RELATIONSHIP BETWEEN PM2.5 CONCENTRATIONS AND METEOROLOGICAL DATA IN NAGASAKI

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ABSTRACT: With the rapid economy development of Asia in recent years, the air pollution problem is becoming more and more serious, especially the PM2.5 problem. Affected by the seasonal wind, the PM2.5 pollution is also a trans-boundary problem. Nagasaki is located at the westernmost part of Japan has been affected by pollutants from outside of the country recently. Therefore it is an appropriate place for study about long range transport pollutants and the correlation between PM2.5 concentrations and meteorological conditions, such as precipitation, hours of sunshine, humidity, wind direction, atmospheric pressure, temperature and so on. These relationships do favor in the understanding of PM2.5formation and the PM2.5 forecast. In this paper, PM2.5 data and meteorological variables were collected in Nagasaki during Jan 1 to Dec 31, 2013. Through linear analysis and Spearman analysis, the correlation between PM2.5 mass concentrations and meteorological variables were analyzed. The results showed that 1) precipitation had negative correlation with PM2.5 and temperature was positive correlated to PM2.5. 2) The correlations between PM2.5 and wind speed, humidity and atmospheric pressure had thresholds. When the meteorological variables were higher or lower than threshold, the correlation is different. 3) In four seasons, the West wind may brought the most pollutants to Nagasaki. It can be concluded that the pollutants in Nagasaki mainly from East Asia through the long range transport.

1. INTRODUCTION

With the development of the economy in the world, the air pollution problem is becoming more and more serious in recent years, especially the PM2.5 problem. Fine particle matters with the aerodynamic diameter less than 2.5 μm is called PM2.5. Because of the effects on visibility, human health and global climate, PM2.5 has attracted much scientific and public attention (Yao *et al.*, 2014; Zhang *et al.*, 2014). Each country has different standards for PM2.5 mass concentration. To meet the standard for PM2.5, it is desirable to find the factors affecting PM2.5(Chatani *et al.*, 2011). Basically, there are three factors affecting the PM2.5 mass concentration, including domestic emission sources, pollutants from outside of the country and the meteorological conditions. In Japan, the government has already put very strict restrictions on emission sources. Therefore, the pollutants from outside of the country play an important role in PM2.5 concentration.

As shown by previous studies, the meteorological conditions can largely diffuse, dilute and accumulate the pollutants (Pohjola *et al.*, 2002). So the PM2.5 mass concentration is mainly up to the meteorological conditions *et al.*, 2010). (Yang *et al.*, 2011) has concluded that the meteorological conditions can at least make a contribution 16% to the reduction of PM2.5 mass concentration. (LaToya Myles *et al.*, 2010) integrated HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) atmospheric dispersion model driven by the advanced research version of Weather Research and Forecasting (WRF) meso−scale atmospheric model to assess source location, transportation trends, and the extent of contribution to PM2.5.

In this paper, PM2.5 data and meteorological variables were collected during Jan 1 to Dec 31, 2013. Through the linear analysis and the Spearman analysis, the correlation between PM2.5 and meteorological variables were analyzed. In addition to, from the relationship between PM2.5 mass concentration and meteorological conditions, such as wind direction, we can also deduce the external pollutant sources.

2. DATA AND METHOD

2.1 Data in Nagasaki

The study was carried out in Nagasaki, Japan. Nagasaki is located at the westernmost part of Japan. Figure 1 shows the location of Nagasaki in Japan. It is a coastal tourist city and forest coverage is more than 60%. There has very little factories (http://ja.wikipedia.org/wiki/%E9%95%B7%E5%B4%8E%E5%B8%82). It can be said that, in Nagasaki, domestic anthropogenic sources are very little. Thus, Nagasaki is a place fitting for doing the research about the pollutants from outside of the country. As shown in Figure 2, there are many monitoring stations in Nagasaki. According to the Nagasaki Prefectural Government website（http://www.pref.nagasaki.jp/）, PM2.5 mass concentration were collected during Jan 1 to Dec 31, 2013. Meteorological data in 2013, including temperature, humidity, atmospheric pressure, wind speed and wind direction, were collected from the Japan Meteorological Agency website (http://www.jma.go.jp/jma/index.html).

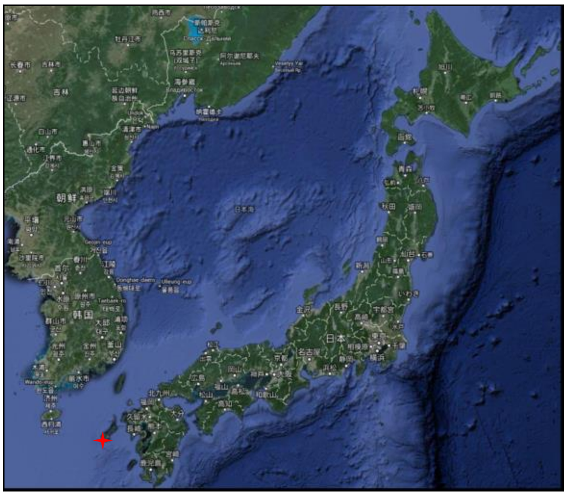

Figure 1. Location of Nagasaki in Japan

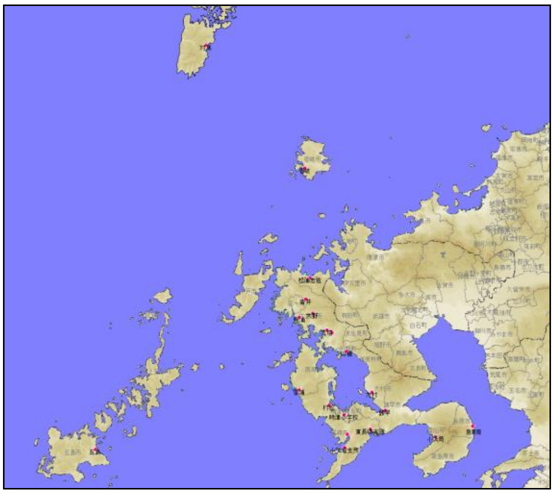

Figure 2. PM2.5 monitoring stations in Nagasaki

2.2 Data processing method

The PM2.5 data and meteorological data were collected for the whole year in 2013. First, we divided the data into four seasons (spring: March to May, summer: June to August, autumn: September to November, and winter: December to February). In this way, the seasonal distribution of PM2.5 was obtained. Second, according to different meteorological variables, linear regression and Spearman rank correlation analysis the correlation between PM2.5 values and meteorological variables. Some studies used linear regression, some used multiple linear regression, and some studies used Spearman rank correlation analysis. The linear regression and the Spearman rank correlation analysis were used in this paper. In this way, the two methods were compared with each other.

For meteorological variables including temperature, humidity, station pressure and wind speed, we used the average values hourly for a whole day during Jan 1 to Dec 31, 2013. The reason is that in a day the PM2.5 values has the biggest range. In this way, we can find out the correlations with meteorological variables. For precipitation and wind direction, I think it is more reasonable to use the average values per day during Jan 1 to Dec 31, 2013. Besides, days with precipitation ≥ 1mm were selected to analyze the correlation with PM2.5.

For wind direction, the source of the PM2.5 outside of the country were obtained in Nagasaki. (Pohjola *et al.*, 2002) has implied that PM10 concentrations originate mainly from local vehicular traffic (direct emissions and resuspension), while the PM2.5 concentrations are mostly of regionally and long-range transported origin. We use the weighted PM2.5 values by wind speed to distinguish which direction bring the most pollutants from outside of the country.

For each direction, the weighted PM2.5 values were obtained with the following equation:

$$AWP=\frac{\sum_{i}\frac{P}{WS}}{N}, \quad 1\leq i\leq N \tag{1}$$

Where, AWP is the average weighted PM2.5 value in a year, P is the daily PM2.5 value, WS is the corresponding wind speed, and N is the times which the wind direction appeared in a year.

3. RESULTS AND DISCUSSION

3.1 Correlations with meteorological variables

As shown in Figure 3, PM2.5 has a strong positive correlation with temperature in most of the months. As the high temperature promotes the photochemical reaction between precursors, the formation of particles was affected significantly.

Figure 4 shows the linear correlation between PM2.5 concentration and humidity. In most of months, PM2.5 has a strong negative correlation with humidity. In some months, there are positive correlations and the correlation coefficient is very low. In summer the humidity is more than 70%, PM2.5 concentration has a strong negative correlation with humidity. In autumn the correlation is all negative. In September, the humidity is very high when the range is 80% to 100%. There was a strong correlation, 0.4 and 0.6 respectively, using the linear analysis and the Spearman analysis. The PM2.5 concentration decreased rapidly with the humidity increasing in summer and September when the humidity is very high. In spring and winter humidity is relatively low. The correlation coefficient is less than 0.1, except in February and March. In February and March, the humidity is relatively high, 60% to 100% and 80% to 100% respectively. When the humidity is low, because of hygroscopic growth, PM2.5 concentration increases with the humidity increasing (Li *et al.*, 2011; Liu, 2011). When the humidity is high enough, the particles become too heavy to stay in the air. Due to the dry deposition, the particles fall to the ground. Finally, the number of particles reduces and the PM2.5 concentration decreases.

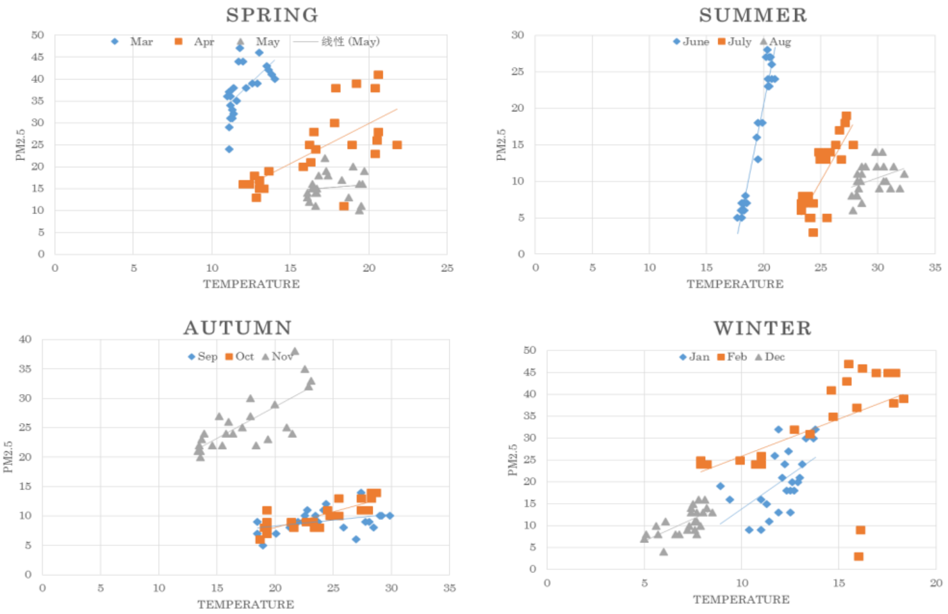

Figure 3. The relationship between PM2.5 and temperature in four seasons. The straight lines are the unary linear regression

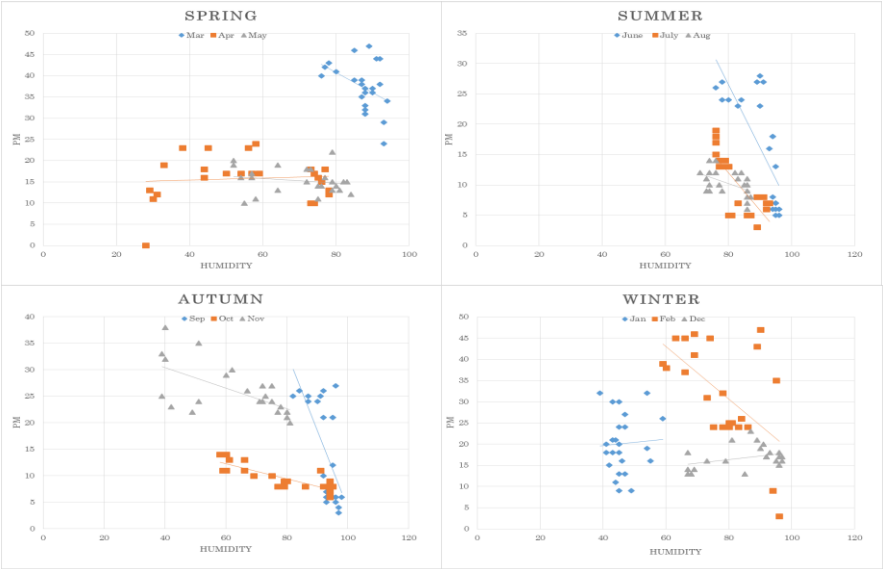

Figure 4. The relationship between PM2.5 and humidity in a year

Figure 5 shows the correlation between atmospheric pressure and PM2.5. In summer the atmospheric pressure is very low and the range between 1001 hPa to 1008 hPa. There was a positive correlation with PM2.5 concentration. In other seasons, the atmospheric pressure is relatively high, 1008 hPa to1018 hPa in winter, 1008 hPa to 1015 hPa in spring, 1008 hPa to 1012 hPa in summer, 1018 hPa to 1021 hPa in autum. When the atmospheric pressure is high, it has a negative correlation with PM2.5 concentration. It seems that there is a threshold, 1008 hPa. When the atmospheric pressure was lower than threshold, the PM2.5 concentration increased with the pressure increase; When surface layer is controlled by high pressure, low pressure air mass flows to the center and form downdraft in the central, suppress the upward diffusion of pollutants and increase the PM2.5 concentration. Otherwise, the atmospheric pressure is higher than threshold, the PM2.5 concentration decreases with the pressure increasing. When the surface layer is controlled by the high pressure, ground wind speed is high resulting in decreasing PM2.5 concentration.

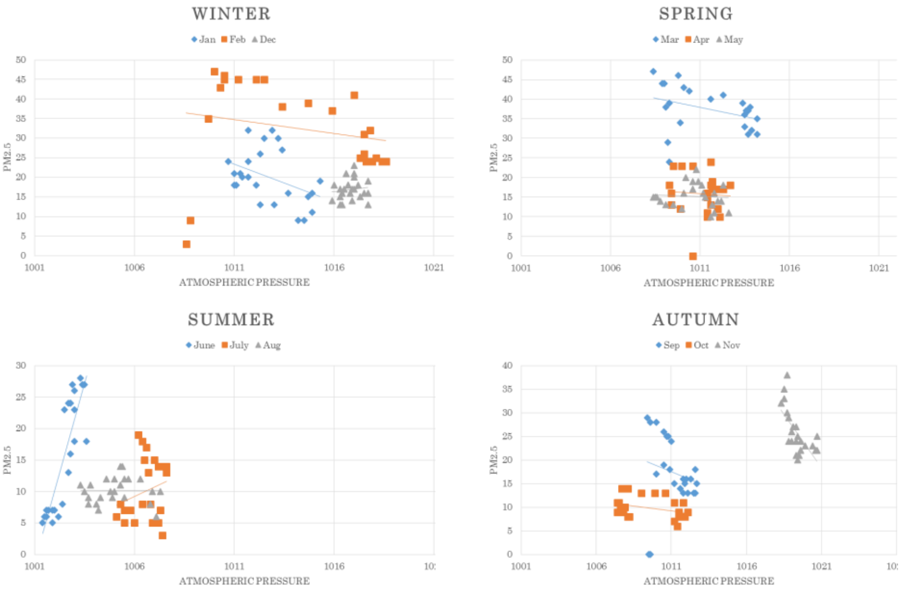

Figure 5. The relationship between PM2.5 and atmospheric pressure in a year

Figure 6 shows negative correlation with PM2.5 when wind speed is lower than 3m/s and positive correlation with PM2.5 when wind speed is higher than 3m/s. when the wind speed is low, the wind can blow away the pollutants within a certain geographical range. But when the wind speed is high enough, the wind can also bring large amount of pollutants from far away.

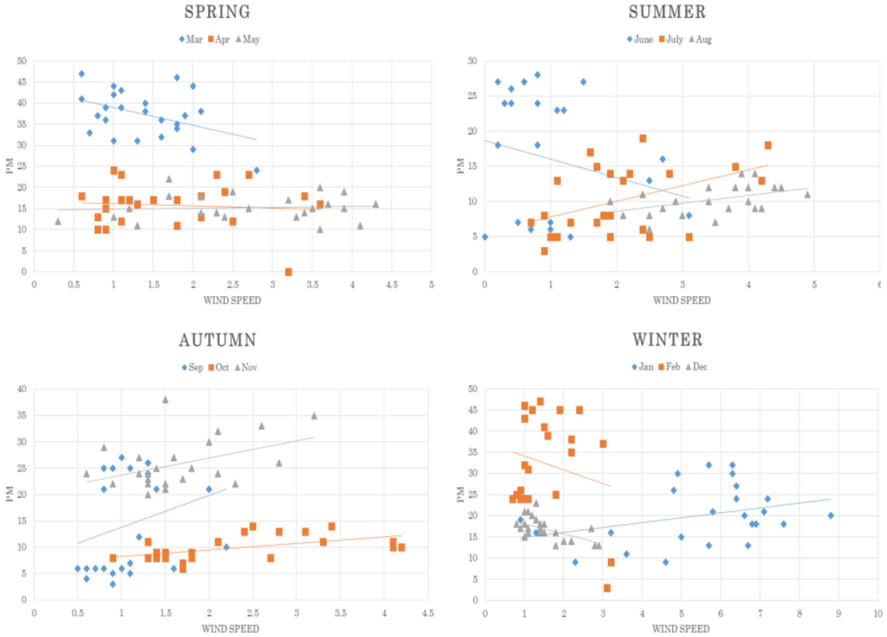

Figure 6. The relationship between PM2.5 and wind speed in a year

Precipitation can effectively decrease PM2.5 mass concentrations were showed in Figure 7. Through wet deposition, precipitation can effectively remove atmospheric particulate matter in different size, especially in small size. Through the linear regression and Spearman analysis, the correlation with PM2.5 is -0.0606 and -0.197. The minus means a negative correlation, that is, the PM2.5 concentration decrease with the precipitation increase.

The wind direction is an important parameter affecting PM2.5 (Yang *et al.*, 2011). The wind from different directions brought different amount of pollutants. Figure 8 shows the AWP (Average Weighted PM2.5 by wind speed) in different wind direction for four seasons. In spring, obviously the west wind brings the most pollutants. In summer, the NNW wind, NW wind, SE wind and west wind bring more pollutants than wind in other directions. In autumn, the ESE wind, SE wind and west wind bring more pollutants than wind in any other directions. In winter, the ESE wind, north wind, SE wind, SSE wind, SW wind and west wind bring more pollutants than wind in other directions. In every season, the west wind always brings more pollutants than other directions. It can be concluded that the pollutants in Nagasaki mainly from East Asia.

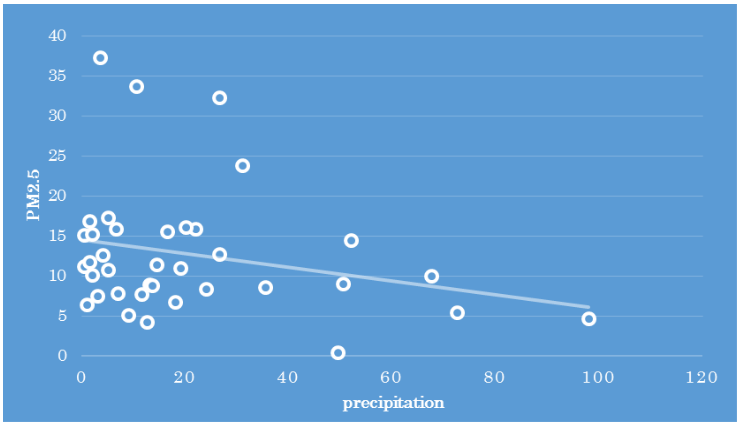

Figure 7. The relationship between PM2.5 and precipitation in a year, SPSS R^2＝-0.197

3.2 Determination coefficients comparison using two kinds of method: linear analysis and Spearman analysis

Table 1 Determination coefficients between PM2.5 and meteorological variables, using linear analysis and Spearman analysis respectively.

R^2		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
T	L-analysis	0.2612	0.3028	0.3585	0.464	0.017	0.9361	0.6016	0.1394	0.1368	0.6449	0.5622	0.4305
	S-analysis	0.6	0.623	0.721	0.714	0.327	0.887	0.657	0.434	0.372	0.804	0.767	0.683
H	L-analysis	0.0029	-0.345	-0.177	0.007	-0.035	-0.577	-0.601	-0.262	-0.421	-0.657	-0.405	0.1293
	S-analysis	-0.044	-0.505	-0.4	-0.023	-0.304	-0.856	-0.749	-0.555	-0.665	-0.804	-0.704	0.224
P	L-analysis	-0.163	0.0473	-0.128	-0.004	-0.004	0.7358	0.0546	0.001	-0.035	-0.112	-0.433	0.0182
	S-analysis	-0.402	-0.421	-0.5	-0.003	-0.117	0.848	0.106	0.141	-0.412	-0.379	-0.723	0.185
WS	L-analysis	0.1104	-0.044	-0.176	-0.007	0.0086	-0.061	0.2118	0.212	0.0722	0.2886	0.1861	-0.310
	S-analysis	0.286	0.166	-0.287	0.124	0.153	-0.182	0.377	0.43	0.382	0.554	0.334	-0.516

R^2: determination coefficient, T: temperature, H: humidity, P: atmospheric pressure, WS: wind speed, L-analysis: linear analysis, S-analysis: the Spearman analysis.

Spearman's rank correlation coefficient is a kind of Non-parametric analysis (distribution-free) which can provide the degree of co-variation trend of two random variables in a linear correlation or nonlinear correlation. Therefore，it may be more objectively reflect the correlation between meteorological factors and PM2.5 mass concentration.

To compare the correlation coefficients using linear analysis with Spearman analysis, Table1 display R^2 in two situations respectively. Basically, the coefficient using Spearman analysis is higher than coefficient using linear analysis. When the absolute value of the correlation coefficient is close to 0, the coefficients may have the positive and negative difference in two kinds of analysis, as shown in red data in Tables 1.

Using unary linear analysis, the R^2 has the range of 0.1 to 0.9 which is in agreement with (Tai, Mickley, and Jacob 2010; Zhao *et al.*, 2014). Using Spearman analysis, the R^2 range from 0.3 to 0.9. From Table 1, the R2 values resulting from Spearman analysis is higher than R^2 using unary linear analysis.

4. CONCLUSIONS

In this paper, PM2.5 data and meteorological variables were collected In Nagasaki during 1/1 to 31/12/2013. Through linear analysis and Spearman analysis, the correlation between PM2.5 mass concentrations and meteorological variables were analyzed. The results showed that 1) precipitation had negative correlation with PM2.5 and temperature was positive correlated to PM2.5; 2) The correlations between PM2.5 and wind speed, humidity and atmospheric pressure had thresholds. When the meteorological variables were higher or lower than threshold, the correlation is different; 3) In four seasons, the west wind may bring most pollutants to Nagasaki. It can be concluded that the pollutants in Nagasaki may mainly from East Asia through long range transport.

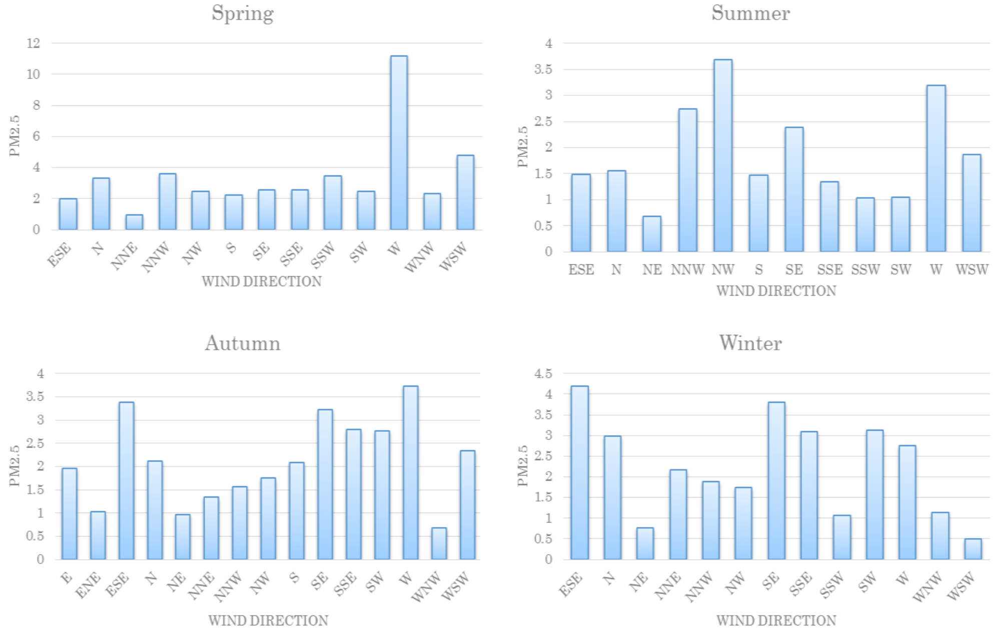

Figure 8. The relationship between PM2.5 and wind direction in a year

References

Chatani, S., Morikawa, T., Nakatsuka, S., Matsunaga, S., and Minoura H., 2011. Development of a framework for a high-resolution, Three-Dimensional Regional Air Quality Simulation and Its Application to Predicting Future Air Quality over Japan. Atmospheric Environment, 45(7), pp. 1383–93.

Myles L, Pendergrass W, Vogel CA, Ridge O, Yerramilli A, Dodla VBR, Dasari HP, Srinivas CV, Tuluri F, Baham JM, Hughes R, Patrick C, Young J, Swanier S, 2010. Evaluation of PM2.5 source regions over the Mississippi Gulf coast using WRF/HYSPLIT modeling approach. 16th Conference on Air Pollution Meteorology, Atlanta, GA, USA.

Li, W. J., Zhang, D. Z., Shao, L. Y., Zhou, S. Z. and Wang, W. X., 2011. Individual particle analysis of aerosols collected under haze and non-haze conditions at a high-elevation mountain site in the north china plain. Atmospheric Chemistry and Physics, 11(22), pp. 11733–44.

Liu, P. F., Zhao, C. S., Gbel, T., Hallbauer, E., Nowak, A., Ran, L., Xu, W. Y., Deng, Z. Z., Ma, N., Mildenberger, K., Henning, S., Stratmann, F., and Wiedensohler, A., 2011. Hygroscopic properties of aerosol particles at high relative humidity and their diurnal variations in the north china plain. Atmospheric Chemistry and Physics, 11(7), pp. 3479–94.

Pohjola, M. A., Kousa, A., Kukkonen, J., Härkönen, J., Karppinen, A., Aarnio, P., Koskentalo, T., 2002. The spatial and temporal variation of measured urban pm10 and PM2.5 in the helsinki metropolitan area. Water, Air and Soil Pollution, 2, pp. 189–201.

Tai, Amos P.K., Loretta J. Mickley, and Daniel J. Jacob., 2010. Correlations between fine particulate matter (PM2.5) and meteorological variables in the united states: implications for the sensitivity of PM2.5 to climate change. Atmospheric Environment, 44(32), pp. 3976–84.

Yang, L., Ye Wu, Jerry M. Davis, and Jiming Hao., 2011. Estimating the effects of meteorology on PM2.5 reduction during the 2008 summer olympic games in beijing, china. Frontiers of Environmental Science & Engineering in China, 5(3), pp. 331–41.

Yao, Ling, and Ning Lu., 2014. Particulate matter pollution and population exposure assessment over mainland china in 2010 with remote sensing. International journal of environmental research and public health, 11(5), pp. 5241–50.

Zhang, F., Cheng, H.R., Wang, Z.U., Lv, X.P., Zhu, Z.M., Zhang, G., Wang, X.M., 2014. Fine particles (PM2.5) at a cawnet background site in central china: chemical compositions, seasonal variations and regional pollution events. Atmospheric Environment, 86, pp. 193–202.

Zhao, C.X., Wang, Y.Q., Wang, Y.J., Zhang, H.L., Zhao, Bing-Qing., 2014. Temporal and spatial distribution of PM2.5 and pm10 pollution status and the correlation of particulate matters and meteorological factors during winter and spring in beijing. Huan jing ke xue, 35(2), pp. 418–27.