Characterizing Air Pollution in Al-Tanaeim Industrial Zone, North the City of Makkah, Saudi Arabia

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Abstracts

This study aims to characterize air pollution in Al-Tanaein industrial zone, near the Holy City of Makkah. A mobile air quality monitoring station was installed about 10 km from the Holy Mosque on the north side of Makkah. Several air pollutants including nitrogen oxides (NOx), nitrogen dioxide (NO_2) nitric oxide (NO), carbon monoxide (CO), sulphur dioxide (SO_2), ozone (O_3), particulate matter with aerodynamic diameter up to 10 micrometer (PM_{10}) and meteorological parameters such as wind speed, wind direction, and temperature were monitored during the year 2013. Preliminary analysis indicated that PM_{10} was the only pollutant which exceeded the annual (80 µg/m^3) and daily (340 µg/m^3) air quality standards set by the General Authority of Meteorology and Environmental Protection of Saudi Arabia. Annual average of PM_{10} for 2013 was 195 µg/m^3 and daily averages (µg/m^3) were 550, 479, 442, 403, 396, 365, 358 and 352 when PM_{10} levels were greater than the air quality standard. There were total 8 exceedances: January (1), February (1), March (2), June (3) and July (1), whereas the number of allowances is 24, which means that daily average of PM_{10} is still lower than the air quality standard. Correlation analysis was performed between various air pollutants and meteorological parameters. PM_{10} had positive correlation with O_3, SO_2, NOx, temperature and wind speed and negative correlation with CO, atmospheric pressure and relative humidity. The strongest positive correlation was observed between O_3 and temperature, whereas the strongest negative correlation was observed between relative humidity and temperature. Correlation plots and polar plots were employed to analyse the association between various pollutants and to identify their emission sources. Further work is required to quantify emission sources of various air pollutants using receptor modelling and dispersion modelling approaches.

Keywords: Makkah, industrial emissions, PM_{10}, NOx, air quality.

1. Introduction

Epidemiological research agree that exposure to air pollution may cause chronic diseases, such as cardiovascular and respiratory morbidity and mortality (Abe et al., 2015). Reducing the levels of PM_{10}, $PM_{2.5}$ and ground level ozone below a certain level can help save lives and money (Abe et al., 2015). Scientific investigations show that there is a link between exposure to high PM concentrations and death and hospital admission due to cardiovascular diseases (Friger et al., 2015). PM affects the respiratory tract and accumulates in nasal, pharyngeal and laryngeal regions (Praznikar and Praznikar, 2012). PM can initiate the most critical disease in humans which is cancer especially lung cancer, such as adenocarcinoma and squamous cell carcinoma. The severity of illness depends on individual level of exposure to the PM plus physical characteristics of the individuals. The most common type of PM that has effective role on health are PM_{10} and $PM_{2.5}$.Many studies show the incidence of lung cancer and high mortality rates due to exposure to PM_{10} and $PM_{2.5}$ (Praznikar and Praznikar, 2012). Implementing policies to improve air quality monitoring, modelling and reducing air pollution can result in clean air leading to better health of individuals and communities (Maesano et al., 2016).

Butenhoff et al. (2015) analysed hourly ozone (O_3), nitrogen dioxide (NO_2), and carbon monoxide (CO) data collected at six cities in Saudi Arabia (Riyadh, Jeddah, Makkah, Yanbu, Dammam, Hafouf) and two remote locations in the mountainous southwestern region of Alsodah for the year 2007. It was reported that O_3 and CO have exceeded international air quality standards and that exceedances increased during Ramadan (Sep. 12 – Oct. 13). Furthermore, they found that the pollutant levels in Makkah were higher than other cities during the Hajj period from December 18 to December 21 because huge number of people comes to Makkah during this period to performing Hajj, which results in high volume of road traffic and use of energy. Several researchers (Alghamdi, 2016; Al-Jeelani 2009; Othman et al. 2010; Seroji 2011; Muniret al. 2013a; Munir et al. 2013b; Habeebullah 2013a; Habeebullah 2013b) have reported that particulate matter exceed air quality standard in Makkah, especially during the Hajj season. Air pollution in Saudi Arabia is now considered to be a significant environmental problem due to the existence of exhaustive anthropogenic activities. Like everywhere else, heavy traffic density in the streets of the urban areas leads to the emission of various pollutants, including NO_2, CO, PM_{10} and VOCs. In addition to the emission of high volume of pollutants, local climatic conditions (high temperature, intense solar radiation, no rain) add to the air quality problem, especially dust pollution in Saudi Arabia (Aljeelani,2009). Dust storm events are the main reason for the highest PM_{10} concentrations in winter and spring seasons (Alghamdi, 2016).

In this study air pollutant concentrations in Al-Tanaeim area in Makkah are analyzed during 2013. This is an industrial area where various atmospheric pollutants are emitted by the industrial units in this area. We aim to make an investigation into the types and levels of various air pollutants and want to determine whether these pollutants exceed air quality standards or not.

2. Methodology

The data used in this study were collected at Al-Tanaeim industrial zone situated in the north of Makkah Al-Mukarramah about 10 km from the Holy Mosque. Using standard air quality monitoring equipment the concentrations of various air pollutants (such as sulphur dioxide (SO_2 $\mu g/m^3$), nitrogen dioxide (NO_2 $\mu g/m^3$), nitric oxide (NO $\mu g/m^3$), nitrogen oxides (NOx $\mu g/m^3$), carbon monoxide (CO mg/m^3), ozone (O_3 µg/m^3), particulate matter with aerodynamic diameter of up to 10 micron (PM_{10} µg/m^3)) and meteorological parameters (e.g. wind speed (WS m/s), wind direction (WD degrees from the north), temperature (Temp ºC) and relative humidity (RH %)) were measured during 2013. Figure 1 shows the map of the monitoring station in Al-Tanaeim industrial zone, which is located next to Makkah – Madinah Road. A summary of the data is given in Table 1.

R programming language ((R Development Core Team, 2012) and one of its package openair (Carslaw and Ropkins, 2012) were used for data analysis and developing the Figures.

Table 1. Summary of the data 2013 collected from industrial zone in Makkah

Variables / metric	SO_2 µg/m^3	NO_2 µg/m^3	NO µg/m^3	NOx µg/m^3	CO mg/m^3	O_3 µg/m^3	PM_{10} µg/m^3	WD Deg.	WS m/s	Temp oC	RH %
Min.	0.18	1.12	0.09	0.17	0.02	0.36	24.00	2.94	0.00	21.84	10.41
1st Qu.	2.42	18.78	12.22	0.57	0.46	33.32	110.00	119.70	0.64	29.19	28.44
Median	6.33	30.03	28.27	2.40	1.15	66.33	159.00	155.00	0.93	32.49	39.98
Mean	12.75	32.22	37.94	33.06	4.86	71.26	194.90	164.90	0.98	32.33	41.13
3rd Qu.	14.08	43.65	50.84	53.81	5.90	101.90	243.00	212.30	1.26	35.28	52.83
Max.	280.10	119.70	328.10	655.60	204.20	347.20	973.00	306.10	3.38	46.02	80.32

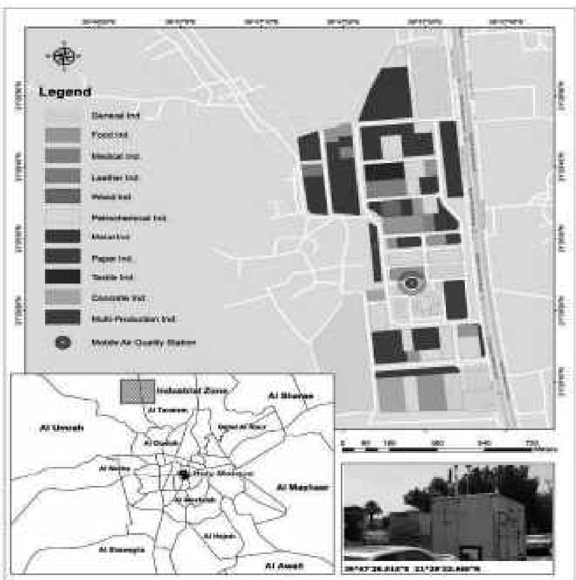

Figure 1. Location of the air quality monitoring station in Al-Tanaeim industrial zone in Makkah Saudi Arabia.

3. Results and Discussion

Preliminary statistical analysis of the data showed that PM_{10} was the only pollutant which exceeded the annual (80 µg/m^3) and daily (340 µg/m^3) air quality standards set by the General Authority of Meteorology and Environment Protection of Saudi Arabia. Figure 2 compares the daily average PM_{10} concentrations with air quality standards. Annual average of PM_{10} for 2013 was 195 µg/m^3 and daily averages (µg/m^3) were 550, 479, 442, 403, 396, 365, 358 and 352 when PM_{10} levels were greater than the air quality standard (Figure 2). There were total 8 exceedances: January (1), February (1), March

(2), June (3) and July (1), whereas the number of allowances is 24, which means that daily average of PM_{10} is still lower than the air quality standard. Monthly average of various air pollutants are presented in Table 2.

Correlation analysis was performed between various air pollutants and meteorological parameters. PM_{10} had positive correlation with O_3, SO_2, NOx, temperature and wind speed and negative correlation with CO, atmospheric pressure and relative humidity. The strongest positive correlation was observed between O_3 and temperature, whereas the strongest negative correlation was observed between relative humidity and temperature. For more details see Figure 3.

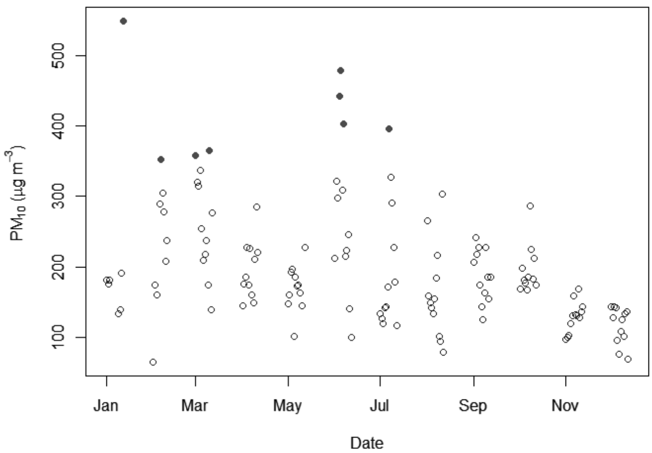

Figure 2. Comparing the 24 hour PM_{10} concentrations (µg/m^3) with air quality standards (340 µg/m^3) set by PME of Saudi Arabia.

Table 2. Monthly average level of each pollutant during various months of the year 2013

Month	**SO_2**	**NO_2**	**NO**	**NOx**	**CO**	**O_3**	**PM_{10}**
Jan	9.20	41.84	36.63	82.12	1.00	54.89	231.99
Feb	11.22	41.32	51.17	102.16	0.97	44.10	235.36
March	19.01	31.90	46.48	80.11	0.74	49.05	263.46
April	11.18	35.48	23.82	59.39	0.50	80.55	195.09
May	7.90	23.92	12.23	36.30	0.40	61.08	167.79
June	6.89	25.06	9.38	34.41	0.41	94.26	281.26
July	7.37	37.82	45.19	0.60	6.22	105.88	197.17
Aug	7.06	27.73	34.79	0.48	5.75	86.55	164.05
Sep	5.87	32.62	38.49	0.58	6.59	92.16	187.81
Oct	47.67	42.95	90.63	1.08	16.30	56.29	198.70
Nov	12.38	20.71	33.09	0.68	7.17	61.73	129.46
Dec	13.51	27.48	40.98	0.80	13.16	62.00	117.97

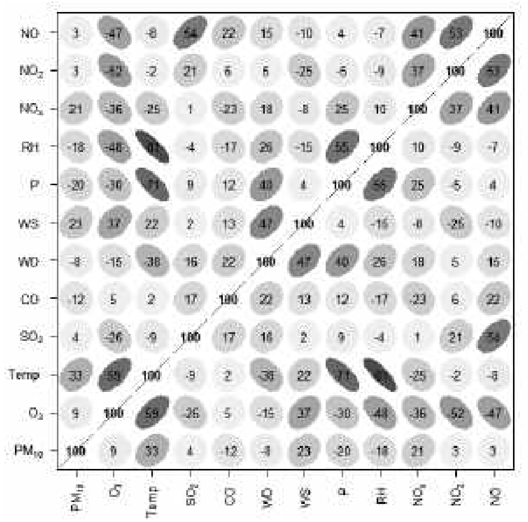

Figure 3. Correlation plot of various air pollutants and meteorological parameters using 2013 data from Al-Tanaeim industrial zone in Makkah.

Polar plots of PM_{10} are shown in Figure 4, where left – panel shows a conditioned plot (number of points < 3) and the right – panel shows unconditioned normal polar plot. The plot shows that high levels of PM_{10} are associated with wind blowing from the northwest direction at a speed of about 3 m/s and above. At low wind speed (ws < 2 m/s), PM_{10} levels are relatively low regardless of the wind direction. Theoretically, at low wind speed locally emitted air pollutants are not diluted and they stay in the atmosphere near the emission sources, whereas at high wind speed the locally emitted air pollutants are quickly dispersed. Therefore, high PM_{10} levels at low wind speed in Figure 4, probably means there are no local sources of PM_{10}. There seem to be some emission sources in the northwest direction as shown in Figure 4 and when wind blows from that direction, the emissions are brought towards the monitoring stations. Therefore, wind speed and wind direction play an important role in the observed PM_{10} concentrations.

In Figure 5, polar plots of NO_2, CO, SO_2 and O_3 are depicted. One thing is common in the polar plots of NO_2, SO_2 and CO that they show low concentrations when wind is blowing from east or southeast direction. NO_2 concentration is higher even when there is no wind blowing or wind speed is low. There are some other minor differences in the polar plots as well. O_3, with some minor exceptions, shows opposite trends to NO_2. This is expected because O_3 is negatively correlated with NO_2. O_3 is not a primary pollutant (it is not directly emitted by emission sources), it is rather formed in the atmosphere from its precursors (NOx and hydrocarbons) in the presence of solar radiation. Therefore, O_3 shows a different pattern. For more details on O_3 behaviour in Makkah and its association with atmospheric conditions and its precursors see Munir et al. (2015).

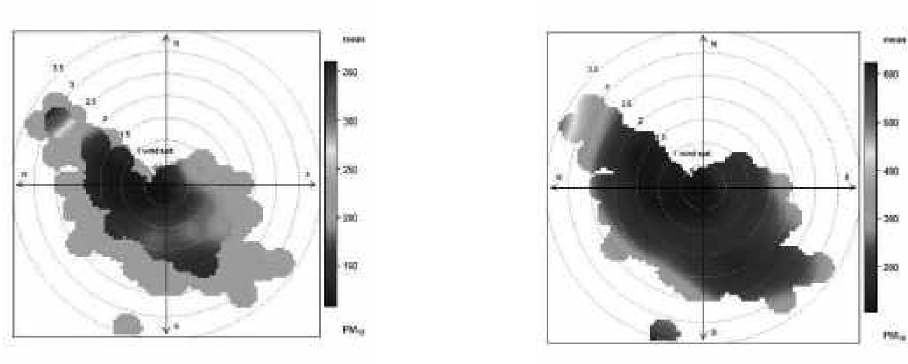

Figure 4. Normal polar plot (right) and conditioned (number of points < 3) polar plot (left) of PM_{10} for year 2013 in Makkah.

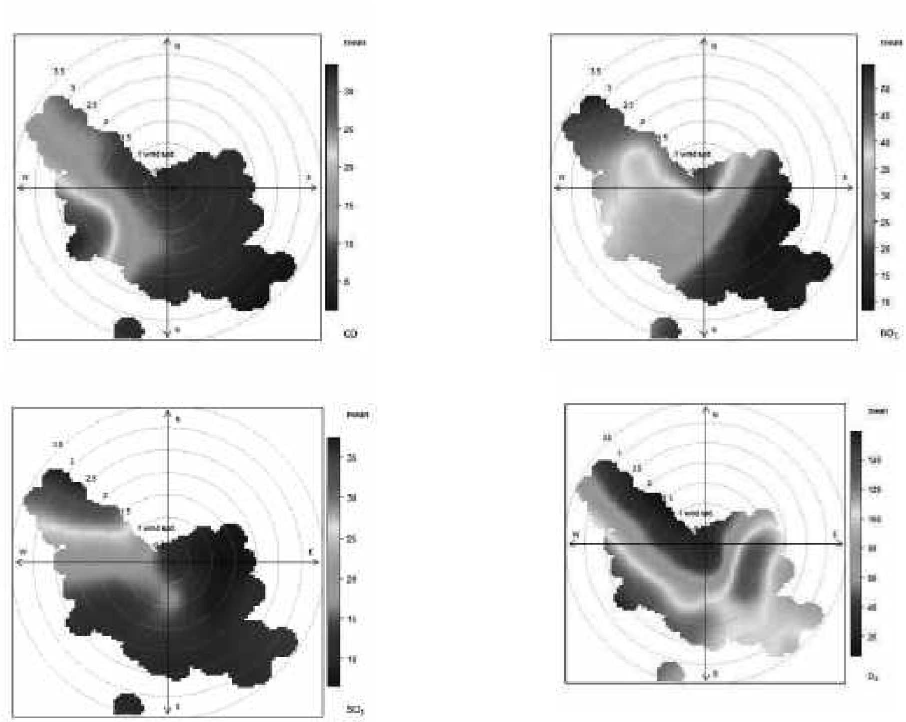

Figure 5. Polar plots of CO, NO_2, SO_2 and O_3 for year 2013 in Makkah.

4. Conclusion

In this study air quality in Al – Tanaeim industrial zone located to the north of Makkah Al-Mukarramah during 2013 is analysed. It was observed that concentrations of most pollutants are below the air quality standards, except PM_{10} annual concentrations. Pollutants are strongly affected by the levels of other pollutants and meteorological conditions, such as wind speed, wind direction, and temperature. Polar plots are employed to analysed the effect of meteorological parameters on the levels of air pollutants and it is observed that the high levels of PM_{10} are more due to local meteorological and geographical conditions, rather than due to emission sources.

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