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Analysis of daily and seasonal variation of fine particulate matter ($PM_{2.5}$) for five cities of China

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Abstract

Monitoring of air quality is demanding, especially in poor air quality regions. China has been suffering from $PM_{2.5}$ pollution associated with the fast urbanization and economic productivity. The purpose of this work is to analyze $PM_{2.5}$ with regard to air quality for five populated cities (Beijing, Chengdu, Guangzhou, Shanghai and Shenyang) of China. In this study, hourly concentration of $PM_{2.5}$ is decomposed into annual and seasonal concentrations and is evaluated. The results show the downward trend of $PM_{2.5}$ for Beijing and Chengdu from 2013 to 2016 and for Guangzhou from 2012 to 2016, but no clear trend is observed for Shanghai and Shenyang. Although trend is decreasing for three cities (Beijing, Chengdu, Guangzhou), but overall annual average is found higher than the annual U.S. national ambient air quality standards for $PM_{2.5}$. Among all five cities, highest annual $PM_{2.5}$ concentration is found to be 104.1 $\mu gm^{-3}$for Beijing in 2010 and lowest (32.6 μgm^{-3}) is found for Guangzhou in 2016. The diurnal variation is high during night for Beijing, Guangzhou and Shanghai and it is high after morning rush hours for Chengdu and Shenyang (during April 2008–June 2017), respectively. In all studied sites, the seasonal variability is found highest in winter and lowest in the summer. Due to more contribution from biomass burning and dust, high $PM_{2.5}$ variation is also found in the autumn and spring, respectively. To the best of our knowledge, this is the first study for Guangzhou, Chengdu and Shenyang that explores $PM_{2.5}$ concentration for 5 years.

Keywords $PM_{2.5}$ concentration · Air pollution · China · Diurnal variation · Seasonal variation · Weekday and weekend variation

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1 Background

Due to rapid urbanization, large amount of domestic and industrialized wastages emitted into the atmosphere that causes air pollution. In recent years, air pollution such as smog occurs frequently and has become a global issue. It is very dangerous for atmosphere as well as for human health (Zhang et al. 2013; Chaichan et al. 2018). Air pollution has effects on human health such as nausea, skin irritation and difficulty in breathing (Barakat-Haddad et al. 2013; Künzli and Tager 2005). World Health Organization presented its estimates about air pollution disease and found that atmospheric pollution caused 3.7 million deaths worldwide in both rural and urban areas in 2012 (WHO 2014).

Air pollutants are categorized into the primary and secondary pollutants. Primary pollutants referred to substances which are emitted directly from sources such as nitrogen oxides (traffic), sulfur dioxides (coal combustion) and particulates matter (traffic, dust and combustion of coal etc.). On the other hand, secondary pollutants are generated through chemical and photochemical reactions in atmosphere (Huang et al. 2014). In the present study, the air pollution due to fine particulate matter $PM_{2.5}$ is examined. A brief overview of $PM_{2.5}$ is given in the following section.

1.1 Fine particulate matter ($PM_{2.5}$)

Particulate matter is the suspended particles or droplets in the atmosphere usually stated as PM (Zhang and Wang 2011). From all atmospheric pollution particles, fine particulate matter $PM_{2.5}$ is the main pollution source that has an aerodynamic diameter less than 2.5 µm. It has dangerous effects on health (Pope et al. 2002; Pope and Dockery 2006). It also has a long residence time in the atmosphere and can be transported for long distances. $PM_{2.5}$ has a large influence on the atmospheric environment (Zhang and Wang 2011).

Asia remained under studies due to its population rate and pollution. China is a huge populated country and its industrialization and development growth has rapidly increased. These exert incredible pressure on the environment (Ji et al. 2014). Due to these reasons, China is facing air quality challenges. For energy sources, China mainly depends on coal and coal burning power plants that release large amount of air pollution. Industry and motor vehicle emission are the fastest source of outdoor pollution, especially in urban areas (Muller et al. 2015). In China, haze or smog is one of the biggest environmental worries (Chan and Yao 2008). A lot of researches on the characterization of $PM_{2.5}$ pollution have been conducted in the past decades (Liu et al. 2008; Wang et al. 2014, 2013). The findings of Song et al. (2012) have exposed that the main source of smog problem is $PM_{2.5}$ which has severe effects on human health, global climate and visibility. The investigation of Yu et al. (2011) suggested that main sources of pollution in Beijing are $PM_{2.5}$ with percentage of secondary sulfur (26.5%), road dust (12.7%), fossil fuel combustion (16.0%), vehicle emission (17.1%), metal processing (6.0%), soil (10.4%) and burning of biomass (11.2%). The air pollution is mainly due to the particulate matter (Fayiga et al. 2018). According to Tao et al. (2013), air pollution was not only spread by transportation, but also from stationary emissions. The $PM_{2.5}$ annual average concentration was found 99.5 µgm^{-3} for Beijing, 96.1 µgm^{-3} for Chengdu, 56.3 µgm^{-3} for Guangzhou, 61.6 µgm^{-3} for Shanghai and 76.3 µgm^{-3} for Shenyang from August 2013 to July 2014 (San Martini et al. 2015). In $PM_{2.5,}$ higher quantity of sulfate, nitrate and ammonium and organic matter is due to vehicle emission and burning solid fuel (Gautam et al. 2018). The assessment of $PM_{2.5}$

concentration is important for environmental perception due to different human activities in day and night time. In this research paper, we evaluated the $PM_{2.5}$ at urban sites of China. We analyzed diurnal, annual, weekday/weekend and seasonal variation in large populated cities of China including Beijing, Shanghai, Guangzhou, Chengdu and Shenyang. We also found and compared the highest and lowest $PM_{2.5}$ concentration across cities and seasons for the study duration.

The study period of San Martini et al. (2015) was from April 2008 to July 2014; however, we presented the analysis of $PM_{2.5}$ for periods including study duration from April 2008 to June 2017 for Beijing. For the overlap and extended duration, we are able to find the emerging (increasing or decreasing) trends of $PM_{2.5}$ across the years, cities and seasons. We presented the seasonal analysis and also compared seasonal average for all study regions in this paper and the result of weekday/weekend and seasonal variation of $PM_{2.5}$ shows a slight different behavior of variation of $PM_{2.5}$ as compare to the one reported in San Martini et al. (2015).

This paper is comprised of the following sections. The data site, source and data preparation are given in Sect. 2. The analysis and results are shown in Sect. 3. Section 4 finally concludes the major findings.

2 Data description

2.1 Data site

The selected sampling sites for monitoring the air quality are five major cities of China as shown in the Fig. 1. Table 1 provides information of $PM_{2.5}$ data used for Beijing, Shanghai, Guangzhou, Chengdu and Shenyang (http://www.stateair.net). All locations are selected from the urban sites. The study sites are the huge populated cities of China which are facing problems related to atmospheric pollution. These cities are main economic and transport centers. Beijing is the capital and is heavily populated industrial city of China. Poor air quality is a main problem in major cities of China. The climate varies all over the regions of China.

Fig. 1 Location map of sites of study area: Beijing, Shanghai, Guangzhou, Chengdu and Shenyang

Table 1 Gives information about sampling site in the form of geographic coordinate, approximate population and starting date of $PM_{2.5}$ data for Beijing, Shanghai, Guangzhou, Chengdu and Shenyang

Cities	Latitude/Longitude (°N/°E)	Approximate population in millions	Starting date of $PM_{2.5}$ data
Beijing	39.95/116.47	21.7	April 08, 2008
Shanghai	31.21/121.44	24.2	December 21, 2011
Guangzhou	23.12/113.32	15	November 21, 2011
Chengdu	30.63/104.07	14.4	June 5, 2012
Shenyang	31.21/121.44	8.1	April 22, 2013

The end date for observation is June 2017 for all cities

2.2 Data source and preparation

U.S. diplomatic mission in China monitors air quality and the mission has presented and made available data of the $PM_{2.5}$ for the public. The data is provided as hourly averaged $PM_{2.5}$ data. Hourly $PM_{2.5}$ is measured from the roofs of the U.S. Embassy using a beta attenuation monitor (BAM-1020, MetOne) for Beijing and consulates in Shanghai, Guangzhou, Chengdu and Shenyang. The details of BAM-1020 sensor and instrumentation can be found in (Mukherjee et al. 2017). We downloaded PM data from the link (http://www.stateair.net), however, other source for $PM_{2.5}$ data could be found at (https://archive.ics.uci.edu/ml/datasets/PM2.5+Data+of+Five+Chinese+Cities).

Hourly $PM_{2.5}$ data was recorded with respect to time. Diurnal and seasonal data is analyzed. The missing observations are removed. All the $PM_{2.5}$ data are collected into one worksheet for a city. The time value is stored in a column with format of "YYYY/mm/dd 00:00:00". The daily mean of $PM_{2.5}$ concentrations is calculated by taking average of values during time: 00:00 to 23:00. Then, we get annual and seasonal mean concentrations and finally data is used to detect the pollution levels. For seasonal variation, we divided the yearly data into the four seasons. For seasons, we considered the months from December to February as winter, from March to May as spring, from June to August as summer and rest three month data is taken as autumn season.

3 Results and discussions

In the following section, we present analysis for annual, weekday/weekend and seasonal evaluation of $PM_{2.5}$for the study duration. Thus, the information about possible $PM_{2.5}$ emission sources and time when the air pollution level exceeds some certain standards is reported. Figure 2 shows cumulative probability for $PM_{2.5}$ calculated for Beijing from April 2008 to June 2017, for Chengdu from June 2012 to June 2017, for Guangzhou from November 2011 to June 2017, for Shanghai from December 2011 through June 2017 and for Shenyang from August 2013 to June 2017. The standards for daily 24-h average $PM_{2.5}$ are at 35 and 75 μgm^{-3} for U.S. and Chinese NAAS, respectively.

Note: yearly and monthly $PM_{2.5}$ concentration and standard deviation values as well as a number of observation are given in the Appendix A Tables 9, 10, 11, 12, and 13 for Beijing from April 2008 to June 2017, for Shanghai from December 2011 through June 2017, for

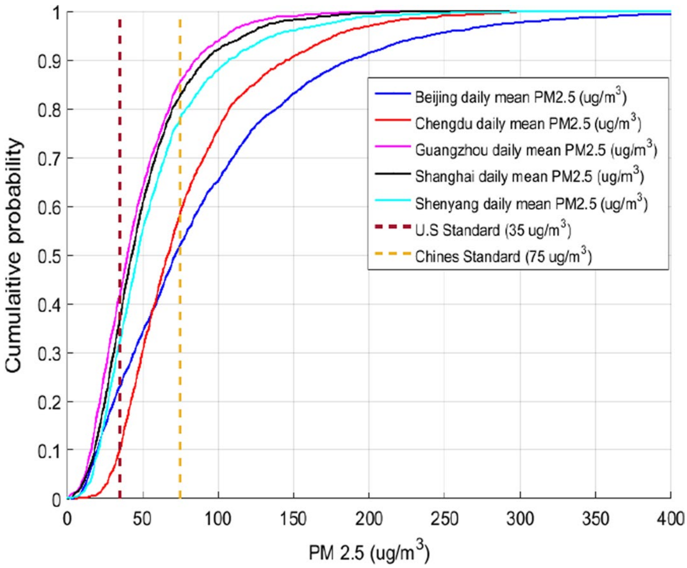

Fig. 2 Cumulative probability for $PM_{2.5}$ is calculated for Beijing from April 2008 to June 2017, for Chengdu from June 2012 to June 2017, for Guangzhou from November 2011 to June 2017, for Shanghai from December 2011 through June 2017 and for Shenyang from August 2013 to June 2017. Daily U.S. and Chinese NAAS of 24-h average are at 35 and 75 μgm^{-3}, respectively

Guangzhou from November 2011 to June 2017, for Chengdu from June 2012 to June 2017 and for Shenyang from August 2013 to June 2017.

3.1 Analysis of $PM_{2.5}$ for Beijing

For Beijing, $PM_{2.5}$ hourly data is analyzed from April 2008 through June 2017. Table 2 shows the values of $PM_{2.5}$ as an annual average, standard deviation, median, minimum, maximum and percentile. The annual average of $PM_{2.5}$ concentration varies between 72.7 and 104.1 μgm^{-3}. $PM_{2.5}$ shows decreasing trend for 2013 to 2016 as $PM_{2.5}$ decreases from 101.7 to72.8 μgm^{-3}. It is also clear from the percentile values given in the Table 2. For Beijing, all studied years show that $PM_{2.5}$ values (average) are greater by two times and three times than that of the value equal to 35 μgm^{-3} (i.e., annual China national ambient air quality standard). Figure 2 shows that there are approximately 78% and 48% of days of Beijing that had daily average concentration greater than U.S. and China 24 h NAAQS of $PM_{2.5}$, respectively. However, in the previous study (San Martini et al. 2015), it was reported daily average is above 35 μgm^{-3} for 81% of days for Beijing, 68% of days for Shanghai, 71% of days for Guangzhou, 94% of days for Chengdu and 80% of days for Shenyang, respectively.

3.1.1 Weekday and weekend variation

To distinguish the sources of pollution, we evaluated the $PM_{2.5}$ in two groups of days: weekdays and weekend. For weekdays, we considered days from Monday to Friday and the remaining days: Saturday and Sunday are treated as weekend. Figure 3 shows $PM_{2.5}$ hourly concentration of Beijing for weekday, weekend and the average from April

Table 2 Shows $PM_{2.5}$ annual average concentrations for Beijing, Shanghai, Guangzhou, Chengdu and Shenyang

City	Year	Days of year with observation	Annual average of $PM_{2.5}$ (μgm^{-3})	STD	Median	Min	Max	90th Percentile
Beijing	2008	212	85.1	50.3	73.9	5.8	235.37	155.6
	2009	301	101.8	69.4	88.2	13.9	482.25	195.7
	2010	351	104.1	75.8	84.5	9	441.5	200.7
	2011	354	99.1	78.8	79.8	10.3	492.7	210.07
	2012	355	90.5	68.12	75.8	2.9	428.5	180.3
	2013	365	101.7	82.6	76.5	7.4	568.58	213.4
	2014	365	97.7	81.7	74.3	6.5	449.75	196.4
	2015	365	82.6	76.3	57.8	5.2	537.25	188.1
	2016	366	72.8	65.4	56.6	5.5	381.6	154.2
Shanghai	2012	361	50.5	32.5	44.5	3.04	204.3	92.6
	2013	363	59.8	45.2	48.0	3.5	382.8	116.3
	2014	365	49.6	29.6	43.3	4.7	182.6	87.0
	2015	362	50.7	32.6	41.8	5.7	220.9	91.4
	2016	363	45.3	28.8	38.6	− 1.5	160.2	85.4
Guangzhou	2012	284	56.8	40.6	48.2	0.8	269	106.1
	2013	359	55.3	29.6	51.4	8.7	162.6	100.07
	2014	353	49.6	28.8	45.5	0	203.9	85.4
	2015	362	39.5	25.4	32.7	7.6	170.9	71.6
	2016	361	32.6	20.8	29.7	0.2	159	59
Chengdu	2013	327	97.1	60.3	76.8	14.5	300.2	187.9
	2014	358	81.8	48.1	69.3	20.0	380	146.5
	2015	362	73	44.3	59.3	13.7	288.6	125.1
	2016	365	72.9	38.4	62.2	14.3	221.7	130.9
Shenyang	2013	230	66.8	50.6	50.7	12.8	307.1	129.9
	2014	363	77.7	52.8	63.8	9.1	558.2	141.8
	2015	340	78.8	68.2	58.06	8.5	661.3	164
	2016	336	55.4	33.6	48.1	− 1.5	212	105.1
	2017	169	60.2	43.8	45.6	7.5	225.2	130.7

Days per year (observations), standard deviation, median, minimum, maximum and 90th percentile values are also given

2008 to June 2017. The daily concentration is found maximum around midnight and it is observed minimum between 14:00 and 16:00 h, afternoon rush hour. After 16:00 h, $PM_{2.5}$ concentration starts to increase due to more motor vehicle emission. The observed diurnal variation is inconsistent with the results reported in Zhao et al. (2009), but our results of diurnal variation for Beijing show agreement with the findings of San Martini et al. (2015). Moreover, pollution by particulate matter (at night) may increase due to diesel trucks which are only allowed to run at night time. Due to restriction on the heavy vehicles during the day, the $PM_{2.5}$ values may also reduce as also suggested by Sun et al. (2013). Figure 3 also shows Beijing $PM_{2.5}$ hourly concentrations and linear fit trend which is increasing for weekday but decreasing for weekend as well as for average

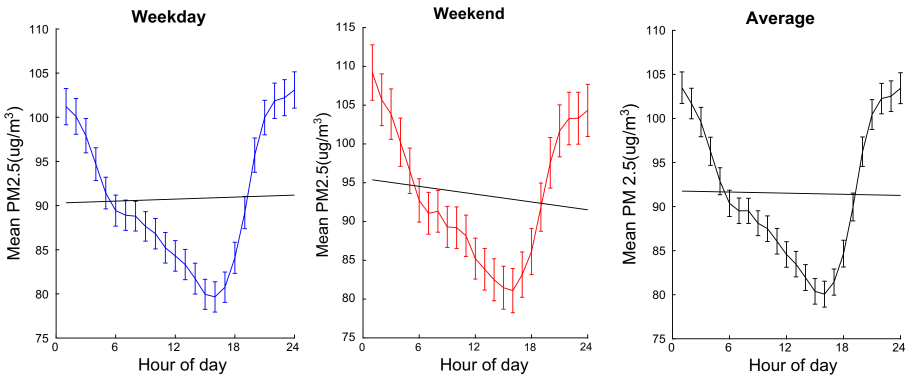

Fig. 3 Beijing $PM_{2.5}$ hourly concentrations and linear fit for weekday, weekend and average for the duration from April 2008 to June 2017. The daily maximum $PM_{2.5}$ concentration is observed around midnight

that can also be verified from the values of slopes given in Table 8. The daily maximum $PM_{2.5}$ concentration is observed around midnight.

3.1.2 Seasonal variation

The linear fit trends and average seasonal variation of $PM_{2.5}$ for 24hour in winter, spring, summer and autumn for Beijing from April 2008 to June 2017 are shown in the Fig. 4. $PM_{2.5}$ variations have got considerably higher fluctuations in winter and autumn generally at midnights. However, concentration in spring seasons is slightly above the one observed in summer unlike previous studies (Zhang et al. 2013; San Martini et al. 2015). This suggests that spring has dry climate, and wind has generated more dust and cold winter has transported more primary pollutants by coal ash used for heating. The comparison of seasonal average between previous finding and the one reported in this study is presented in the Table 3. The linear curve fit shows that winter and autumn have increasing trend, but spring as well as summer has decreasing trend that can also be confirmed from the values of slopes given in Table 8.

3.2 Analysis of $PM_{2.5}$ for Shanghai

For Shanghai, hourly $PM_{2.5}$ data are evaluated from December 2011 to June 2017. The highest $PM_{2.5}$ annual average is found 59.8 μgm^{-3} in 2013. The above city is not showing a clear trend like Beijing, but annual $PM_{2.5}$ concentration in Shanghai is less than that of Beijing as shown in the Table 2. Figure 2 shows that there are approximately 36% of days that are matched with $PM_{2.5}$ 35 μgm^{-3} (24-h U.S NAAQS).

3.2.1 Weekday and weekend variation

$PM_{2.5}$ hourly average concentrations for weekday, weekend and average from December 2011 to June 2017 for Shanghai and the linear fit trends are shown in Fig. 5. The diurnal variation of $PM_{2.5}$ concentration for working days starts increasing in the after morning (working hour) as well as in the evening. The diurnal concentration is high at night which suggests that low temperature and stagnant weather may buildup the

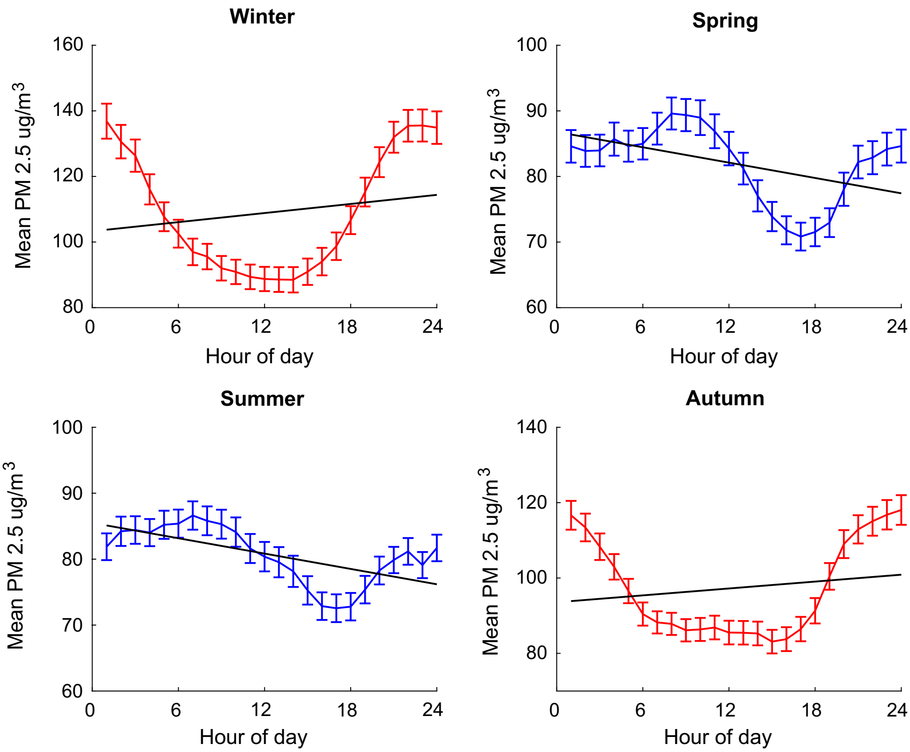

Fig. 4 Seasonal variations and linear fit for winter, spring, summer and autumn for Beijing from April 2008 to June 2017. Highest $PM_{2.5}$ concentration is found in winter season

Table 3 Seasonal averaged $PM_{2.5}$ concentrations for Beijing as reported by Zhang and San Martini (Zhang et al. 2013; San Martini et al. 2015) and for this study

Season	Mean $PM_{2.5}$ (μgm^{-3})			Comments
	Zhang et al. (2013)	San Martini et al. (2015)	This study (2020)	
Winter	139	111.5	109.1	Decrease
Spring	126	83.3	81.9	Different
Summer	138	96	80.6	Different
Autumn	135	103.3	97.4	Decrease

air pollutants overnight in Shanghai likewise Beijing. The weekend peak is above the weekday peak at most of the hours of the day unlike the findings of San Martini et al. (2015). The weekday peak shows that the contribution of traffic pollution to $PM_{2.5}$which is smaller than that of other sources (coal combustion or dust). However, linear fit curve shows that all trends are increasing and are also shown from the values of slopes given in Table 8.

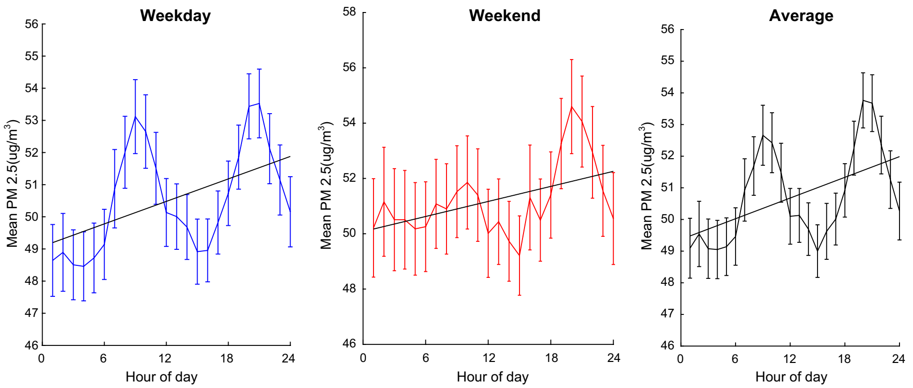

Fig. 5 $PM_{2.5}$ hourly concentrations and linear fit for weekday, weekend and average from December 2011to June 2017 for Shanghai. The daily maximum $PM_{2.5}$ concentration is observed between 20:00 and 22:00 h

3.2.2 Seasonal variation

The linear fit trends and average $PM_{2.5}$ concentration for all seasons for 24 h are presented for Shanghai in the Fig. 6. Linear curve fit shows that winter has decreasing and the rest of the seasons have increasing trend that can also be visualize from the values of slopes given in Table 8. However, the seasonal annual concentration is found highest during the winter and autumn and is found less in spring and summer, similar to previous studies, but overall trend is decreasing. Highest concentration in winter indicates importance of coal burning in Shanghai (or in China). The monthly maximum is found in December, and monthly minimum is found in August. Our diurnal trend of results for Shanghai is similar to the finding of San Martini et al. (2015). The comparison for seasonal average for previous finding and the one reported in this study is presented in Table 4.

3.3 Analysis of $PM_{2.5}$ for Guangzhou

For Guangzhou, the $PM_{2.5}$ data are investigated from November 2011 to June 2017. In case of annual average, we consider year when data is available for the full year. The annual average concentration for 2012–2016 is found in the range from 56.8 to32.6 (μgm^{-3}) as shown in Table 2. The annual $PM_{2.5}$ concentration for Guangzhou is less than that of Beijing. Figure 2 shows that there are more than 80% of days that have better quality of air (i.e., match with the $PM_{2.5}$ standard) in case of Guangzhou.

3.3.1 Weekday and weekend variation

For weekday and weekend, the daily maximum is found at 21:00 h, and minima are found at 16:00 and 17:00 h, respectively, as shown in the Fig. 7. In Guangzhou, weekday concentration of $PM_{2.5}$ is found above the weekend concentration peak which suggests that major air pollution discharge is coming from vehicle. The night higher concentration may be due to heating from coal burning in winter.

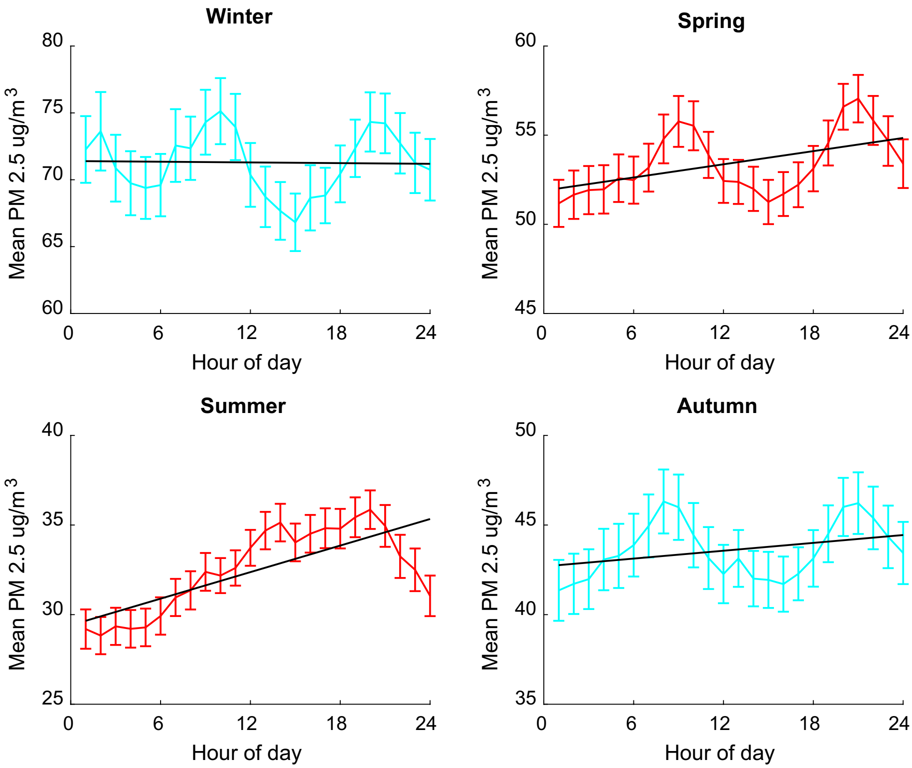

Fig. 6 Diurnal variations and linear fit for winter, spring, summer and autumn for Shanghai from December 2011 to June 2017

Table 4 Seasonal-averaged $PM_{2.5}$ concentrations for Shanghai as analyzed by San Martini (San Martini et al. 2015) and by our study

Season	Mean $PM_{2.5}$ (μgm^{-3})		Comment
	San Martini et al. (2015)	This study (2020)	
Winter	75.8	71.1	Decrease
Spring	58.5	53.4	Decrease
Summer	33.8	32.5	Slight difference
Autumn	51.7	43.6	Decrease

3.3.2 Seasonal variation

The average seasonal concentration is found highest during the winter and it is approximately half of that of winter in summer as shown in Table 5 for Guangzhou. Figure 8 shows the average seasonal variation for Guangzhou for 24 h in winter, spring, summer and autumn for the duration from November 2011 to June 2017. Similar to that of Beijing, diurnal concentration of $PM_{2.5}$ for Guangzhou is found maximum during winter at night. In winter, $PM_{2.5}$ concentration is 59.8 and it is 30.9 μgm^{-3} in summer. The maximum variation for

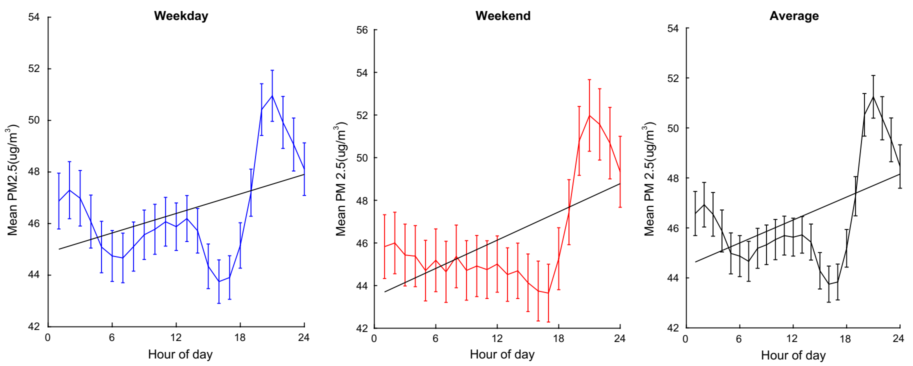

Fig. 7 Hourly concentrations and linear fit from November 2011 to June 2017 $PM_{2.5}$ for weekday, weekend and average are presented for Guangzhou. The daily maximum $PM_{2.5}$ concentration is observed around 9 pm

Table 5 $PM_{2.5}$ seasonal averaged concentration for Guangzhou in this study from November 2011 to June 2017and compare with previous seasonal research of San Martini (San Martini et al. 2015)

Season	Mean $PM_{2.5}$ (μgm^{-3})		Comments
	San Martini et al. (2015)	This study	
Winter	70.6	59.8	Decrease
Spring	61.1	48.6	Decrease
Summer	37.2	30.9	Decrease
Autumn	59.6	46.3	Decrease

winter is due to heating activities, especially at night. Linear fits of Figs. 7 and 8 show that all trends are increasing that can also visualize from slope values given in Table 8.

3.4 Analysis of $PM_{2.5}$ for Chengdu

$PM_{2.5}$ hourly data are evaluated from June 2012 to June 2017 for Chengdu. For 2013–2016, the annual average concentration of $PM_{2.5}$ is 97.1–72.9 μgm^{-3} as shown in Table 2. Like Beijing, Chengdu also shows a decreasing trend of $PM_{2.5}$. However, our annual measurements are still double to that of China annual NAAQS and more than thrice to that of U.S. NAAQS. But, $PM_{2.5}$ annual concentration is found lower than that of reported by Tao (Tao et al. 2013). On the other hand, there are 89% of days that cross the U.S, air quality standards for Chengdu are shown in Fig. 2.

3.4.1 Weekday and weekend variation

For Chengdu, weekday and weekend variation is different from that of Beijing. Figure 9 shows daily maximum is just after the morning working hour that is approximately at 10:00–11:00 h and minimum is at 18:00 h. The difference between weekday and weekend peaks is less, but weekday peaks are higher. This suggests that working days show some contribution to daily $PM_{2.5}$ concentrations due to traffic. The diurnal results of Chengdu in this study are showing an agreement with the finding of Tao et al. (2013).

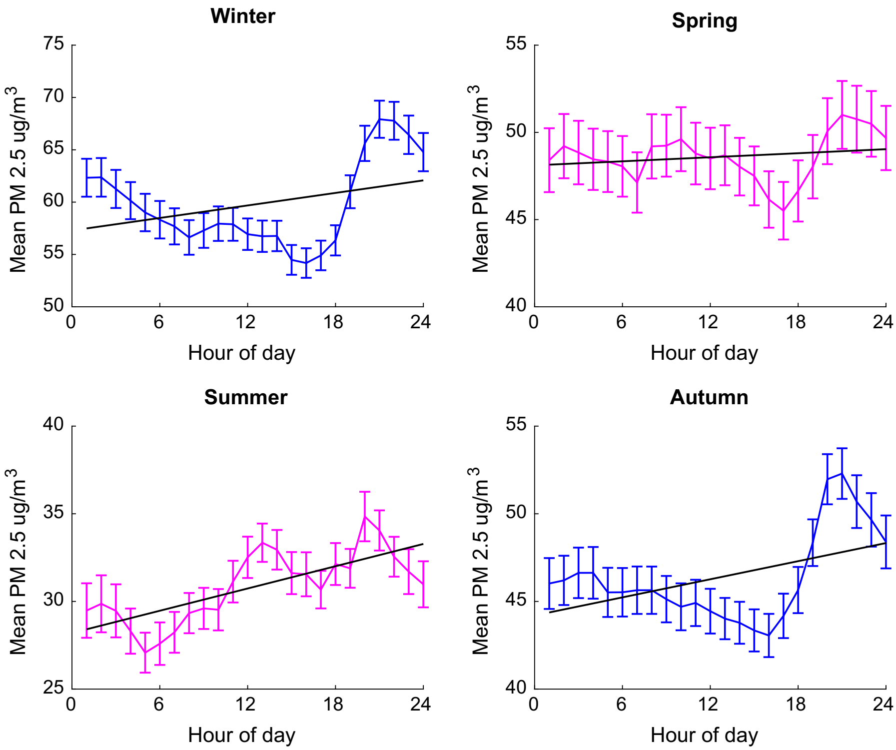

Fig. 8 Guangzhou's seasonal variations and linear fit for winter, spring, summer and autumn from November 2011 to June 2017

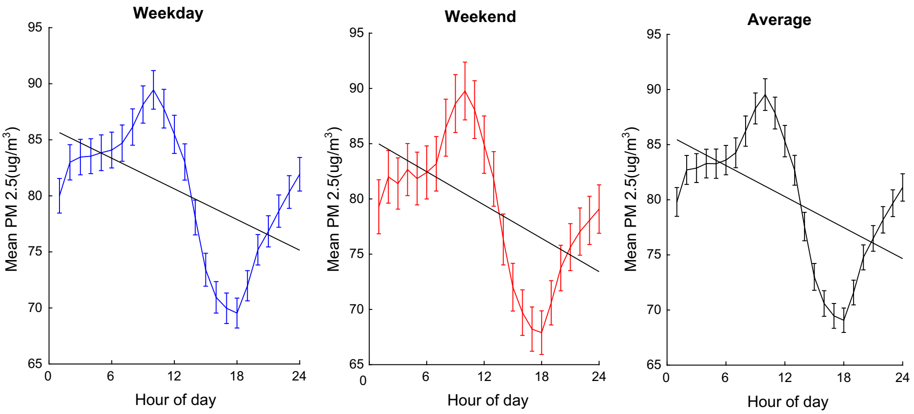

Fig. 9 $PM_{2.5}$ hourly concentrations and linear fit for weekday, weekend and average from June 2012 to June 2017 for Chengdu. The daily maximum $PM_{2.5}$ concentration is measured around 10:00–11:00am

3.4.2 Seasonal variation

For Chengdu, we found pronounced seasonal variation in winter. Figure 10 shows the linear fit trends and average seasonal variation for 24 h. As previous study suggests that the $PM_{2.5}$ concentrations are found higher during the winter than that of during the summer. The winter concentration is almost double to that of summer. Seasonal concentration in Chengdu is different from Beijing, but our results are similar to Tao et al. (2013, 2014) (San Martini et al. 2015) that show highest concentration in winter. The average seasonal $PM_{2.5}$ concentration is decreasing as shown in Table 6.

3.5 Analysis of $PM_{2.5}$ for Shenyang

For Shenyang, $PM_{2.5}$ data is examined from April 2013 through June 2017. The annual trend of $PM_{2.5}$ for Shenyang is similar to that of Shanghai. The highest annual average concentration of $PM_{2.5}$ is found as 78.8 μgm^{-3} in year 2015 as shown in Table 2.

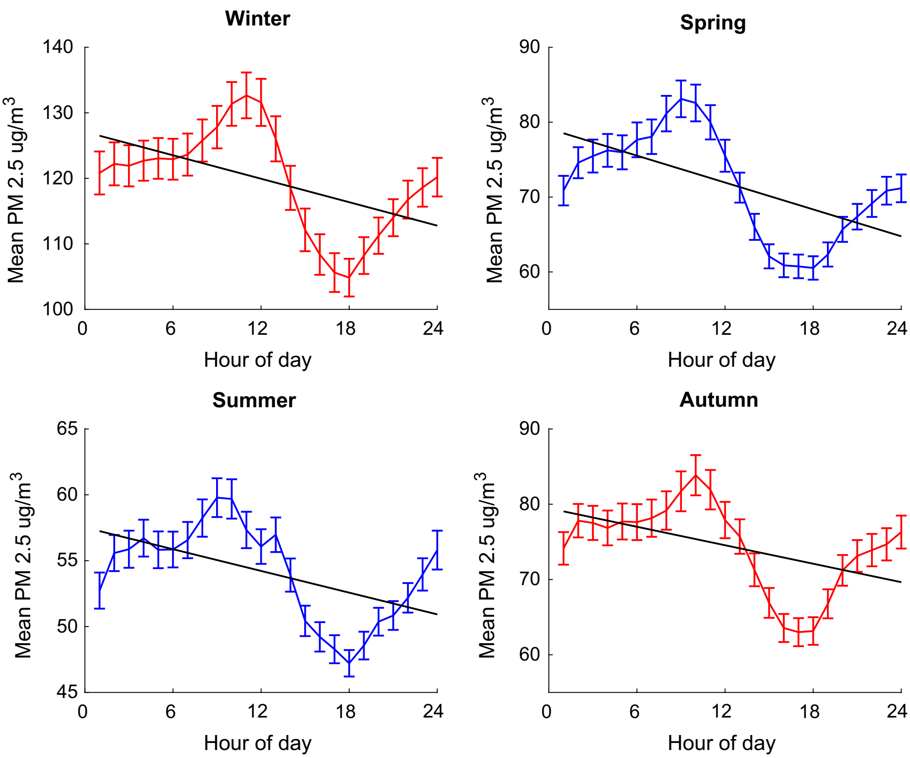

Fig. 10 Chengdu's seasonal variations and linear fit for winter, spring, summer and autumn from June 2012 to June 2017 are shown

Table 6 Comparison of $PM_{2.5}$ seasonal averaged variation measured by Tao et al. (2013) from April 2009 to January, (Tao et al. 2014) for 2011, (San Martini et al. 2015) from June 2012 to July 2014 and in this study from June 2012 to June 2017 for Chengdu

Season	Mean $PM_{2.5}$ (μgm^{-3})				Comments
	Tao et al. (2013)	Tao et al. (2014)	San Martini et al. (2015)	This study	
Winter	225	158	137.9	119.6	Decrease
Spring	133	126	77.5	71.6	Decrease
Summer	144	89	60.4	54.1	Decrease
Autumn	188	158	90.4	74.3	Decrease

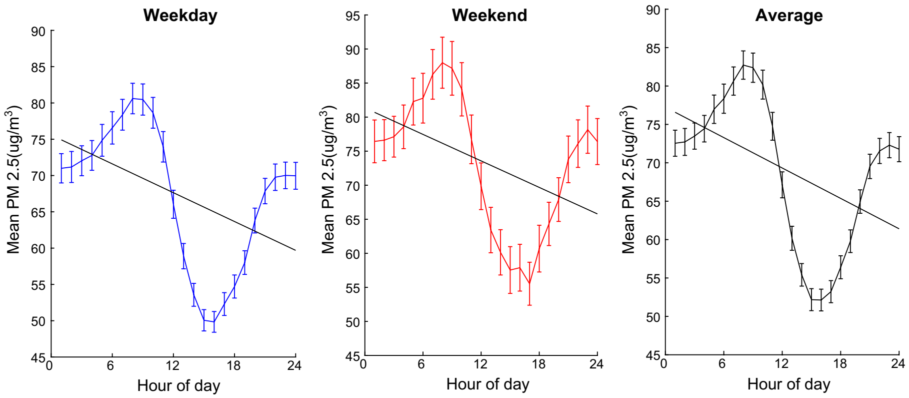

Fig. 11 Weekend, weekday and average variation of $PM_{2.5}$ and linear fit for Shenyang from April 2013 to June 2017. Similar to Beijing weekend peaks are higher than weekdays in Shenyang

3.5.1 Weekday and weekend variation

The weekday and weekend variation in Shenyang is similar to Chengdu. Figure 11 shows daily maxima and minima arise in Shenyang before that of Chengdu. The result suggests that wind during night clears many pollutants from the air in Shenyang as well as in Chengdu. Likewise Beijing, weekend peaks are found higher than that of weekdays in Shenyang too. The soil, dust and ash of coal were the leading sources of $PM_{2.5}$ in Shenyang as also suggested by Ni et al. (2012). So, our result is consistent with Ni et al. (2012) for Shenyang.

3.5.2 Seasonal variation

The seasonal variation is more pronounced in winter than the other seasons. The average seasonal concentration is found as 79.1 μgm^{-3} in winter, 53.9 μgm^{-3} in spring, 39.4 μgm^{-3} in summer and 59.1 μgm^{-3} in autumn, respectively. The seasonal average $PM_{2.5}$ concentrations for Shenyang as reported by San Martini et al. (2015) and in this study from April 2013 to June 2017 are compared and are given in the Table 7.The concentration of winter is more than double of that of summer. This seasonal variation is higher than Guangzhou and Shanghai but lower than Chengdu and Beijing. The

Table 7 Seasonal averaged $PM_{2.5}$ concentrations for Shenyang by San Martini et al. (2015) and in this study from April 2013 to June 2017 are compared

Season	Mean $PM_{2.5}$ μgm^{-3}		Comments
	San Martini et al. (2015)	In this study	
Winter	106.6	97.9	Decrease
Spring	64.8	60.05	Decrease
Summer	49.9	41.5	Decrease
Autumn	67.3	76.91	Increase

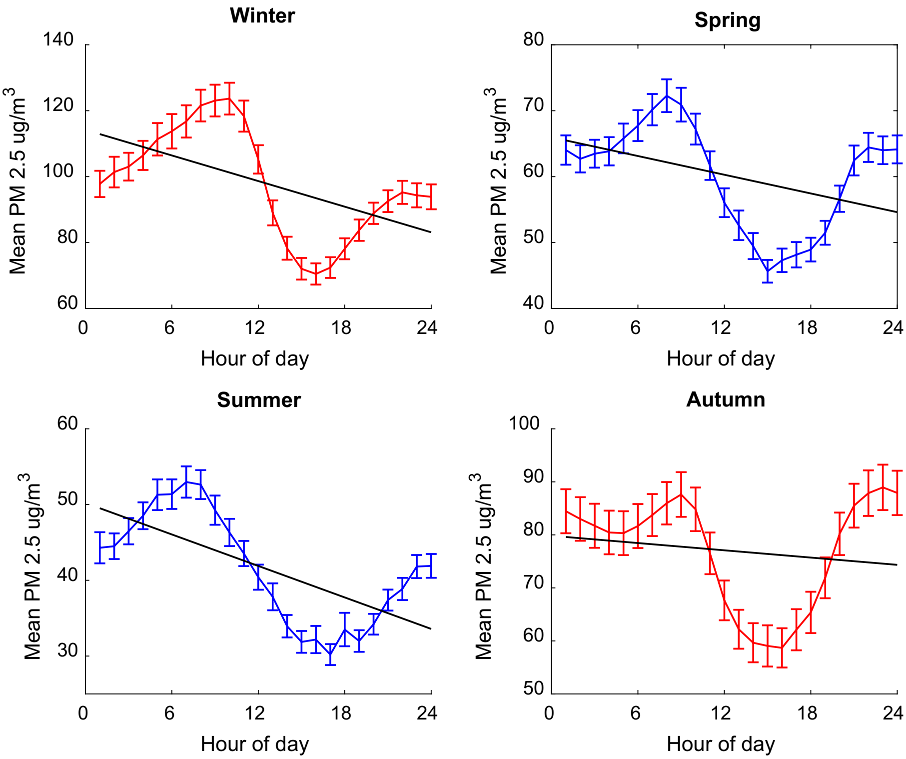

Fig. 12 Diurnal variations and linear fit for winter, spring, autumn and summer for Shenyang. In summer, $PM_{2.5}$ concentrations are almost half of that of winter

average concentrations of $PM_{2.5}$ for all seasons for 24 h for Shenyang as well as linear fit trends are shown in the Fig. 12. Linear fit curve of Figs. 9, 10, 11 and 12 show that all trends are decreasing that can also be justified from slope values given in Table 8.

3.6 Linear fit curves for five cities of China

The linear fit analysis of $PM_{2.5}$ with regard to air quality for five populated cities (Beijing, Chengdu, Guangzhou, Shanghai and Shenyang) is given in the Table 8. We study $PM_{2.5}$ variations for annual, weekday/weekend and seasonal evaluation for the study duration. $PM_{2.5}$

Table 8 The equation of linear fit for weekday, weekend, and average and seasons (winter, spring, summer and autumn) for five cities

	Beijing	Shanghai	Guangzhou	Chengdu	Shenyang
Weekday	$Y=0.03776x+90.28$	$Y=0.1166x+49.08$	$Y=0.1261x+44.88$	$Y=-0.4559x+86.09$	$Y=-0.6619x+75.58$
	$R^2=0.001163$	$R^2=0.2472$	$R^2=0.22$	$R^2=0.292$	$R^2=0.2253$
	SSE = 1408	SSE = 47.64	SSE = 73.14	SSE = 579.4	SSE = 1732
Weekend	$Y=-0.1679x+95.54$	$Y=0.0907x+50.08$	$Y=0.2209x+43.48$	$Y=-0.5027x+85.48$	$Y=-0.6486x+81.35$
	$R^2=0.0183$	$R^2=0.2323$	$R^2=0.3679$	$R^2=0.3059$	$R^2=0.2075$
	SSE = 1739	SSE = 31.29	SSE = 96.45	SSE = 659.3	SSE = 1848
Average	$Y=-0.0213x+91.78$	$Y=0.109x+49.37$	$Y=0.153x+44.48$	$Y=-0.4692x+85.92$	$Y=-0.6599x+77.24$
	$R^2=0.00035$	$R^2=0.2635$	$R^2=0.2577$	$R^2=0.297$	$R^2=0.2219$
	SSE = 1495	SSE = 38.17	SSE = 77.57	SSE = 599.4	SSE = 1756
Winter	$Y=0.462x+103.3$	$Y=-0.00869x+71.4$	$Y=0.1995x+57.29$	$Y=-0.5966x+127.1$	$Y=-1.295x+114.2$
	$R^2=0.03168$	$R^2=0.0006971$	$R^2=0.1138$	$R^2=0.2733$	$R^2=0.2968$
	SSE = 7503	SSE = 124.6	SSE = 356.3	SSE = 1088	SSE = 4569
Spring	$Y=-0.39x+86.79$	$Y=0.1231x+51.89$	$Y=0.03862x+48.11$	$Y=-0.5983x+79.12$	$Y=-0.4731x+65.97$
	$R^2=0.2208$	$R^2=0.2438$	$R^2=0.03952$	$R^2=0.3444$	$R^2=0.1688$
	SSE = 623.2	SSE = 54.01	SSE = 41.68	SSE = 783.5	SSE = 1268
Summer	$Y=-0.3879x+85.5$	$Y=0.2469x+29.41$	$Y=0.2116x+28.2$	$Y=-0.2748x+57.52$	$Y=-0.6928x+50.21$
	$R^2=0.3914$	$R^2=0.5616$	$R^2=0.5387$	$R^2=0.2802$	$R^2=0.4455$
	SSE = 269.1	SSE = 54.72	SSE = 44.12	SSE = 223	SSE = 686.9
Autumn	$Y=0.3051x+93.56$	$Y=0.0736x+42.69$	$Y=0.1721x+44.2$	$Y=-0.409x+79.46$	$Y=-0.2284x+79.83$
	$R^2=0.02789$	$R^2=0.1081$	$R^2=0.2205$	$R^2=0.2378$	$R^2=0.02335$
	SSE = 3731	SSE = 51.38	SSE = 120.4	SSE = 619.4	SSE = 2509

concentration and linear fit for weekday/weekend and average are shown in the Figs. 3, 5, 7, 9 and 11 for five cities. $PM_{2.5}$ concentration and linear fit for four seasonal variations are shown in the Figs. 4, 6, 8, 10 and 12. The Table 8 shows the equation of linear fit for weekday, weekend and average as well as seasons that are winter, spring, summer and autumn for five cities, respectively. Linear fit equation is in the form of $y=mx+c$, where x represents the hour of day of weekday, weekend, average for seasons that are winter, spring, summer and autumn The "m" shows slope of trend line, and "y" represents the mean values of $PM_{2.5}$. If the slope of trend line is positive then it shows increasing trend, whereas the negative slope is the indication of decreasing trend. The values of R^2 represent goodness-of-fit which means the difference of given data and fitted values, while SSE values show the sum of square of residuals which means the expected deviation from the actual data.

4 Conclusion

Although there are decreasing trends in pollutions with respect to set standards in the past few years, but overall China is still facing increasing trend for fine particulate pollution significantly so far. In this study, we analyzed the $PM_{2.5}$ concentration for four cities of China including Beijing, Shanghai, Guangzhou, Chengdu and Shenyang. For Beijing, our study duration is from April 2008 to June 2017. We, for the first time, presented the long-term diurnal and seasonal analysis of $PM_{2.5}$ for China, especially for Chengdu (June 2012–2017 June), Guangzhou (November 2011–2017 June) and Shenyang from April 2013–2017 June. It is found that Beijing and Guangzhou had the highest and lowest annual average $PM_{2.5}$ concentrations, respectively. The highest diurnal concentrations are found in Beijing, Shanghai and Guangzhou at night. For Chengdu and Shenyang, diurnal (weekday) concentrations are found highest after the morning working hours which suggests that night wind clears many of the pollutants from the air which leads to morning maximum. However, the diurnal concentrations for weekend and weekday are found lowest during 15:00–18:00 h for all studied cities except for Shanghai (weekday) where lowest concentration is found during (3:00 am–4:00 am).Weekend peaks are found above to that of the working day for Beijing, Shenyang and Shanghai. This suggests that in these cities traffic contribution to daily $PM_{2.5}$ concentrations is relatively small than rest of the cities. We found significant seasonal concentration in winter and autumn. The summer concentrations are half the winter concentrations. Unfavorable weather condition and burning of coal may lead to high $PM_{2.5}$ concentrations in winter and autumn season at night. Finally, our results show that air quality has improved for Beijing and Chengdu from 2013 to 2017 and for Guangzhou (2012–2017 June), but it is needed to perform more progressive measures to come close to that of set $PM_{2.5}$ standards.

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Appendix A

Yearly & monthly $PM_{2.5}$ concentration and standard deviation values as well as number of observation are given in the Tables 9, 10, 11, 12, and 13 for Beijing from April 2008 to June 2017, for Shanghai from December 2011 through June 2017, for Guangzhou

Table 9 Shows $PM_{2.5}$, observations per month, mean and standard deviation (monthly and yearly) for Beijing

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2008	4	537	103.8976	68.44375			
2008	5	738	98.4065	67.40747			
2008	6	720	99.79444	52.78989			
2008	7	587	89.73595	55.68362			
2008	8	684	65.36111	44.85568			
2008	9	679	59.31222	42.52488			
2008	10	742	84.24933	80.38281			
2008	11	134	73.1194	59.54805	8	88.07765	25.08383
2009	1	0	NaN	NaN			
2009	2	220	65.41364	42.04669			
2009	3	680	80.55	76.17914			
2009	4	660	87.06818	61.10291			
2009	5	522	84.02107	50.01429			
2009	6	590	96.84068	88.29195			
2009	7	698	105.841	67.75686			
2009	8	711	107.3952	58.02277			
2009	9	714	108.6555	67.35395			
2009	10	714	92.84594	74.69873			
2009	11	650	155.1446	144.057			
2009	12	620	109.0403	100.5744	12	99.34692	23.10828
2010	1	654	90.40367	93.87595			
2010	2	671	97.23994	84.83023			
2010	3	709	94.04654	84.31744			
2010	4	718	80.07242	73.49656			
2010	5	737	87.07191	59.15686			
2010	6	565	109.0389	52.32043			
2010	7	744	123.4261	72.47735			
2010	8	676	97.68343	67.28428			
2010	9	468	122.7927	78.5849			
2010	10	742	118.7844	124.5303			
2010	11	664	138.384	133.7581			
2010	12	743	97.11575	114.8124	12	104.6717	17.6516
2011	1	673	44.8737	46.28088			
2011	2	672	150.2902	143.2098			
2011	3	624	57.99199	73.77889			
2011	4	537	91.72067	67.02386			
2011	5	712	65.10815	51.49925			
2011	6	711	108.7947	76.13396			
2011	7	740	107.3865	80.02464			
2011	8	571	103.7338	54.72261			
2011	9	719	94.9694	84.86208			
2011	10	616	145.5568	122.9577			

Table 9 (continued)

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2011	11	715	109.435	89.43194			
2011	12	743	108.7214	107.4037	12	99.04852	31.65075
2012	1	670	118.9224	131.3984			
2012	2	690	84.44203	78.87185			
2012	3	740	96.47432	86.32166			
2012	4	719	87.83588	69.41509			
2012	5	691	90.96671	55.62455			
2012	6	708	96.63418	68.47835			
2012	7	688	80.64971	56.73281			
2012	8	623	81.16533	59.31235			
2012	9	714	59.78431	52.20757			
2012	10	740	94.95135	92.42798			
2012	11	698	87.43696	85.22176			
2012	12	614	109.1873	96.97873	12	90.70421	14.86514
2013	1	739	193.3924	168.8691			
2013	2	671	123.6319	117.3539			
2013	3	739	123.3829	104.8073			
2013	4	715	65.82517	58.23406			
2013	5	727	85.21733	55.82272			
2013	6	718	111.4861	68.77393			
2013	7	737	68.82225	43.56956			
2013	8	735	61.93333	40.57958			
2013	9	717	90.91213	65.16523			
2013	10	738	106.5854	95.22329			
2013	11	718	90.70334	92.34			
2013	12	724	98.50552	107.3668	12	101.6998	35.60748
2014	1	737	118.7734	110.9488			
2014	2	669	174.5949	145.3495			
2014	3	743	110.4738	97.72485			
2014	4	717	95.14226	57.53138			
2014	5	742	72.23989	45.02231			
2014	6	703	59.04836	41.80395			
2014	7	737	89.64179	65.15916			
2014	8	733	62.81583	44.23216			
2014	9	715	70.25874	47.81701			
2014	10	743	140.6931	118.0654			
2014	11	706	104.1912	109.6926			
2014	12	716	78.60894	93.90044	12	98.04019	34.32105
2015	1	739	107.9147	101.6596			
2015	2	666	96.73724	91.39883			
2015	3	713	89.27489	74.53018			
2015	4	711	78.85513	57.30843			
2015	5	740	60.12838	43.27989			

Table 9 (continued)

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2015	6	702	54.39744	44.71412			
2015	7	742	55.08356	30.97556			
2015	8	743	44.64738	33.13465			
2015	9	720	46.84861	44.34977			
2015	10	740	72.37432	88.53582			
2015	11	720	124.8222	111.8821			
2015	12	735	161.7156	156.2346	12	82.7333	35.44741
2016	1	743	72.1467	85.71622			
2016	2	692	43.95954	63.79865			
2016	3	743	93.12517	96.65939			
2016	4	720	66.5	54.03687			
2016	5	741	55.24561	41.77762			
2016	6	716	58.66899	46.7186			
2016	7	742	59.16173	39.02359			
2016	8	742	38.67385	27.17184			
2016	9	720	51.59583	47.94598			
2016	10	737	82.09227	68.02267			
2016	11	717	104.7392	84.38446			
2016	12	742	144.628	131.7317	12	72.54474	29.93629
2017	1	734	123.8229	135.4933			
2017	2	670	76.1597	87.17909			
2017	3	742	63.67385	56.64456			
2017	4	713	55.7237	41.96398			
2017	5	742	60.469	86.64765			
2017	6	715	40.13427	21.84921	6	75.07286	33.32015

Table 10 Shows $PM_{2.5}$, observations per month, mean and standard deviation (monthly and yearly) for Shanghai

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2011	12	77	68.09091	81.91317	1	68.09091	0
2012	1	740	64.43919	42.85085			
2012	2	691	53.07236	40.14146			
2012	3	738	67.27913	43.14292			
2012	4	640	54.07031	22.95569			
2012	5	637	54.0471	30.36462			
2012	6	709	40.12553	34.78087			
2012	7	737	26.72592	24.06458			
2012	8	735	16.06803	14.71031			
2012	9	708	44.22881	33.97538			
2012	10	731	55.4145	50.41908			
2012	11	697	67.81779	45.45937			
2012	12	742	64.41375	35.7191	12	50.64187	16.30092
2013	1	724	102.1754	61.73217			
2013	2	670	64.35672	54.90391			
2013	3	743	65.00135	43.029			
2013	4	712	61.77528	28.67344			
2013	5	730	53.21918	33.85823			
2013	6	705	44.2695	32.41306			
2013	7	717	31.72664	19.59087			
2013	8	722	26.30055	20.56025			
2013	9	661	27.84569	17.41639			
2013	10	742	36.1752	22.15481			
2013	11	718	79.11978	44.03358			
2013	12	743	122.1803	86.20953	12	59.51214	29.97727
2014	1	742	72.63073	56.13139			
2014	2	670	52.27761	41.23291			
2014	3	741	54.49123	28.78441			
2014	4	718	51.67688	26.52772			
2014	5	728	61.09066	33.63482			
2014	6	718	42.09889	22.05382			
2014	7	741	35.06748	27.14238			
2014	8	737	29.14518	19.80714			
2014	9	693	28.89322	23.8026			
2014	10	727	38.72215	24.29643			
2014	11	699	53.61087	34.53735			
2014	12	743	74.66756	39.60324	12	49.53104	15.30071
2015	1	740	84.62703	57.50575			
2015	2	665	66.8797	50.77221			
2015	3	720	50.49583	30.02285			
2015	4	575	53.50435	26.06491			
2015	5	743	41.00404	17.81346			

Table 10 (continued)

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2015	6	717	36.49372	20.34889			
2015	7	734	35.43597	20.58392			
2015	8	696	36.02299	21.347			
2015	9	718	27.99164	17.42039			
2015	10	676	37.77367	19.86228			
2015	11	660	56.00152	35.82653			
2015	12	741	82.07152	56.5585	12	50.69183	18.73258
2016	1	740	72.43919	43.77888			
2016	2	693	57.5873	31.88019			
2016	3	683	56.347	30.68195			
2016	4	714	55.70308	30.29104			
2016	5	743	48.52759	24.04962			
2016	6	719	35.32684	18.54822			
2016	7	739	34.75237	20.63582			
2016	8	721	20.59223	10.13041			
2016	9	636	28.14308	23.42682			
2016	10	720	20.65278	14.65349			
2016	11	717	50.01813	31.40706			
2016	12	721	63.05825	46.35062	12	45.26232	17.02625
2017	1	738	52.41734	32.68296			
2017	2	650	56.40615	36.30509			
2017	3	734	51.1921	22.2841			
2017	4	695	49.97842	20.1584			
2017	5	741	32.94737	18.35664			
2017	6	713	30.73352	22.26277	6	40.90765	14.53851

Table 11 Shows $PM_{2.5}$, observations per month, mean and standard deviation (monthly and yearly) for Guangzhou

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2011	11	212	79.72642	35.81734			
2011	12	685	71.06277	34.32035	2	75.39459	6.12612
2012	1	82	80.15854	34.71559			
2012	2	0	NaN	NaN			
2012	3	390	4.382051	9.358069			
2012	4	710	99.34789	75.75893			
2012	5	574	83.74216	55.49894			
2012	6	720	35.48056	21.26643			
2012	7	740	29.46216	23.95914			
2012	8	742	55.27763	27.64892			
2012	9	704	45.22301	24.06925			
2012	10	720	72.43611	36.41251			
2012	11	511	54.87867	31.11095			
2012	12	703	67.46088	35.31576	12	57.07724	27.43843
2013	1	741	83.02429	37.62941			
2013	2	597	60.53434	40.4779			
2013	3	729	68.63374	33.85719			
2013	4	714	69.97619	38.7507			
2013	5	740	41.19459	25.8615			
2013	6	709	24.91678	13.36061			
2013	7	658	24.94073	18.25886			
2013	8	670	41.94776	26.00917			
2013	9	719	47.10014	21.69588			
2013	10	695	70.73525	24.3582			
2013	11	716	55.98743	25.97064			
2013	12	701	72.54066	36.53105	12	55.12766	19.10289
2014	1	740	86.18784	37.64863			
2014	2	654	48.33486	28.09102			
2014	3	715	55.57902	32.85313			
2014	4	366	50.27869	22.00956			
2014	5	701	41.11412	25.30688			
2014	6	662	64.67372	59.83615			
2014	7	740	25.83243	23.24329			
2014	8	738	25.34553	15.81151			
2014	9	719	32.14325	21.37718			
2014	10	649	52.97689	22.73379			
2014	11	707	53.64781	25.01946			
2014	12	730	61.29863	30.24983	12	49.7844	17.31489
2015	1	718	70.21031	36.74772			
2015	2	657	67.24049	36.11195			
2015	3	737	41.23881	29.78469			
2015	4	719	39.89847	26.69375			

Table 11 (continued)

Year	Month	No of observa-tion	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2015	5	736	29.3288	23.36124			
2015	6	719	17.94298	9.972571			
2015	7	742	22.8504	14.37405			
2015	8	740	31.81892	14.98117			
2015	9	709	37.36812	16.19055			
2015	10	743	42.04307	25.29936			
2015	11	624	38.40224	19.44156			
2015	12	740	38.3027	30.79084	12	39.72044	15.47219
2016	1	704	35.41335	27.67713			
2016	2	684	37.05702	24.99074			
2016	3	583	50.40137	34.17265			
2016	4	661	40.71104	25.43946			
2016	5	713	26.9467	15.82142			
2016	6	652	22.25	14.47145			
2016	7	738	19.65312	14.99539			
2016	8	685	29.06423	21.73529			
2016	9	629	22.22099	14.70432			
2016	10	737	22.15604	11.63841			
2016	11	718	38.67827	29.22616			
2016	12	732	48.91803	21.01283	12	32.78918	10.65687
2017	1	678	53.39823	36.86685			
2017	2	672	50.83631	21.0138			
2017	3	678	44.27286	20.23147			
2017	4	699	38.88126	20.52949			
2017	5	551	33.11797	17.28801			
2017	6	643	23.46501	27.43789	6	35.38853	12.17819

Table 12 Shows $PM_{2.5}$, observations per month, mean and standard deviation (monthly and yearly) for Chengdu

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2012	6	268	41.85448	36.87296			
2012	7	729	59.02606	25.29715			
2012	8	608	78.31908	38.6906			
2012	9	693	76.01154	47.15238			
2012	10	731	87.21888	47.46495			
2012	11	672	107.7515	57.61157			
2012	12	711	117.9873	59.31179	7	81.16698	26.36122
2013	1	718	183.1699	73.27398			
2013	2	666	131.0571	79.4828			
2013	3	409	147.6161	64.49564			
2013	4	257	89.61089	56.74956			
2013	5	744	61.13844	36.8922			
2013	6	718	55.85376	26.99278			
2013	7	624	52.03526	26.65327			
2013	8	743	61.15343	30.17618			
2013	9	706	70.4915	44.65128			
2013	10	488	100.4201	64.04854			
2013	11	577	95.16638	55.74748			
2013	12	717	133.7922	60.93297	12	98.45875	42.13991
2014	1	742	159.0633	89.44056			
2014	2	671	101.2668	44.92477			
2014	3	742	85.05795	49.22101			
2014	4	719	64.88734	33.56679			
2014	5	740	82.34189	40.32179			
2014	6	720	62.59861	29.65375			
2014	7	563	56.69627	27.62346			
2014	8	741	57.42915	25.04945			
2014	9	706	48.66431	30.00689			
2014	10	689	84.71263	53.08283			
2014	11	706	69.26062	31.01105			
2014	12	736	103.3016	55.14645	12	81.27338	30.09234
2015	1	741	142.2497	64.65937			
2015	2	670	96.81045	51.24129			
2015	3	741	80.23347	33.70096			
2015	4	717	62.71827	35.86102			
2015	5	740	58.15135	30.57166			
2015	6	717	47.75732	21.71925			
2015	7	639	51.51956	19.11644			
2015	8	732	50.35519	26.88974			
2015	9	713	45.07293	21.99796			
2015	10	743	72.18977	40.52782			
2015	11	719	60.09179	25.11145			

Table 12 (continued)

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2015	12	730	105.4671	69.45711	12	72.71807	29.159
2016	1	724	95.3895	50.12033			
2016	2	694	84.26225	35.30964			
2016	3	731	86.14501	37.55126			
2016	4	718	70.22563	37.33649			
2016	5	707	62.52192	30.95772			
2016	6	716	53.88827	24.15113			
2016	7	742	41.34367	18.85434			
2016	8	742	46.56604	17.30875			
2016	9	704	52.85795	20.71646			
2016	10	739	58.65494	33.86929			
2016	11	717	99.94421	50.70588			
2016	12	727	124.227	46.44446	12	73.0022	25.12915
2017	1	740	125.2622	65.5443			
2017	2	670	83.6	38.62372			
2017	3	741	64.36707	26.44546			
2017	4	703	53.59033	25.00951			
2017	5	726	49.41047	22.15256			
2017	6	687	44.50801	20.87048	6	70.36098	30.51407

Table 13 Shows $PM_{2.5}$, observations per month, mean and standard deviation (monthly and yearly) for Shanyang

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2013	4	184	55.59239	43.60368			
2013	5	741	63.15385	48.52069			
2013	6	716	43.57542	26.40393			
2013	7	637	35.97017	29.01801			
2013	8	203	33.34975	28.19119			
2013	9	720	52.8	35.41098			
2013	10	732	85.71311	67.91726			
2013	11	716	73.26397	58.52149			
2013	12	741	120.2578	89.51761	9	62.63071	27.4874
2014	1	727	91.42916	64.84015			
2014	2	667	101.8831	60.45308			
2014	3	742	79.10647	51.77279			
2014	4	674	65.76113	41.57162			
2014	5	693	53.18182	34.65705			
2014	6	681	58.56094	45.16854			
2014	7	618	59.21197	37.57843			
2014	8	738	50.86856	38.51335			
2014	9	713	45.47686	32.79246			
2014	10	737	111.7761	104.4429			
2014	11	718	113.1504	78.76928			
2014	12	740	97.42297	80.36494	12	77.31912	24.84589
2015	1	726	130.6515	93.28512			
2015	2	640	103.475	97.38277			
2015	3	720	75.35	43.71035			
2015	4	717	66.56904	30.65554			
2015	5	696	44.54167	26.22517			
2015	6	719	41.69541	25.51138			
2015	7	443	36.19413	25.03217			
2015	8	376	34.83245	27.01271			
2015	9	717	39.55927	31.01515			
2015	10	734	69.17984	61.95673			
2015	11	719	147.4395	128.7901			
2015	12	742	119.6253	82.41945	12	75.75943	40.06501
2016	1	740	86.2473	52.00916			
2016	2	695	63.47626	45.88065			
2016	3	696	78.20115	47.76025			
2016	4	720	48.0375	29.8468			
2016	5	685	43.71971	28.32601			
2016	6	710	44.78732	25.73125			
2016	7	681	39.74009	30.23611			
2016	8	710	23.8169	22.54055			
2016	9	608	40.55757	26.13909			

Table 13 (continued)

Year	Month	No of observation	Monthly mean	Monthly Std	Total month	Yearly mean	Yearly Std
2016	10	620	53.77097	37.87697			
2016	11	703	81.71408	67.1764			
2016	12	159	63.42767	44.59969	12	55.62471	19.2162
2017	1	743	97.12382	72.71746			
2017	2	672	70.5372	53.44071			
2017	3	583	76.92624	56.66756			
2017	4	564	44.72163	33.88255			
2017	5	743	41.77524	35.76879			
2017	6	692	28.60983	22.04451	6	55.22677	22.70954

from November 2011 to June 2017, for Chengdu from June 2012 to June 2017 and for Shenyang from August 2013 to June 2017.

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