IOP Conf. Series: Earth and Environmental Science **133** (2018) 012031 doi:10.1088/1755-1315/133/1/012031

Variations of PM2.5, PM10 mass concentration and health assessment in Islamabad, Pakistan

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Abstract. Sparse information appears in lack of awareness among the people regarding the linkage between particulate matter (PM) and mortality in Pakistan. The current study is aimed to investigate the seasonal mass concentration level of PM2.5 and PM10 in ambient air of Islamabad to assess the health risk of PM pollution. The sampling was carried out with two parallel medium volume air samplers on Whatman 47 mm quartz filter at a flow rate of 100L/min. Mass concentration was obtained by gravimetric analysis. A noticeable seasonal change in PM10 and PM2.5 mass concentration was observed. In case of PM2.5, the winter was a most polluted and spring was the cleanest season of 2017 in Islamabad with 69.97 and 40.44 μgm^{-3} mean concentration. Contrary, highest (152.42 μgm^{-3}) and lowest (74.90 μgm^{-3}) PM10 mass concentration was observed in autumn and summer respectively. Air Quality index level for PM2.5 and PM10 was remained moderated to unhealthy and good to sensitive respectively. Regarding health risk assessment, using national data for mortality rates, the excess mortality due to PM2.5 and PM10 exposure has been calculated and amounts to over 198 and 98 deaths annually for Islamabad. Comparatively estimated lifetime risk for PM2.5 ($1.16\times10\text{-}^{6}$) was observed higher than PM10 (7.32×10^{-8}).

1. Introduction

Hastily particulate matter (PM) pollution in the air has been evolved all around the world, predominantly in developing countries. World health organization [1] claimed that high exposure to the particulate matter has potential to reduce projected life expectancies by 1 year which increases up to 5.5 years [2].

Airborne particulate matter emerges from both natural (volcanic eruption, forest fire and weathering of parent material and sea salt) and anthropogenic sources including power plants, internal combustion engines as well as from thermo-degradation process. These particles are known to be air toxins and were the subject of WHO guidelines in 2008 when 24-h maximum thresholds for fine (PM2.5) and coarse (PM10) particulate matter were set at 25 and 50 µgm-3 respectively. The extent of toxicity and residence time of particulate matter in the atmosphere directly associated with their morphology, size and surface area [1]. The literature showed that long persistent in the air and deeper penetration inside lungs makes PM2.5 more toxic than PM10 which cause respiratory and cardiovascular diseases due to short-term exposure and mortality by long-term exposure respectively [3].

The World Health Organization (WHO) reported approximately 360,000 premature deaths in Asia each year due to urban air pollution [4]. Pakistan is the most urbanized region in Asia with approximately 35% population resides in cities and towns which is predicted to increase up to 60% by 2050 [5]. This appears in ever increasing air pollution extent in all major cities of Pakistan including Karachi, Lahore, Quetta, Peshawar, and Islamabad. Previous studies have reported high TSP concentrations in Lahore and Karachi compare to other most polluted sites worldwide. Karachi ranked first among the top 18 polluted cities in the world with average 668 µgm-3 PM2.5 concentrations [6]. In the same lines, Lahore was reported to be more polluted with average PM2.5 mass concentration than New York City, Seoul, and Hong Kong. In 2001, a joint venture of Pak-EPA and JICA [7] monitoring of air quality of three cities (Rawalpindi, Islamabad, and Lahore) reported higher PM10 concentration in the ambient air than WHO limits i.e. 520, 709 and 895 µgm-3 respectively. Hence the PM10 and PM2.5 mass concentration were very higher than the national environmental quality standards for ambient air with maximum thresholds for PM10 (annual, 120; 24-h, 150 µgm-3) and PM2.5 (annual, 15; 24-h, 35 µgm-3) respectively [4]. So far, Pakistan bears economic health burden equal to 1% of the gross domestic product due to PM which is responsible for 22000 premature deaths among adults and 700 deaths among children in Pakistan [8].

In spite of the fact, monitoring and management of PM are not among the top priority in Pakistan due to insufficient information, inadequate law practices, and poorly managed organizations. Resultantly, little sporadic updates and reports which illustrated the emerging and seriousness of PM pollution in Pakistan could be found in the literature [7]. There is no sufficient work has been done on PM mass concentration in Pakistan, especially on PM2.5 size friction of PM which appears in lack of public awareness and increasing rate of mortality and respiratory diseases in Pakistan.

For a better understanding and measuring the extent of current PM pollution in the ambient air of Islamabad, the present study has been designed to measure PM10 and PM2.5 mass concentration in Islamabad. Apparently, the previous studies showed a significant change in PM mass concentration with a change in the season [9]. Hereby, the results were fourthly optimized by evaluating seasonal trends in change of PM concentration. In addition, it is the first time to measure the PM2.5 and PM10 mass concentration simultaneously in Islamabad. The results of this study will be used as a baseline for future studies and will be a good addition to existing data of PM pollution in Pakistan. Furthermore, the air quality index of Islamabad during this period along with health consequence of particulate matter pollution is also discussed in this study.

2. Material and Methods

2.1. Sampling Site

The current study was set to find out the PM2.5 and PM10 concentration in the ambient air of Islamabad. Islamabad is a capital city of Pakistan, located at approximately 500 m above sea level (Latitude 33◦49ˈN; Longitude 72◦24ˈN) and is 14 km northeast of its twin city Rawalpindi. It is surrounded by Margalla Hills in its north, and plains of Punjab and water bodies on other sides. The city expands over 906 km2 with a current population of about two million. Islamabad has four distinct seasons; warm and rainy summer (June to August), followed by dry autumn (September to November), cold and dry winter (December to February) and spring (March to May) [10]. Higher precipitation was recorded for summer during the monsoon while other seasons, for the most part, remained dry and the predominant wind direction was north-east. The industrial sectors, I-9/10 and Kahuta Triangle to the south of I-10, have high vehicular traffic density which is the main source of city's air pollution arising from obnoxious gases and metal particulates. The key industries present in these sectors are steel mills, marble factories, flour mills, oil and ghee units, soap/chemical factories, ceramics, paints, pigments, pharmaceutical manufacturing plants, and several other industrial units.

The samples were fixed 20 meters above from ground level on the top roof of Experimental Physics Directorate building at the national center for physics, Islamabad. The sampling site represents the clean urban area which has no influence on any specific air pollution source. It was approximately 4 km away from Murree road, 4.5 km from Bharakhu (high traffic area) and 22 km away from I-10 (industrial area). Filter-based PM10 and PM2.5 samples were collected on Whatman 47 mm quartz filter papers. The sampling was carried out across four seasons with two paralleled medium volume air samplers (Laoying 2030 intelligent TSP sampler and Laoying 2034 Heavy Metal in Air Sampler). All samplings were operated at a medium rate of 100 L/min and lasted for 24 h for each sampler. Total 30 days representative samples (excluding rainy days) were collected from each season. Samples were collected through all seasons of the year, the number at each site appearing in Table 1.

Table 1. Sampling schedule for each season of 2017 in Islamabad.

Season	Sampling dates (2017)	Total Samples
Winter	11 January-16 February	30
Spring	07 March-10 April	30
Summer	13 June- 10 August	30
Autumn	21 August- 01 October	30

After sampling, each loaded filter was stored in a refrigerator below 0 ℃ before gravimetric and chemical analysis.

2.2. Gravimetric Analysis

The PM2.5 and PM10 mass were determined by gravimetry. Gravimetric analysis of the filters was performed by weighing sample filters before and after sampling period. Quartz filter papers were equilibrated in a temperature and relative humidity controlled chamber for 24 hours and then weighted using an electronic balance (CPA-26P, Sartorius, German). The mass difference determined attributed to the total suspended particulate matter.

2.3. Meteorological information

Meteorological data was received from Pakistan meteorological department and online source (www.wunderground.com).

3. Results and Discussion

The sampling site represents a typical urban site which is just 3 km away from the Quaid-e-Azam University, a well-known site used in much previous air sampling research works [11]. A sum of 240 samples, 120 samples for each PM2.5 and PM10 was collected which was equally divided into 30 for every season. The rain affected days were not included in our sampling.

3.1. PM2.5

The seasonal variation in PM2.5 mass concentration i.e. winter (31.90-121.50 μgm^{-3}); spring (19.70-60.16 μgm^{-3}); summer (11.58-79.94 μgm^{-3}) and autumn (26.56-74.62 μgm^{-3}) was presented in figure 1. During the whole sampling period, PM2.5 values fluctuate from 11.58 to 121.50 μgm^{-3}. Figure 3 showed the seasonal average PM2.5 mass concentration. The maximum days of each season in Islamabad observed a higher level of PM2.5 than WHO permissible limit (of 25 μgm^{-3}), however highest PM2.5 concentration (149.80 μgm^{-3}) was observed in winter, on 23 February 2017.

The observed concentration of PM2.5 in winter was almost two times more than that of the summer seasons in Islamabad same as reported by Rasheed et al. [6]. They observed a higher level of PM2.5 in winter with the highest hourly average concentrations as 303 μgm-3 (December 2007); 495.0 μgm-3 (November 2008); 259.8 μgm-3 (September 2009); 456.0 μgm-3 (October 2010) and 379.0 μgm-3 in January 2011 respectively. PM2.5 in winter with the highest hourly average concentrations as 303 μgm-3 during December 2007, 495.0 μgm-3 during November 2008, 259.8 μgm-3 during September 2009, 456.0 μgm-3 during October 2010 and 379.0 μgm-3 during January 2011. In Islamabad, a sporadic information available about the PM concentration especially PM2.5 which addressed average annual PM2.5 mass concentrations in the range of 81.1 ± 48.4 μgm-3, 93.0 ± 49.9 μgm-3, 47.8 ± 33.2

µgm-3, 79.0 ± 49.2 µgm-3 and 66.1 ± 52.1 µgm-3 during 2007 to 2011 respectively. Comparatively higher PM 2.5 mass concentration in winter could be due to the burning of agricultural residue in the surrounding areas during these months [12]. Mansha et al. [13] have also reported higher PM2.5 mass concentrations during fall and winter seasons as compared to summer and forest fire in Margalla Hills [6]. Hence PM levels in Islamabad were on the same order of magnitude as previous studies in this capital city [6, 7, 12, 13] and other urban locations in Pakistan [7, 14, 15], but were significantly higher than in less-populated Asian locations [4].

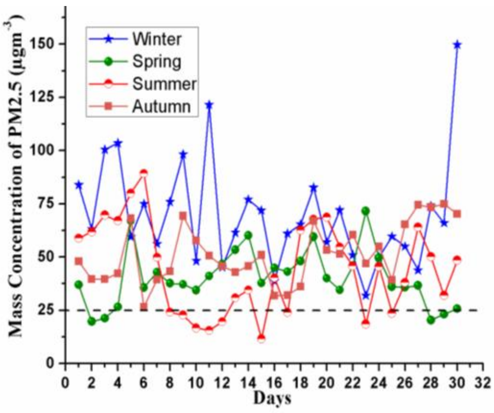

Figure 1. 30 days PM2.5 mass concentration

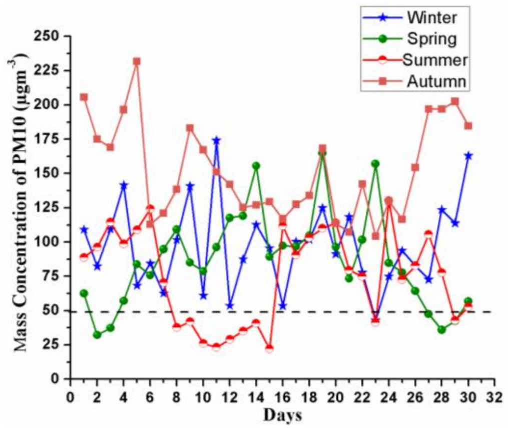

Figure 2. 30 days PM10 mass concentration

3.2. PM10

In 2017, a big variation (21.9-231 µgm^{-3}) in the mass concentration of PM10 was observed in Islamabad. However autumn and winter were a more polluted season with maximum days having a 24-h PM10 mass concentration above than permissible limit (150 µgm^{-3}) set by World Health Organization (WHO) and Pakistan National Environmental Quality Standards (Pak-NEQS). Maximum concentration of PM10 was found in autumn (104-231 µgm^{-3}) followed by winter (42.9-163 µgm^{-3}) spring (32-155 µgm^{-3}) and summer (21.9-130 µgm^{-3}) (figure 2).

The average PM10 concentrations were found to follow the decreasing order: autumn > winter > spring > summer; having 152.4, 97.22, 86.52 and 40.45 µgm-3 respectively (figure 3). Current results are in good agreement with the finding of Sha et al., 2010 in Islamabad [16]. They found a higher level of TSP (198 µgm-3) in autumn compared to the levels of TSP 138,148,190 µgm-3 in winter, summer and spring respectively. However, the observed PM10 concentrations for the year of 2017 in Islamabad were comparatively little higher than 2016 reported by Bulbul et al. [17]. They addressed the concentration of Islamabad in the winter, 2016 were in the range of 123-202 µgm-3 with an overall mean concentration of 177 µgm-3. Contrary, less pollution in spring and summer may be attributed to higher precipitation in Islamabad during monsoon (July-August) and in cold winter (January-February), the atmosphere was cleaned via washing out processes [18].

3.3. Meteorological condition during study period

A noticeable change in the PM concentration with a change in season is mainly attributed to a change in meteorological conditions [9]. The stable atmospheric condition with low temperate and high humidity facilitates the accumulation PM [18]. The higher values of PM10 and PM2.5 in winter and autumn in this studies may be directly influenced by the meteorological conditions as the lowest mean temperature 14.5˚C with 44.5% humidity was observed in winter whereas, autumn has the highest humidity 51.5% with mean 37.6˚C temperature. Although autumn observed higher temperature, it was well compensated by frequent rainfall [19], as it received higher average precipitation (126mm) compared to winter (93 mm), summer (88.5 mm) and spring (58mm) respectively. Additionally higher average wind velocity in summer (14.5 kmh^{-1}) and spring (14 kmh^{-1}) dilute air pollution more compare to autumn and winter with 12 and 12.5 kmh^{-1} respectively.

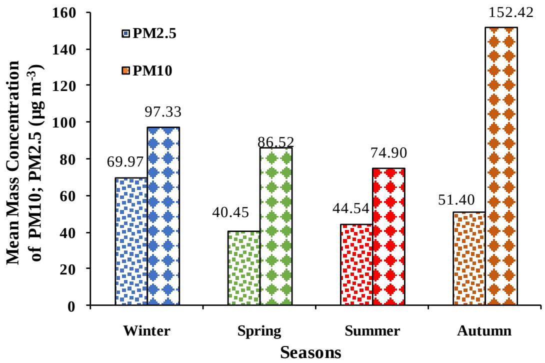

Figure 3. Average mass concentration of PM2.5 and PM10 in four seasons.

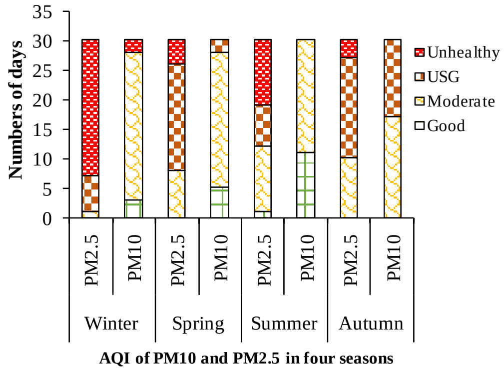

Figure 4. No. of days of each season with respect to specific AQI category.

3.4. Air quality index

Air quality index (AQI) is a relevant term used to describe the degree of the health risk of the air pollution and indicates its potential to affect the health. It is divided into 6 groups ranging from 0 to 500: good (0-50); moderate (51-100); unhealthy for sensitive individuals (USG) (101-150); unhealthy (151-200); very unhealthy (201-300) and hazardous (301-500) [20]. In Pakistan, the AQI related to

PM pollutants proposed by US-EPA (US-EPA, 2012) is being used to describe the air quality status. The AQI was calculated by relating PM mass concentrations to the relevant standards (US-EPA) [21].

Table 2. Air quality standards (annual mean mass concentration μgm^{-3}).

Pollutant	Time	WHO (2006) [22]	USEPA (2016) [20]	NEQSAA (Pak) 2010 [4]
PM2.5	(24-hours)	25	35	25
	(annual)	10	12	15
PM10	(24-hours)	50	150	150
	(annual)	20	54	120

The results of the current study showed that AQI of Islamabad remained confined from good to unhealthy (figure 5). The AQI for PM2.5 remained higher compare to PM10 throughout the sampling period. In case of PM2.5 AQI, winter was a most polluted season of 2017 in Islamabad as it contains 23 and 6 days with unhealthy and unhealthy levels for sensitive group correspondingly. However, autumn showed moderated to sensitive AQI for PM2.5 with 10 and 17 days respectively. On the other hand, AQI for PM10 remained comparatively well with 25, 23, 19 and 17 days of moderated pollution level in winter, spring, summer, and autumn respectively. The order of AQI of the current study was very similar to that found in Henan, China i.e. winter > spring > autumn > summer [23]. Summer stood most clean with 11 days of clean values of AQI. Results showed that AQI behaves periodically, peaking in the winter, same higher values of AQI for the winter was found in Xian, China. The numbers of days that are light, moderately, heavily and severely polluted air in the year 2016 are 71, 34, 32 and 8. These are all higher than those (66, 20, 16, 1) in the year 2015 in Xian [24]. However the overall AQI was observer lower in Islamabad (highest, 185) compare to the other big cities like Pakistan (Faisalabad, 909-715) [21]; India (Delhi, 336) [25]; Iran (Sistan, 316) [26].

3.5. Health risk assessment

Comparative finding from the observed mean concentrations of PM10 and PM2.5 for all four season (Fig.3) and the reference and standard concentrations (Table 2) showed higher values than the recommended values of the WHO and EU requirements. The method applied to calculate health risk was taken from the study conducted by Harrison et al. [3]. The lifetime risk can be calculated by use of equation no. 1;

$$\mathrm{LTR} = \frac{(\beta/\mathrm{C_{obs}})}{\mathrm{L_e}} \tag{1}$$

Where; LTR is Lifetime risk; β is the coefficient of giving pollutant; Cobs is an observed concentration of giving pollutant and Le is the life expectancy of exposed group.

Table 3. Health risk associated with the mean exposures.

Pollutant	Mean concentration	Coefficient	Lifetime risk	Endpoint
PM2.5	51.6	4%/10	1.16×10^{-6}	Mortality in all cases
PM10	102.8	0.5%/10	7.32×10^{-8}	Mortality in all cases

For all-cause mortality, PM10 and PM2.5, a coefficient has been obtained from WHO (2006) and rather than the usual mortality burden calculation, an incremental risk has been estimated for the mean concentration exposure assuming a mean life expectancy of 66.4 years [27]. Results showed high risk with the PM2.5 (1.16×10^{-6}compare) to PM10 (7.32×10^{-8}) in Islamabad. The risk associated with PM exposure subsequently increases due to chemical carcinogens attached to PM [6]. The calculated PM2.5 associated lifetime risk in Islamabad is lower than the finding of Harrison et al. in Saudi Arabia (Jeddah,1. 2×10^{-3}) [3].

3.6. Premature mortality due to PM2.5 and PM10 exposure

According to world population review, the current population of Islamabad is 1,502,000 persons (males and females). The data of population was compared with the average PM10 and PM2.5 mass concentration of four seasons obtained from current study to estimate premature mortality in Islamabad (Table 4).

Table 4. Premature mortality due to PM2.5 and PM10 exposure.

Pollutant	Observed values (mean)	Population in thousands [28]	Crud death rate [29]	Total Premature death
PM2.5	51.6	150.2000	6.4/1000	198
PM10	102.8			98

The premature mortality was simply calculated through the method (equation no. 2) used by Harrison et al. [3].

$$\mathrm{PMR} = \frac{\mathrm{T_p} \times \mathrm{CDR}}{\mathrm{C_t}} \times \mathrm{C_{obs}} \quad (2)$$

Where; PMR is Premature mortality rate; Tp is total population exposed to a pollutant, CDR is crude death rate, Ct is toxic mean concentration (daily*annual) of pollutant defined by WHO and Cobs is observed the concentration of specific pollutant.

The method used to determine the level of premature mortality; the numbers are directly related to the number of people exposed and exposure concentration of PM10 and PM2.5. Thereby, the number of premature mortality will be more in a larger city with a similar concentration of PM, in the case of smaller cities, the number will enhance directly with increasing level of PM concentration. The present study showed the average four seasons values of PM2.5 and PM10 were 51.6 and 102.8 μgm^{-3} respectively. These values are within the range of previously reported average annual PM2.5 mass concentration values (81.2 ± 47.4 μgm^{-3}) by Rasheed et al. for the duration of 2007-2011 [6].

According to reported studies, 865,000 premature deaths are caused every year by air pollution and about 60% of these deaths found occurred in Asia [1].

4. Conclusion

The current study showed higher particulate matter pollution in Islamabad during the four seasons of 2017. The maximum days from all season have higher PM2.5 and PM10 values than the NEQSAA and WHO. The positive trend has been observed between PM10 and PM2.5 mass concentration; however PM10 values remain higher than PM2.5 in all sampling days. In case of AQI, days with PM2.5 pollution was more compared to PM10. In general, AQI results of PM2.5 from this study addressed winter as the most polluted season in Islamabad for the year of 2017 followed by spring, autumn and summer descendingly. Overall, winter and autumn were observed to be more polluted seasons followed by spring and summer respectively. This study only carries the mass concentration and health consequence with public exposure to particulate matter exposure. The health assessment for the mean mass concentration level of PM2.5 and PM10 observed in this study showed significant incensement in premature mortality and associated lifetime risk in Islamabad. However mass concentration alone is only a part of the threat to life but other chemical species also enhance its effect on life. Thereby, a detailed study has been designed including chemical characterization and source identification. The results of the further investigation will be discussed in future.

Acknowledgement

The Authors are thankful to Beihang University Beijing, China and National Center for Physics (NCP) Islamabad, and Pakistan Meteorological Department (PMD) Islamabad, Pakistan. Moreover, Mr. Tariq Mehmood is also thankful to Chinese Government and Chinese Scholarship Council for providing him P.hD. scholarship.

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