The Impact of Meteorological Factors on PM2.5 Variations in Hong Kong

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X Li[1,2], Y J Feng[1], H Y Liang[2]

1 Shandong Agricultural University, Tai'an, Shandong 271000, China
2 The Hong Kong Polytechnic University, Hong Kong 999077, China
vivianyoxi@gmail.com

Abstract. This paper aims to explore the impact of meteorological factors on PM2.5 concentrations in Hong Kong. The PM2.5 and meteorology data including temperature, pressure, rainfall, relative humidity (RH), wind speed and wind direction from January to December of 2013 were collected. The correlation analysis between PM2.5 and meteorological factors were conducted for each month and season. The meteorology data were classified into several intervals and the mean PM2.5 concentrations for each interval were calculated to see the tendency. According to the correlation analysis results, the PM2.5 concentrations have a positive relationship with pressure with correlation coefficients 0.507 while have negative relationships with temperature, RH, rainfall, wind speed with correlation coefficients -0.512, -0.237, -0.524, -0.284, respectively. In addition, the wind direction influence PM2.5 concentrations through affecting the spreading direction of PM2.5. The north wind in winter increased the PM2.5 in Hong Kong while the south wind in summer decrease the PM2.5. Therefore, the meteorological factors affect the aggregation, diffusion, spread of PM2.5. They have a leading impact on PM2.5 concentrations when the domestic emission stays stable.

1. Introduction

The rapid development of urban construction and accelerated urbanization have caused serious pressure on atmosphere environment. As one result of the process, air pollution has increased concerns about people's health, especially for the fine particular matter (PM2.5). PM2.5 is the particular matter with an aerodynamic diameter less than 2.5 μm, which not only attenuates atmospheric visibility, but also has an adverse impact on human health [1]. Some epidemiology studies reveal that a certain relationship exists between particular matter of pollution and the mortality rate, cardiovascular and respiratory diseases [2], [3].

The PM2.5 concentrations were mainly influenced by local pollution emission, external pollution propagation and meteorological conditions including pressure, temperature, humidity, cloud coverage, precipitation and wind, etc. The meteorological factors cause spatio-temporal variation of particulate matter concentrations through influencing the conglomeration and diffusion of pollutants. Tai [4] indicate that the daily variation of meteorological parameters can cause up to 50% of the change of PM2.5 concentrations. Wang and Ogawa [5] investigated the correlation between PM2.5 and meteorological conditions in Nagasaki, Japan. The results shown that temperature had a negative, and precipitation had a positive, correlation with PM2.5. Elminir [6] found that temperature, humidity, wind speed and wind direction contribute to the air pollutants concentration. Wind direction was found to have influence on both pollutant concentrations and the correlation between pollutants.

Hong Kong is located in southern China with sea on three sides and is one of the most densely populated areas. In the last decades, the economic cooperation between Hong Kong and Pearl River

Delta (PRD) area is growing rapidly. In addition, the increasing of population mobility and transportation brings enormous pressure to the local atmospheric condition.

Since the correlation between PM 2.5 concentration and meteorological factors varies with study area due to different regional climate conditions, the correlation model for other regions may not represent their relationship in Hong Kong. Moreover, due to the lack of heavy industry, the main sources of PM2.5 pollution in Hong Kong are vehicle exhaust, construction dust and other domestic sources [7]. Comparing with other areas suffering heavy pollution, such as Beijing, the impact of meteorological conditions on PM 2.5 variation in Hong Kong is more apparent. Therefore, it is essential to investigate this relationship in Hong Kong area.

This study utilized PM 2.5 concentration and meteorological data (including temperature, pressure, precipitation, humidity, wind speed and wind direction) during 2013 in Hong Kong, aiming to examine the impact of meteorological conditions on local PM2.5 variations. In this paper, the relationship between PM 2.5 pollution and local weather condition will be revealed, which will provide theoretical support for predicting PM 2.5 change based on meteorological parameters.

2. Data Collection

The daily averaged meteorological data including pressure (hPa), temperature (℃), relative humidity (%), rainfall (mm), wind speed (km/h), wind direction (°) from 1 Jan 2013 to 30 Dec 2013 at four automatic weather stations were collected from Hong Kong Observatory (HKO) (http://www.hko.gov.hk). Correspondingly, the hourly averaged PM2.5 concentrations data at four air quality monitoring stations which are most close with automatic weather stations in space were downloaded from Environmental Protection Department (EPD) website (http://www.epd.gov.hk/epd/). In order to be consistent with meteorological data in time unit, the daily averaged value of PM2.5 concentrations were calculated. Table 1 shows the locations of air quality stations and automatic weather stations.

Table 1. The location of PM2.5 monitoring stations and automatic weather stations

Air quality monitoring stations	Coordinate	Automatic Weather Stations	Coordinate
Sham Shuipo	114 °9’ 33’’ 22 °19’ 49’’	King's Park	114 °10’22’’ 22 °18’43’’
Shatin	114 °11’ 4’’ 22 °22’ 35’	Shatin	114 °12’36’’ 22 °24’09’’
Tung Chung	113 °56’ 37’’ 22 °17’ 20’’	Sha Lo Wan	113 °54’25’’ 22 °17’28’’
Yun Long	114 °1’ 22’’ 22 °26’ 43’’	Wetland Park	114 °00’32’’ 22 °28’00’’

3. Result and Discussion

3.1. The Tendency of PM2.5 Concentration and Meteorological Factors

To explore the tendency of PM2.5 concentration and meteorological factors and their relationship, the monthly values of PM2.5 and meteorological factors are averaged from daily data. It’s hard to compare all factors together due to their different units. For example, temperature’s unit is ℃ and ranges from 10-30 ℃ while pressure’s unit is hPa with values around 1000 hPa. Therefore, all kinds of data were processed by normalization and their values changes to 0-1 without units.

The monthly tendency of PM2.5 concentrations and normalized meteorological factors is shown in Figure1. According to Figure 1, the monthly average PM2.5 concentrations are lowest in summer (June, July, August), which are followed by spring (March, April, May) and autumn (September, October, November), and are highest in winter (January, February, December). Among all meteorological factors, only pressure has the similar monthly tendency with PM2.5 concentrations while temperature, rainfall, RH, wind speed and wind direction have opposite tendency with PM2.5.

In order to have a better knowledge of the correlation between PM2.5 and meteorological factors, the correlation coefficients of PM2.5-meteorology and each two meteorological factors were calculated from the daily average data in 2013. As shown in Table 2, PM2.5 concentrations have a positive correlation with pressure and negative correlation with temperature, rainfall, RH, wind speed and wind direction, which is consistent with Figure1. The correlation coefficients of PM2.5 concentration with temperature and relative humidity are -0.513 and -0.524 respectively, showing strong negative correlations. The correlation coefficients of PM2.5 concentration with rainfall and wind speed are -0.237 and -0.284 respectively. The PM2.5 concentration has a weak correlation with wind direction, which is -0.1 while has a strong positive correlation with the pressure of 0.507.

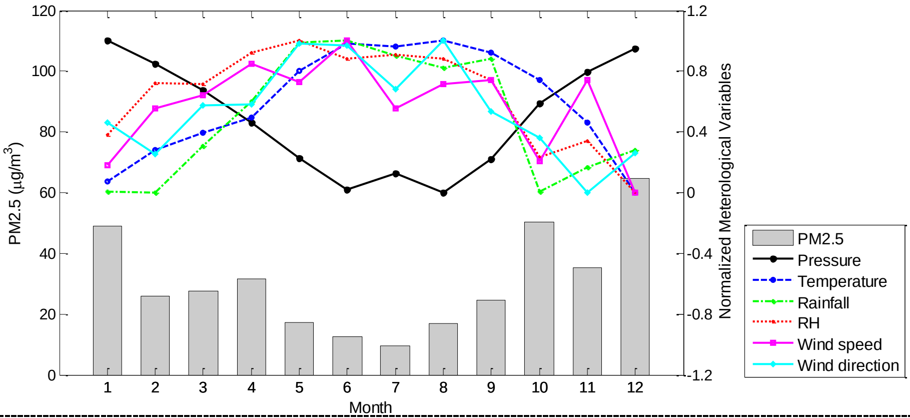

Figure 1. The monthly tendency of PM2.5 concentration and normalized meteorological factors

Table 2. The correlation coefficient between PM2.5 and meteorological factors in 2013

Correlation Coefficient	PM2.5	Temperature	Pressure	RH	Rainfall	Wind speed	Wind direction
PM2.5	1						
Temperature	-0.5132	1					
Pressure	0.5073	-0.8461	1				
RH	-0.5239	0.4002	-0.5244	1			
Rainfall	-0.2370	0.1219	-0.3133	0.3916	1		
Wind speed	-0.2843	0.1303	-0.1979	0.1128	0.0770	1	
Wind direction	-0.0997	0.2258	-0.2956	0.1460	0.1069	-0.0573	1

3.2. Correlations between PM2.5 and Temperature

According to the range of temperature in 2013, it is classified into 5 intervals which are 10-15, 15-20, 20-25, 25-30, 30-35. The amplitude of variation of temperature in Hong Kong is much smaller than that in high latitude area due to the subtropical monsoon climate. As shown in Figure 2, the low temperature 10-15 and high temperature 30-35 have low frequency, which are 8% and 2%, respectively. The highest frequency appears in the interval 25-30, which is 43%. The mean values of PM2.5 concentrations for each temperature intervals are calculated. The results show that PM2.5 concentrations decrease with temperature increase. The mean value of PM2.5 concentrations is highest (42 μg/m^3) when the temperature ranges between 10-15℃. When the temperature is higher than 25℃, PM2.5 mean concentrations become lower than 10 μg/m^3. This because when the temperature is higher, the air convection at lower surface is stronger, which benefits the upward transport of particular matter [8].

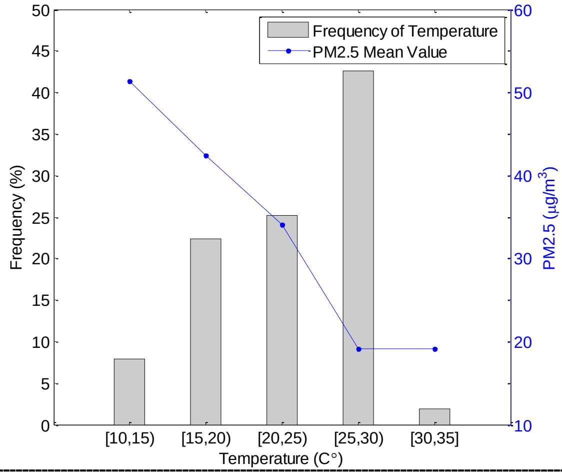

Figure 2. The frequency of temperature intervals and mean value of PM2.5 concentration for each interval

The linear regression between PM2.5 concentration and temperature was made for each season. As shown in Figure 3, the correlations of PM2.5 concentration and temperature are positive in winter, spring, and autumn. They have best linear regression fit in spring which R^2 is 0.23. The correlation is different in summer, which is positive with R^2 =0.022.

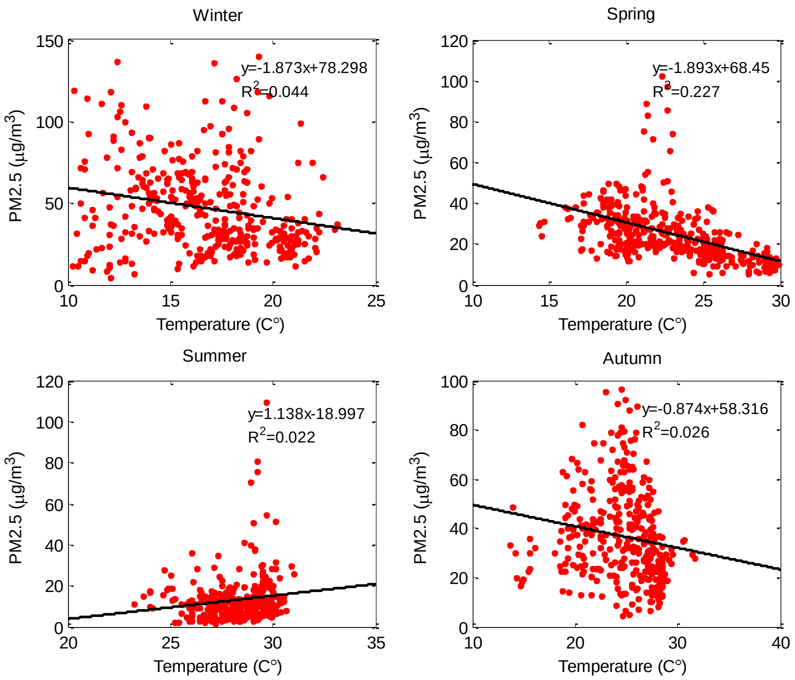

Figure 3. The linear regression of PM2.5 and temperature of four seasons in 2013

3.3. *Correlations between PM2.5 and Pressure*

The pressure in 2013 ranges from 990 hPa to1030 hPa. It was divided into 8 intervals: 990-995, 995-1000, 1000-1005, 1005-1010, 1010-1015, 1015-1020, 1020-1025, 1025-1030. According to Figure 4, pressure concentrates between 1005 hPa and 1020 hPa in most of the year. With pressure's increase, PM2.5 concentrations have a general increase tendency. Since when pressure is low, the surrounding air masses with high-pressure airflow to center. The upward airflow is formed in the center and helpful for the diffusion of pollutants. On the contrary, when the surface is dominated by high pressure, the center area has downward air flow. This condition is not helpful for the dilution and diffusion of pollutants and thus increase its concentration [9].

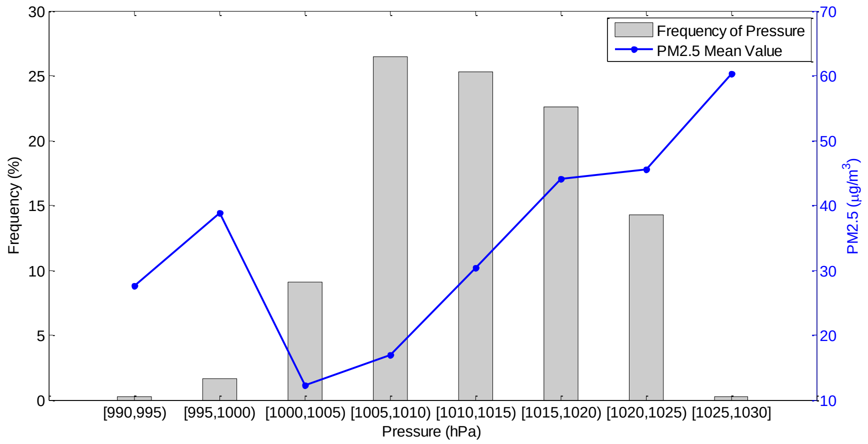

Figure 4. The frequency of pressure intervals and mean value of PM2.5 concentration for each interval

Figure 5 shows the linear regression analysis of PM2.5 concentration and pressure. In winter, spring and autumn, they have a positive correlation while in summer, they have a negative correlation.

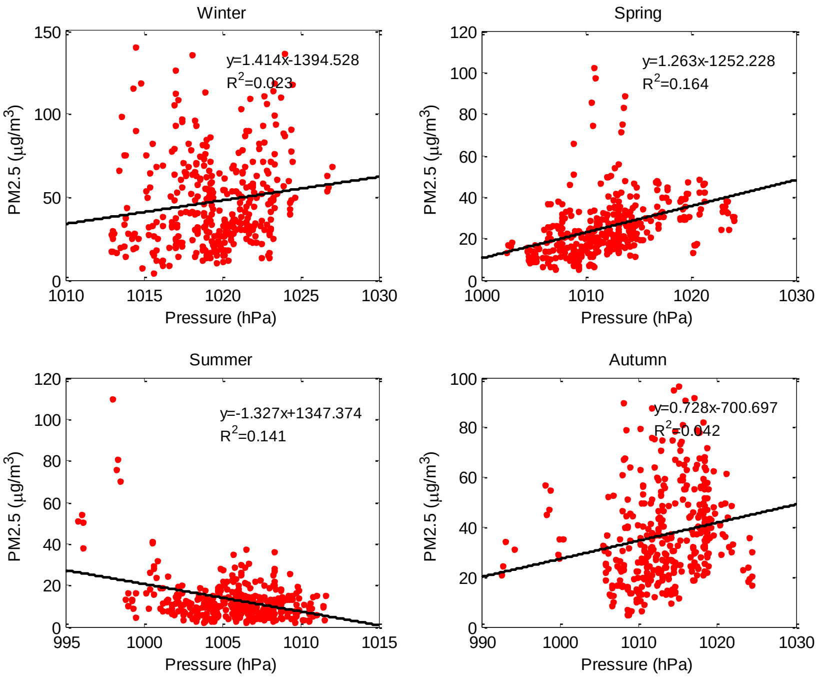

Figure 5. The linear regression of PM2.5 and pressure of four seasons in 2013

3.4. *Correlations between PM2.5 and RH*

The relative humidity in 2013 ranging from 20% - 100% was classified into 8 intervals: 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100. The frequency of each interval is shown by the histogram of Figure 6. Hong Kong has a humid climate and the frequency of RH between 70% and 90% exceeds 60%. The mean value of PM2.5 concentration in each RH interval is shown by the broken line in

Figure 6, which decrease with the increase of RH. Although there is an increase of PM2.5 when RH changes from 20-30 to 30-40, the frequency of RH in 20-30 is very low <1%. Therefore, the increase does not have universal representation.

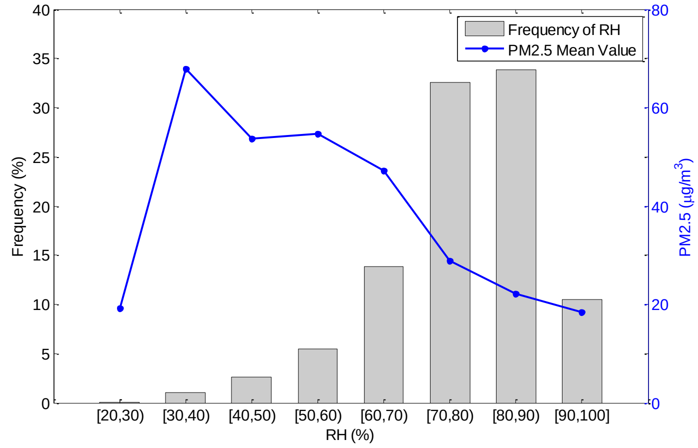

Figure 6. The frequency of RH intervals and mean value of PM2.5 concentration for each interval

Figure 7 shows the linear regression between PM2.5 concentration and RH. The PM2.5 concentrations and RH have negative correlations in winter, spring, autumn. They fit best in winter with R^2=0.247, followed by autumn R^2=0.114. In summer, PM2.5 doesn't have obvious correlations with RH (R^2=0.001).

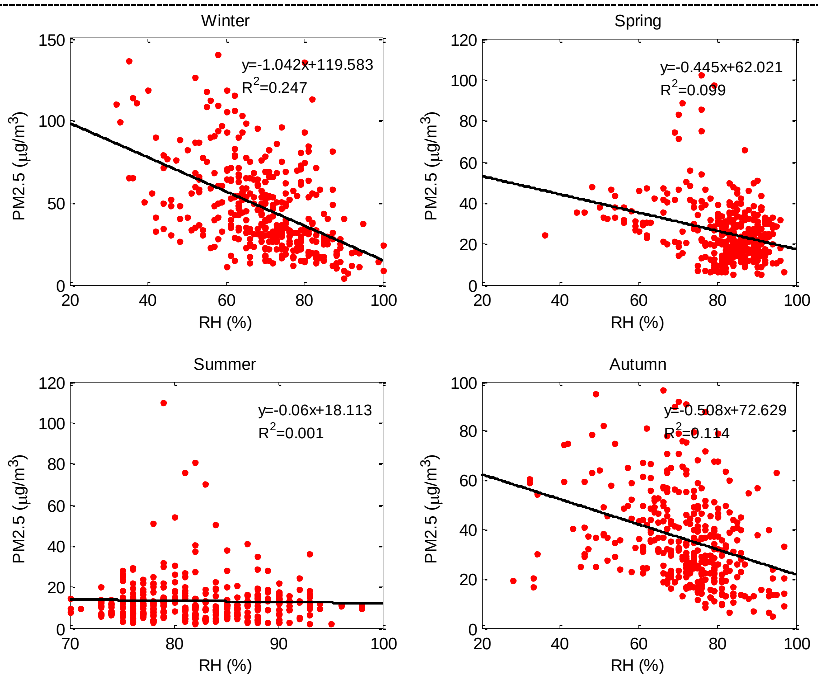

Figure 7. The linear regression of PM2.5 and RH of four seasons in 2013

3.5. Correlations between PM2.5 and Rainfall

Since rainfall mainly concentrates in summer, we don't make the correlations analysis of PM2.5 and rainfall for different seasons and months. We only analyze the PM2.5 tendency for different rainfall levels. The rainfall in 2013 were divided into12 intervals: <1, 1-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100, >100. The RH values for each interval were made statistics and the mean values of PM2.5 for each interval were calculated. As shown in Figure 8, the histogram shows the RH frequency and the broken line shows the PM2.5 variations tendency. About 70% days in 2013 have rainfall less than 1 mm. The frequency in 1-10 is 15%. The rainfall >70 mm has a very low frequency with 1%. Generally, the mean PM2.5 concentrations for different RH intervals decrease with rainfall. Especially when the rainfall changes from <1 to 1-10, PM2.5 has a big decline from 37 μg/m^3 to 22 μg/m^3. Therefore, the rainfall can clean the air and thus decrease the particular matter content.

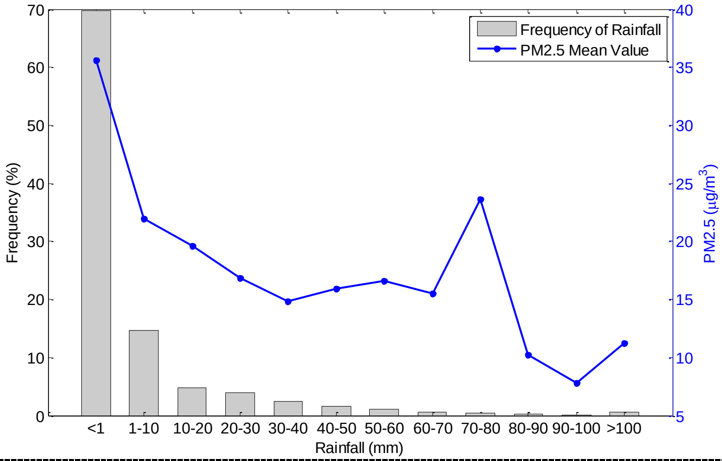

Figure 8. The frequency of rainfall intervals and mean value of PM2.5 concentration for each interval

3.6. *Correlations between PM2.5 and Wind Speed*

As an important meteorological factor, wind influence the horizontal and vertical transport of air pollutants. It also affects the speed of concentration and diffusion of pollutants directly [8]. The wind speed in 2013 is slow in general, ranging in 0-30 km/h. The wind speeds were classified into 6 intervals: 0-5, 5-10, 10-15, 15-20, 20-25, 25-30. The wind speeds of 5-10 km/h account for 60% of the whole year (Figure 9). The PM2.5 concentration reduces significantly with wind speed increases. When wind speed increase from 0-5 km/h to 5-10 km/h, the PM2.5 mean concentration has a largest reduce from 56 μg/m^3 to 34 μg/m^3. This is because high wind speed is beneficial for the diffusion of PM2.5 [10]. On the contrary, low wind speed inhibits the diffusion of PM2.5 and makes the PM2.5 concentrates in the surface.

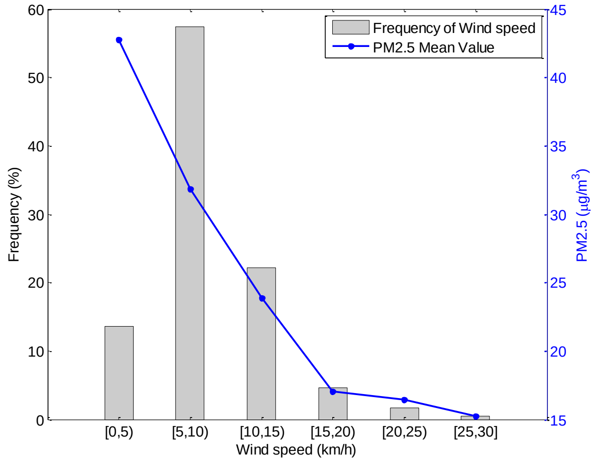

Figure 9. The frequency of wind speed intervals and mean value of PM2.5 concentration for each interval

According to Figure 10, the linear regressions between PM2.5 and wind speed are different in four seasons, but the slopes are all negative, which means PM2.5 decreases with wind speed increases.

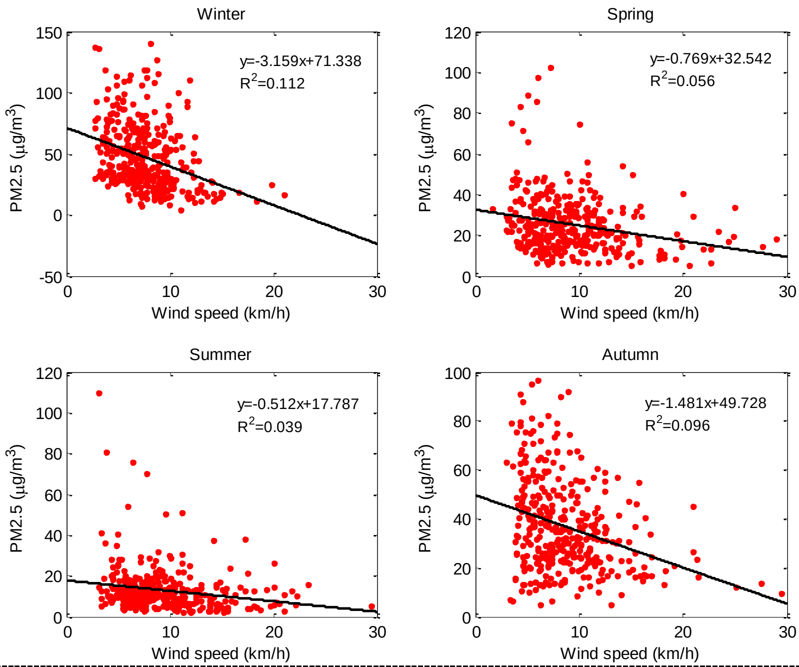

Figure 10. The linear regression of PM2.5 and wind speed of four seasons in 2013

3.7. *Correlations between PM2.5 and Wind Direction*

Besides wind speed, wind direction influences the transport direction of PM2.5 concentration [10]. The impact of wind speed on PM2.5 concentration was evaluated by Average Weighted PM2.5 (AWP), which represents the average PM2.5 concentration for each unit of wind speed. The AWP of one direction was calculated by the following equation [5]:

$$AWP = \frac{\sum_{i=1}^{N} P_i / WS_i}{N} \tag{1}$$

P_i is PM2.5 concentration, WS_i is wind speed, N represents the number of the direction.

Figure 11 depicts the AWP in four seasons of 2013. The AWP values for different directions are higher in winter ranging from 5μg/m^3 to 25 μg/m^3 than that in other three seasons. The AWP values (2-14 μg/m^3) are obviously lower in summer than that in other three seasons. Compared with the wind rose chart in Figure 12, winter is dominated by North wind with main directions of NNW, N, NE, ENE. The AWP of N wind is highest, larger than 20 μg/m3. The main reason is that the north wind in winter bring pollutants from Guangdong to Hong Kong and increase the PM2.5 concentration [11], [12]. The main winds in spring are southeast and northeast wind. The directions of NE, ENE, SSE, S have relative high frequency. The AWP values of NE and ENE wind (about 5 μg/m^3) are higher than that of SSE and S wind (about 4 μg/m^3). In autumn, east wind is the main direction. The frequency of directions ENE and E are 30% and 23%, respectively. The AWP values for all directions don’t have a big difference. Summer was dominated by southeast wind with main directions of SSE, ENE, SSE (frequency is close to 40%). The AWP values for SSE and ENE are 2.1 μg/m^3 and 3.5 μg/m^3, respectively. This is because the southeast wind in summer brings clean air from ocean to Hong Kong [11].

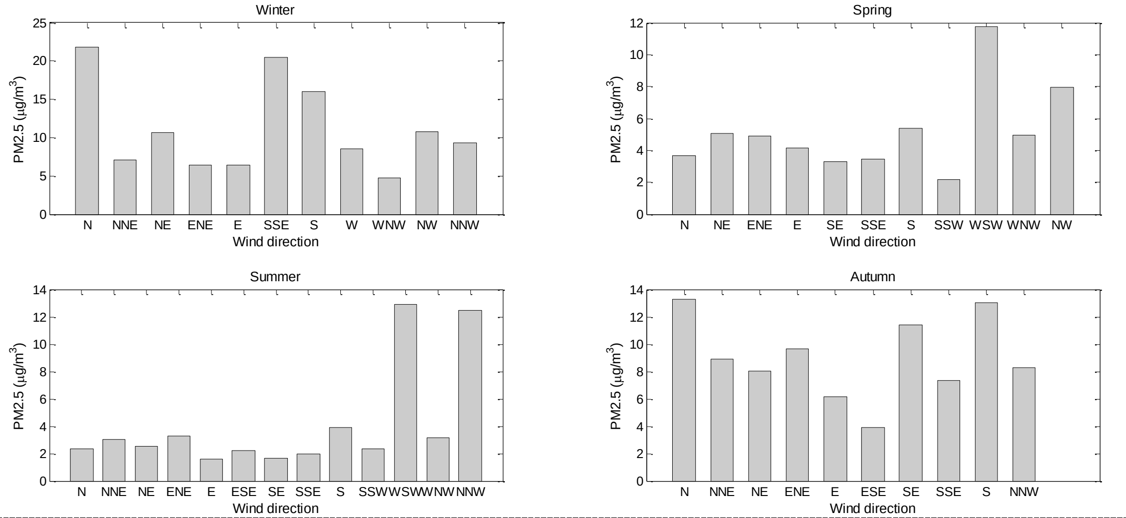

Figure 11. The AWP values of different wind directions in 4 seasons in 2013

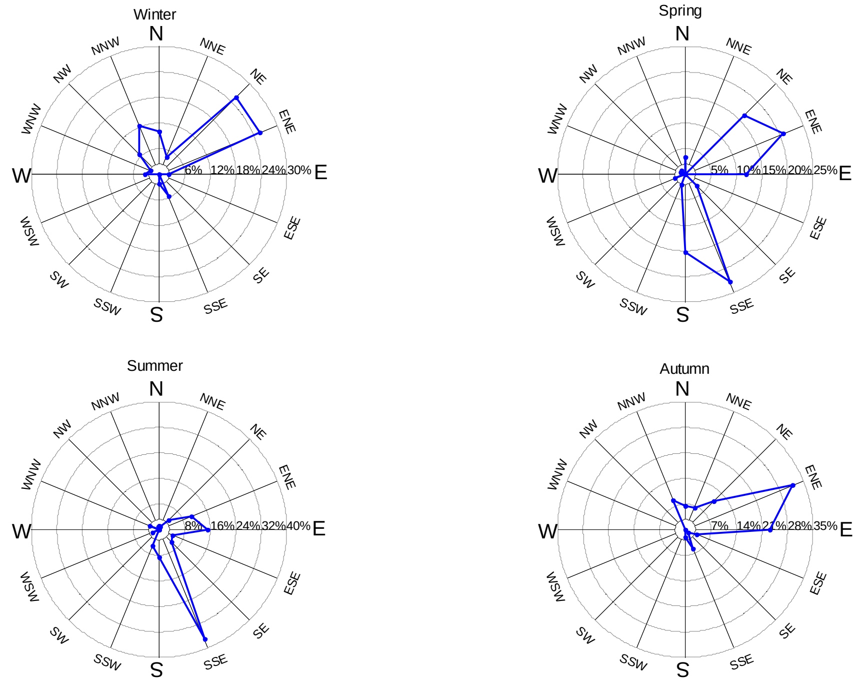

Figure 12. The wind rose of 4 seasons in 2013

4. Conclusion

This study has analyzed the systematic impact of meteorological factors on PM 2.5 variation based on PM 2.5 and weather data during 2013 in Hong Kong, the main findings of this study are concluded as follows:

- The PM2.5 concentration has positive correlations with pressure and negative correlations with temperature, rainfall, RH and wind speed. The correlation coefficients are highest with temperature, pressure, and RH, which indicates the three factors mainly influence the PM2.5 concentrations.
- The wind direction influences the transport direction of PM2.5 pollutants. The north wind in winter increases the PM2.5 concentration while the southeast wind in summer decreases the PM2.5 concentration.

- The correlations between PM2.5 and meteorological factors vary with different seasons. For example, PM2.5 has a positive correlation with temperature in winter and a negative correlation in summer.

In summary, meteorological factors have leading impacts on PM2.5 pollutions when the local emission is stable. In future studies, the correlation between PM2.5 concentration and meteorological factors can be used for prediction of air pollution and help government to make emission-control polices to prevent and reduce health impact of PM2.5.

5. Acknowledgments

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6. Reference

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