Zhong, M., Sun, H., Costa, M., Chen, L.C. and Maciejcczyk, P.M., Source apportionment and elemental composition of $PM_{2.5}$ and PM_{10} in Jeddah City, Saudi Arabia, Atmospheric Pollution Research, 2012, 3, 331-340.
27. AlHarbi, B.H., Pasha, M.J. and Tapper, N., Assessment of ambient air quality in Riyad city, Saudi Arabia, *Current World* Environment, 2014, 9 (2), 227-236.
28. Spektor, D.M., A Review of the scientific literature as it pertains to gulf war illnesses, Volume 6, OIL WELL FIRES, National Defense Research Institute, RAND, 1998.
29. Husain, T., Abdulwahab Khalil, A., Environment and Sustainable Development in the Kingdom of Saudi Arabia: Current Status and Future Strategy, Journal of Sustainable Development; 2013, 6 (12), 14-30.
30. Munir, S, Habeebullah, T.M., Seroji, A.R., Gabr, S.S., Mohammed, A.M.F. and Morsy, E.A., Quantifying temporal trends of atmospheric pollutants in Makkah, Atmospheric Environment, 2013, 77, 647-655.
31. Habeebullah, T.M., An analysis of air pollution in Makkah—A view point of source identification, Environment Asia, 2013, 6 (2), 11-17.
32. Habeebullah, T.M., Said Munir, Abdel Hameed, A.A., Morsy, E.A., Seroji, A.R., Atif, M.F.M., The interaction between air quality and meteorological factors in an arid environment of Makkah, Saudi Arabia, International Journal of Environmental Science and Development, 2015, 6 (8), 576-580.
33. WHO, Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005, Summary of risk assessment, World health organization, 1211 Geneva 27, Switzerland 2006.

*****