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Ambient Air Quality of Karachi City as Reflected by Atmospheric Particulate Matter (PM_{10}) Concentrations

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Abstract: The present study examines the variation of ambient aerosol (PM_{10}) concentrations in Karachi, city. Samples were collected from ten different locations, representative of urban background, residential, traffic and industrial areas from 2007 to 2011. At each location, PM_{10} was measured continuously from 08:00 am to 06:00 pm at local time. The maximum 10 h average particulate matter (PM_{10}) mass concentrations were found at Tibet Centre (440.1µg/m³) and minimum at PCSIR Campus (21.7µg/m³) during 2008. A rising trend during 2008 may be due to the civil works for bridges and extension of roads at different locations in Karachi. The results also suggest that urban traffic and industrial areas appeared to have higher PM_{10} concentration than residential and background areas.

Keywords: PM_{10}, annual averages, statistics, co-relation

Introduction

Ambient aerosol is a suspension of a complex mixture of liquid and solid particles in the air that vary greatly in shape, size, composition and concentration, depending on their source, processes in the atmosphere and spatial and temporal factors. It also has a wide variety of physical and chemical properties in the atmosphere. The particles may originate both from natural or anthropogenic sources.

Exposure to particulate air pollution can result in serious short-term and long-term effects on human health even at low concentrations, because it can be absorbed into the lung tissues during breathing. Research has shown that short-term health effects include lung function disorder and resultant hospital admissions and mortality, whereas long term health effects result in increased incidence of mortality due to respiratory diseases. The adverse effects of particulate matter (PM) pollution on human health and the environment is a major problem for the population and administration. A number of reports have shown that particulate matter pollution is associated with an increase in hospitalization, lung function disorder, asthma, bronchitis, other respiratory diseases and premature deaths (Sicard *et al.,* 2011). A large number of epidemiological studies show a strong co-relation between the concentration of particulate matter and human health hazards (Pop *et al*., 2002).

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As the air pollution increases, the mortality due to the probable deaths particularly of vulnerable people also increases (Zanobetti *et al.,* 2002; Schwartz., 2001). This shows that air pollution is not only the cause of death of people living in a 'high risk pool', but also includes new habitants to that 'high risk pool'. Results of recent studies showed that short-term inhalation of aerosol particulate found in the urban environment increases hospital admission for asthma and chronic obstructive pulmonary diseases (COPD). There is also an acute relationship of PM and cardiovascular outcomes (Brook *et al*., 2010). Association between air pollution and cause-specific pattern between particulate matter with aerodynamic diameters < 10 µm (PM_{10}) and cause specific mortality in a multicity hierarchical model has been studies by Schwartz (2000) who has looked at mortality displacement with regard to cause-specific deaths. Some studies also found an association between airborne particulate and mortality by age groups (Goldberg *et al.,* 2000)

Urbanisation and industrialisation have brought together large concentrations of people in small areas. The growing urban population, level of industrialisation and traffic congestion are the main factors responsible for poor air quality in Karachi city. According to population Karachi ranks as the largest city of Pakistan. It is the most urbanised and largest economic centre of Pakistan. During the last three decades, it has faced mass urbanization, huge population growth and many fold increase in vehicles and industrial development. Pollution concentrations within Karachi are the worst in Pakistan (Sanchez-Triana *et al.,* 2014).

The main focus of this study is to analyse the particulate matter (PM) concentrations and their trends over different areas of Karachi city. This will in turn help to overcome air pollution and rate of mortality due cordiopulmorary diseaes.

Materials and Methods

Study areas. The present research has been focused on Karachi, the provincial capital of Sindh, Pakistan. Karachi has an area of 3,640 km^2 and is located along the cost of the Arabian Sea. Its geographical co-ordinates are 24°45' N and 66°37' E. It is the largest metropolitan city of Pakistan, has an estimated population of over 23.5 million people as reported in 2013. With respect to the population, Karachi is the 2nd largest city in the world, 7th largest urban agglomeration in the world and the largest city in the Muslim world. Karachi has a moderately temperate climate with a generally high relative humidity that varies from 58% in December (the driest month) to 85% in August (the wettest month). In winter, the average temperature of the city is about 21°C while in summer it reaches up to 35°C. Karachi receives about 256 mm of average annual rainfall (Sajjad *et al.*, 2010).

Karachi is the financial and commercial capital of Pakistan as well as a major sea port. It plays an important role in the economy of Pakistan and is considered as the economic and financial gateway of Pakistan. Karachi has several large industrial zones such as Karachi Export Processing Zone, Sindh Industrial Trading Estate, Korangi Industrial Area, Northern by-pass Industrial Zone, Bin Qasim and North Karachi Industrial Zone, located on the fringes of the main city (Sajjad *et al.,* 2010). Its primary industries are textiles, pharmaceuticals, steel, and auto-mobiles. Due to industrialisation, business activities and employment opportunities, Karachi has been facing mass scale rural-urban migration from all over the Pakistan.

Sampling map. Locations for sampling have been selected at ten different areas of Karachi city marked as urban background (UB), residential (R), Commercial (C) and industrial (I) areas.

Air monitoring locations. Daily 10 h (from 8 am to 6 pm) continuous air monitoring was carried out in urban traffic areas T-1 and T-2 (Karimabad and Tibet Centre),

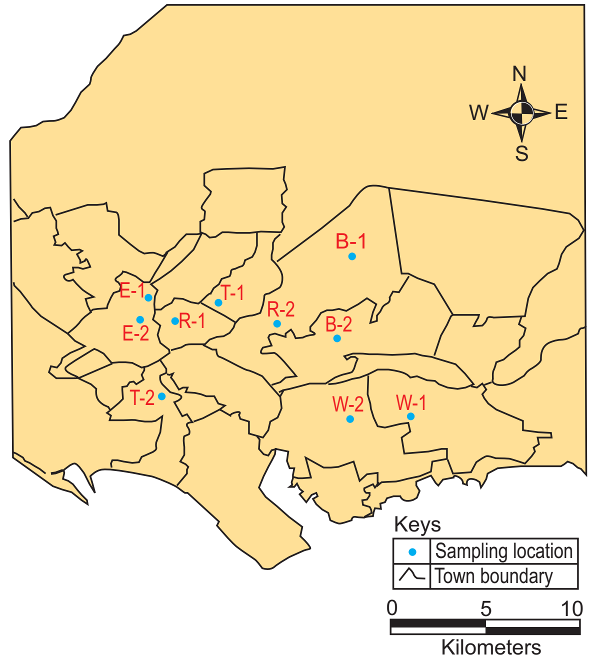

Fig. 1. Air monitorning locations in Karachi city.

city core residential areas R-1 and R-2 (Nazimabad and Gulshan-e-Iqbal), industrial areas in the west W-1 and W-2 (Singer chorangi and Chamra chorangi), industrial areas in the east E-1 and E-2 (Siemens chorangi and Naurus chorangi) and urban background areas B-1 and B-2 (PCSIR Campus and COD filter plant) (Fig. 1).

The air monitoring areas represented predominantly urban areas associated with high, medium and low human activities. This was done with an intention to get a better representation of the city. R-1 and R-2 (Nazimabad and Gulshan) were located almost in the central region of the city and represented residential areas with moderate vehicular traffic. T-1 and T-2 (Karimabad and Tibet Centre) were located in the city core area having large commercial buildings and heavy vehicular traffic. Industrial areas in the west W-1 and W-2 (Singer chorangi and Chamra chorangi) represent regions with moderate vehicular traffic, whereas those in the east E-1 and E-2 (Siemens chorangi and Naurus chorangi) represent areas with high vehicular traffic. The B-1 and B-2 locations (PCSIR Campus and COD filter plant) fall in the outskirts/background areas of the city and are sparsely populated with low vehicular traffic.

Air monitoring instrument and method. Particulate matter concentration was monitored by a standard method on daily basis. Daily 10 h (from 8 am to 6 pm) air monitoring was carried out on same days of the week (working days Monday to Thursday) and the samples were collected on the glass fibre filters (203× 254 mm) by using high-volume air samplers. The high volume is considered a reliable instrument for measuring the weight of PM_{10} in ambient air. Three high-volume apparatus were used for sampling and ambient samples were collected at a height of about 10 m (US EPA, 1999) above the ground level.

Results and Discussion

This study shows the result of PM_{10} concentration carried out at 10 different locations, representative of urban background (UB), residential (R), traffic (T) and industrial (I) areas during the years 2007-2011. This is the first step in simple linear inter air monitoring areas correlation analysis with PM_{10} concentration. Pearson's coefficient of correlation for PM_{10} concentration as calculated between the monitoring areas, are presented in Table 1.

All correlation coefficients were found to be significant (at the 0.05 level). Although the concentration levels exhibit significant variability, the strength of Pearson's coefficient correlation between B-1 and B-2 (PCSIR campus and COD Filter plant) was found to be higher than other monitoring stations. The reason was that they are located at the urban background areas of the city and that they are mutually close by aerial distance. T-1 and T-2 (Karimabad and Tibet Centre), was higher than other air monitoring sites. The reason was that they are located within the city core area. The strength of correlation of R-1 and R-2 (Nazimabad and Gulshan), was found to be higher than other monitoring stations, both are residential places with moderate vehicular traffic. Similarly, the strength of correlation of W-1 with W-2 (Singer chorangi and Chamra chorangi) and E-1 with E-2 (Siemens chorangi and Naurus chorangi) was found to be higher than other monitoring stations, both are located at the industrial zone of Karachi city.

The correlations found in this study, between B-1 and B-2 suggested that any one location is enough to represent urban background areas. It can also be observed that all the air monitoring stations are inter-correlated but hold the characteristics of the individual area due to particulate emissions. Regarding the level of consistency with respect to particulate pollution during the study period, more consistency was found in T-1 and T-2 which are surrounded by high rise buildings with commercial activities and high traffic density producing high vehicular emissions and hence, the pollution load is also found higher in static.

Table 2 depicts descriptive statistics of PM_{10} for different air monitoring areas during the study period. The highest daily 10 h average PM_{10} mass concentration (440.1µ g/ m³) for the study period was recorded at T-2 (Tibet centre) in 2008. Within the urban areas of Karachi city daily 10 h average PM_{10} ranged from 21.7µg/m³ (at B-1 in 2008 and 2011) to 440.1 µg/m³ (at T-2 in 2008). Over the 5 year period the sites with the highest average PM_{10} concentrations were T-2 (224.8 µg/m³), T-1 (189.9 µg/m³) and E-2 (182.7 µg/m³).

The average concentration of PM_{10} in urban traffic places T-1 and T-2 were 1.93 and 2.13 times higher than urban background site B-1 and B-2 whereas, the average concentrations in R-1 and R-2, W-1 and W-2, E-1 and E-2 were 1.16 & 1.34, 1.53 & 1.58 and 1.67 and 1.86 times higher than that observed in urban background locations B-1 and B-2 (PCSIR Campus and COD Filter plant), respectively.

Table 1. Inter-station co-relation co-efficient: daily 10 h average PM_{10}

	B-1	B-2	R-1	R-2	T-1	T-2	Ind.W-1	Ind.W-2	Ind.E-1	Ind.E-2
B-1	1.000	-	-	-	-	-	-	-	-	-
B-2	0.986	1.000	-	-	-	-	-	-	-	-
R-1	0.944	0.908	1.000	-	-	-	-	-	-	-
R-2	0.952	0.951	0.977	1.000	-	-	-	-	-	-
T-1	0.918	0.902	0.931	0.949	1.000	-	-	-	-	-
T-2	0.976	0.976	0.932	0.967	0.973	1.000	-	-	-	-
Ind.W-1	0.590	0.477	0.777	0.660	0.728	0.603	1.000	-	-	-
Ind.W-2	0.821	0.794	0.914	0.917	0.968	0.895	0.821	1.000	-	-
Ind.E-1	0.720	0.669	0.742	0.663	0.468	0.570	0.468	0.413	1.000	-
Ind.E-2	0.550	0.494	0.514	0.421	0.220	0.358	0.252	0.127	0.947	1.000

Table 2. Statistic of daily 10h Average PM10 concentrations for different air monitoring areas

Year	PM_{10}($\mu g/m^3$) at different areas									
2007	B-1	B-2	R-1	R-2	T-1	T-2	Ind.W-1	Ind.W-2	Ind.E-1	Ind.E-2
N	48	48	48	48	48	48	48	48	48	48
Mean	110.0	119.7	120.1	147.0	221.1	263.5	141.8	165.9	152.7	173.4
Median	100.5	107.5	107.8	112.0	236.4	225.0	112.9	135.6	121.8	160.0
Stdev	30.5	35.8	44.8	59.8	79.3	97.1	52.0	62.5	54.1	54.7
Max	221.7	241.8	294.6	316.0	339.9	410.0	300.0	320.5	281.2	323.0
Min	48.6	61.4	49.3	48.8	61.7	76.9	90.3	61.5	39.9	91.8
2008										
N	48	48	48	48	48	48	48	48	48	48
Mean	120.4	131.1	162.2	200.5	247.6	288.6	181.6	198.9	208.6	211.3
Median	110.4	112.4	129.4	204.5	248.1	272.6	181.8	192.1	213.7	210.6
Stdev	34.6	44.2	68.1	78.7	69.8	102.2	61.7	87.5	85.3	79.1
Max	237.3	254.5	310.1	344.4	382.2	440.1	345.1	329.8	340.2	357.1
Min	21.7	69.9	59.4	71.3	97.3	103.9	107.8	60.3	94.4	95.2
2009										
N	48	48	48	48	48	48	48	48	48	48
Mean	91.0	93.5	113.6	121.6	196.2	211.6	190.1	170.6	143.9	156.0
Median	89.2	90.1	110.3	121.0	210.5	212.9	202.0	160.9	132.5	132.5
Stdev	21.7	19.5	25.1	29.6	52.4	76.6	55.4	61.5	32.9	50.0
Max	210.4	211.8	227.9	242.5	322.2	338.2	301.4	281.6	294.2	276.3
Min	41.7	41.7	49.9	57.8	61.8	88.8	73.4	66.6	113.6	92.2
2010										
N	48	48	48	48	48	48	48	48	48	48
Mean	75.6	84.5	71.6	84.3	134.4	167.0	100.0	119.3	122.5	145.0
Median	76.6	85.8	70.0	85.0	114.4	158.6	106.3	110.4	112.4	134.7
Stdev	14.7	15.4	18.7	20.5	45.3	55.3	23.9	34.3	31.1	36.7
Max	137.6	153.5	192.6	229.9	251.7	289.9	248.6	241.1	261.2	281.2
Min	25.2	39.3	25.0	24.6	38.9	58.8	49.3	40.5	75.5	81.2
2011										
N	48	48	48	48	48	48	48	48	48	48
Mean	93.7	97.8	102.3	105.3	150.1	193.1	139.2	122.5	194.3	227.9
Median	90.9	91.8	106.6	109.0	129.4	206.4	114.4	121.8	212.0	237.2
Stdev	20.5	24.4	24.9	26.5	55.4	58.0	47.0	27.0	46.1	45.5
Max	191.2	222.5	232.5	250.6	301.7	316.9	235.2	229.5	241.6	292.6
Min	41.7	29.7	39.8	42.1	48.1	66.4	73.8	72.2	68.8	95.2
Total										
N	240	240	240	240	240	240	240	240	240	240
Mean	98.1	105.3	114.0	131.7	189.9	224.8	150.5	155.4	164.4	182.7
Median	90.9	91.8	107.8	112.0	210.5	212.9	114.4	135.6	132.5	160.0
Stdev	8.0	11.9	20.3	25.1	13.8	21.6	14.5	24.3	22.0	15.9
Max	237.3	254.5	310.1	344.4	382.2	440.1	345.1	329.8	340.2	357.1
Min	21.7	29.7	25.0	24.6	38.9	58.8	49.3	40.5	39.9	81.2

The Government of Pakistan has set National Ambient Air Quality standards and the maximum 24 h average PM_{10} concentration in ambient air is 150 $\mu g/m^3$. An 'exceedence' is one when the pollutant measurement surpasses Pakistan National Ambient Air Quality Standard for a specific averaging time. Assuming that the 10 h averages are a good indicator of 24 h averages then the number of exceedences at each site was calculated.

In the total there were 20 exceedances at B-1 (7.38 %), 30 at B-2 (11.0 %), 60 at R-1 (22.1 %), 93 at R-2 (34.3 %), 129 at T-1 (47.6 %), 138 at T-2 (50.9 %), 101 at W-1 (37.2 %), 112 at W- 2 (41.3 %), 107 at E-1 (39.5 %) and 119 exceedances out of 240 observations at E- 2 (43.9 %).

In Nepal, the Ministry of Population and Environment (MOPE) has categorized five different types of air quality categories based on levels of PM_{10}. The categories prescribed are range 0-60 μg/m^3 as "Good", 60-120 μg/m^3 "Moderate", 121-350 μg/m^3 "Unhealthy", 351-425 μg/m^3 "Very Unhealthy" and > 425 μg/m^3 as "Hazardous" (Giri *et al.*, 2006).

The same categories have been maintained for explanation of the statistical analysis. In B-1 and B-2 most of the observations were "moderate", R-1, R-2, W-1 and W-2 were predominantly "unhealthy" categories. In E-1 and E-2 most of the observations were found to be "very unhealthy" category. The percentage of observations falling under "hazardous" were high in T-1 (66.6%) and T-2 (73.1%).

The proportion of exceedances related with air monitoring locations indicated that the locations situated away from the inner city and outside the commercial activities such as B-1 and B-2 tend to have lower concentration of pollution. In contrast, the locations situated in the inner-city such as T-1 and T-2 experience larger variations in daily concentrations due to high traffic density, various commercial activities and consequent sources of emissions. From the analysis of PM_{10} data, it was found that the quality of air in B-1 and B-2 was under 'Moderate' category. The quality of air in R-1 and R-2 were under the 'unhealthy' category, in W-1, W-2, E-1 and E-2 were under 'very unhealthy' category, whereas the quality of air in T-1 and T-2 were under 'hazardous' category. The locations and surroundings of T-1 and T-2 are quite similar therefore, it can be assumed that the difference in the observed concentrations can mostly be attributed to the traffic.

Conclusion

PM_{10} were characterised at four different areas representative of urban background, residential, traffic and industrial areas in Karachi city to identify the source and correlation between areas and PM_{10} concentration. Local sources of particulate concentrations are high traffic density, industrial emissions, construction activities, road dust re-suspension etc.

Overall, it was found that the traffic areas of Karachi are significantly more polluted than other locations. The pattern of particulate pollution was traffic > industrial > residential > background areas. Possible health risks include high estimated blood lead levels due to vehicular emission, pulmonary infections, cancer, heart attack and eye irritation due to high industrial emission in Karachi city. The infants, elders, and the persons who suffer with chronic cardiopulmonary diseases, influenza or asthma are at the risk of mortality and serious morbidity effects.

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