IOP Conf. Series: Earth and Environmental Science **153** (2018) 062015 doi:10.1088/1755-1315/153/6/062015

Characteristics of Atmospheric Pollutants Distribution and Removal Effect of Rainfall on Atmospheric Pollutants in Mining Cities

Tang Wen-feng [1,2] Hu You-biao[1]

[1]College of Eearth and Environment, Anhui University of Science & Technology, huainan 232001, China

[2]College of Civil Engineering, Huainan union University, huainan 232038, China

fengtang0@163.com

Abstract. This paper studies the characteristics of atmospheric pollutant（SO_2, NO_2, $PM_{2.5}$ and PM_{10}）and the effects of rainfall on the removal of atmospheric pollutants. The results show atmospheric pollutants concentration vary in different seasons and functional area: atmospheric pollutants concentration in summer and autumn is lower than that in winter and spring; the concentration of SO_2 and NO_2 in coal-chemical industry areas and light industrial areas is higher, the concentration difference of $PM_{2.5}$ and PM_{10} in different functional areas is very small, the removal efficiency of rainfall on atmospheric pollutant is gradually improved with the increasing of daily rainfall, rainfall intensity and rainfall duration, the ability of rainfall to remove pollutants tends to be stable after daily rainfall and rainfall intensity exceeds 30mm and 20mm/h respectively, the effect of rainfall on the removal of $PM_{2.5}$ was slightly worse than the effect of rainfall on other atmospheric pollutants, the rainfall duration should be 60min, 60min and 80min respectively when the effect of rainfall on NO_2, PM10 and SO_2 tends to be stable.

1. Introduction

In recent years, the problem of atmospheric pollution in our country is becoming more and more serious, there are many reasons for atmospheric pollution, and coal combustion, industrial emissions and increasing vehicle use are important reasons. Rainfall is an important way to reduce the concentration of pollutants in the atmospheric, and the study indicates that rainfall is one of the important factors to change the concentration of gaseous pollutants [1-4], The removal of particulate matter and gaseous pollutants by rainfall is an important source of ion components in rainwater [5].

Huainan city is located in the Middle East of China and is an important coal, electric power and chemical base in our country, where coal combustion and chemical exhaust emissions are the main sources of atmospheric pollution. This paper studies the distribution characteristics of SO_2, NO_2, $PM_{2.5}$ and PM_{10} in huainan and the removal effect of rainfall on atmospheric pollutants, and the relationship between precipitation, duration of rainfall, intensity of rainfall and removal of atmospheric pollutants was discussed in order to provide a reference for further experimental study and to provide theoretical basis for the future use of artificial measures to control atmospheric pollution.

2. Materials and methods

2.1. Layout of sample points

The layout of sample collection points is based on the distribution of huainan urban area and industrial, coal and commercial areas. Six sampling points are set up in urban areas and industrial and mining areas, which are located in Datong district, Panji district, Tianjia'an district, Xiejiaji district, Bagongshan district and Fengtai county respectively, and see Fig.1 for each site.

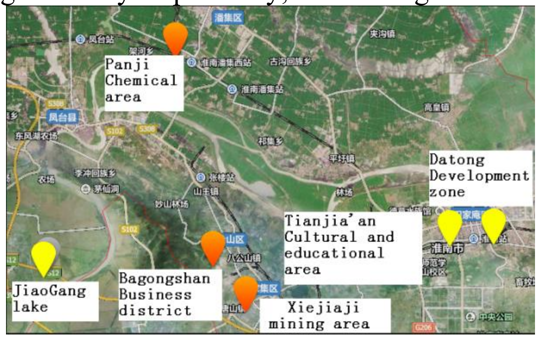

Fig.1 Sampling point setting map

2.2. Sampling time and method

The sampling time of this study was from January 2015 to December 2015 and samples were taken in 4 seasons. The first sampling was arranged before the rainfall and then a sample was taken every 5min during rainfall until the rain stops. The total number of over 5mm precipitation occurred 29 times during the sampling period, and rainfall characteristics are shown in table 1.

Tab.1 Rainfall characteristics in sampling period

date	rainfall /mm	sunny days/d	rainfall duration/h	rainfall intensity/ $mm\cdot h^{-1}$	date	rainfall /mm	sunny days/d	rainfall duration/h	rainfall intensity/ $mm\cdot h^{-1}$
2.15	9	—	3.0	3.0	6.30	70	—	8.0	8.75
2.20	8	5	4.0	2.0	7.3	24	2	1.0	24.00
3.17	42	24	3.5	12.0	7.16	111	12	14.0	7.93
4.4	10	17	3.0	3.33	7.23	22	6	11.5	1.91
4.5	12	0	12.5	0.96	8.7	54	14	13.0	4.15
4.19	12	13	6.5	1.85	8.19	43	11	16.0	2.69
5.2	10	12	6.5	1.54	9.22	11	17	12.0	0.92
5.15	7	12	5.0	1.4	9.30	35	7	2.0	17.5
5.29	8	13	9.5	0.84	10.7	9	6	20.0	0.45
6.1	13	2	18	0.72	11.7	13	30	2.5	5.20
6.16	60	14	13.5	4.44	11.12	14	4	11.0	1.27
6.23	18	6	5.5	3.27	11.22	6	9	5.0	1.20
6.27	96	3	16.0	6.0	11.23	8	—	2.0	4.00
6.28	27	—	6.0	4.5	11.24	11	—	3.0	3.67
6.29	86	—	6.0	14.33					

2.3. Test items and methods

SO_2: Formaldehyde absorption-para-rose aniline spectrophotometric method; NO_2: Naphthalene hydrochloride spectrophotometric method; PM_{10}, $PM_{2.5}$: Laser scattering method.

3. Test results and analysis

3.1. Characteristics of atmospheric pollutants by seasonal variation

The author has recorded the pollutant concentration of SO_2, NO_2, $PM_{2.5}$ and PM_{10} of six monitoring stations in each season of 2015 before rainfall, the average value of atmospheric pollutant of 6 monitoring points was used as the representative value of atmospheric pollutant concentration in each season of Huainan city and the concentration of typical atmospheric pollutant indexes in different seasons in Huainan city was analyzed in this paper, and Fig.2 shows the characteristics of atmospheric pollutants by seasonal variation.

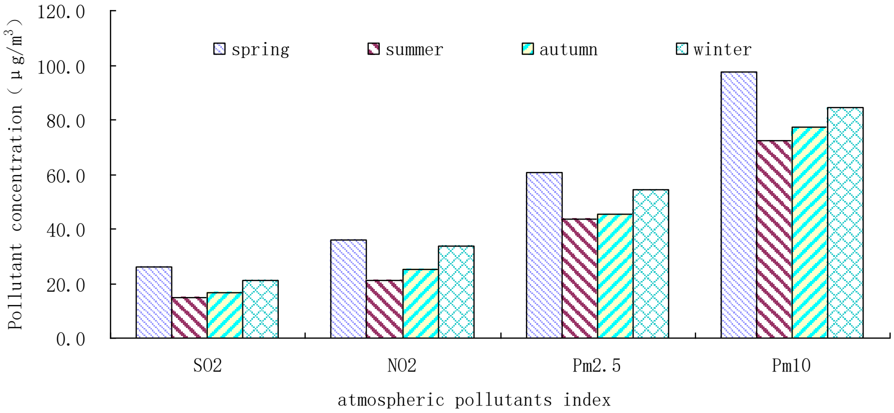

Fig.2 Atmospheric pollutants characteristics with the seasons change

As can be seen from Fig.2, the concentration of four atmospheric pollutants is different in different seasons, but there is a similar pattern, that is, the concentration of four atmospheric pollutants in summer and autumn is lower than that in the winter and spring season. There may be three reasons for this analysis, firstly, the temperature of winter and spring is lower and a lot of coal is burned to meet heating demand, which causes an greatly increase of atmospheric pollution concentration. Secondly, higher temperatures in summer and autumn are conducive to the diffusion of atmospheric pollutants, however, there is likely to be static wind phenomena in winter and spring, which is not conducive to the diffusion of atmospheric pollutants, and the accumulation of pollutants is aggravated. In addition, rainfall is also an important factor affecting the accumulation of atmospheric pollutants, the frequency of rainfall in summer and autumn is higher than that in winter and spring, and frequent atmospheric rainfall has washed and dissolved a certain amount of atmospheric pollutants, therefore, the concentration of atmospheric pollutants in summer and autumn is lower than that in winter and spring.

3.2. Characteristics of atmospheric pollutants by spatial variation

The author chooses six monitoring points to represent different functional areas, which represents scenic areas, commercial areas, mining areas, coal-chemical industry areas, cultural and educational areas and light industrial areas. Table 2 shows the average concentration value of SO_2, NO_2, $PM_{2.5}$ and PM_{10} in 2015.

The data in table 2 shows that the concentrations of SO_2 in coal-chemical industry areas and light industrial areas are 33.6μg•m^{-3}, 32.5μg•m^{-3} respectively which are higher than that in mining areas, commercial areas, cultural and educational areas and scenic areas, and cultural and educational areas and scenic spots are less polluted, in which the concentrations of SO_2 are 10.2μg•m^{-3}, 6.8μg•m^{-3} respectively. The pollutant concentration of NO_2 is basically the same as that of SO_2, and the reason for this is that a large amount of nitrogen and sulfur gas pollutants are released because coal and fuel are required for industrial production in coal-chemical industry areas and light industrial areas, and a certain amount of nitrogen and sulfur gas pollutants are released in the process of coal mining in mining areas and the NO_2 concentration is slightly higher; while the concentration of nitrogen and sulfur gas is increased in commercial areas because of the dense crowd, coal combustion of residents, exhaust emissions of vehicle; however, the atmospheric pollution is relatively light because there are no large quantities of coal mining and burning in cultural and educational areas and scenic spots.

It can also be seen from the table 2 that the concentration difference of each functional area is not significant for $PM_{2.5}$ and PM_{10} pollutants. Pollutant concentrations of $PM_{2.5}$ and PM_{10} are 40.8μg•m^{-3}-54.8μg•m^{-3}, 68.9μg•m^{-3}-84.6μg•m^{-3} respectively, which also indicates that the causes of $PM_{2.5}$ and PM_{10} pollution are more complex and other human activities contribute a large proportion of pollution in addition to mining activities and industrial production.

Tab.2 Concentration of atmospheric pollutants of each monitoring stations in 2015

Monitoring stations	SO_2/μg•m^{-3}	NO_2/μg•m^{-3}	$PM_{2.5}$/μg•m^{-3}	PM_{10}/μg•m^{-3}
scenic areas	6.8	16.7	40.8	68.9
commercial areas	17.2	25.6	51.7	76.4
mining areas	28.2	26.6	54.8	84.6
coal-chemical industry areas	33.6	36.2	48.9	75.0
cultural and educational areas	10.2	20.5	42.1	72.9
light industrial areas	32.5	32.4	52.6	80.6

3.3. Effect of rainfall on the removal of atmospheric pollutants

The purification effect of rainfall is associated with the rainfall duration and rainfall [6]. In this paper, the removal efficiency of atmospheric pollutants is measured by the atmospheric pollutant removal rate before and after rainfall to eliminate the influence of different atmospheric pollutant background concentration before rainfall. The ability of rainfall to remove atmospheric pollutants is expressed by monitoring the changes of atmospheric pollutant concentration before and after rainfall. It is assumed that the concentration of atmospheric pollutants before rainfall is C_{T-1}, the post-rainfall concentration is C_T, and ΔC is the ratio of atmospheric pollutant concentration changes before and after the rain to atmospheric pollutant concentration before rainfall and then.

$$\Delta C=\frac{-(C_{T-1}-C_T)\times 100\%}{C_{T-1}}$$

According to the above formula, the atmospheric pollutant concentration decreases after rainfall and atmospheric quality improves if ΔC is positive; otherwise, the concentration of atmospheric pollutants rises and atmospheric quality deteriorates after rainfall.The first rainfall is discussed in this paper, which time interval between two consecutive rainfall is more than 3 days. Take the monitoring point of coal-chemical industry areas as an example, this paper analyses the effect of rainfall on atmospheric pollutant removal, as shown in Fig.3.

It can be seen from Fig.3 rainfall has a certain effect on SO_2, NO_2, $PM_{2.5}$ and PM_{10}; the clearance rates of atmospheric pollutant concentration are 13.3%, 25.6%, 21.8% and 35.4% respectively when daily rainfall is 5.0-10mm. The clearance effect of rainfall on 4 kinds of atmospheric pollutants is obviously enhanced as the daily rainfall increases; the effect of rainfall on atmospheric pollutant removal is obvious when the daily rainfall is over 15mm, but after the daily rainfall increases to 30mm, the ability of precipitation to remove atmospheric pollutants tends to be stable and atmospheric pollutant clearance rates of SO_2, NO_2, $PM_{2.5}$ and PM_{10} are 8.7%-62.1%, 54.7%-56.4%, 63.4%-65.6% and 68.4%-71.5% respectively.

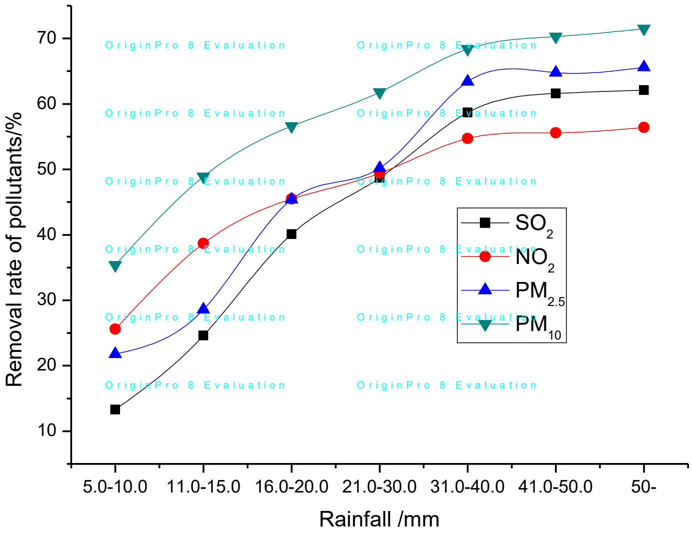

Fig.3 Influence of rainfal on atmospheric pollutant removal ability

It can also be seen from the Fig.3 that the effect of rainfall on the concentration of atmospheric pollutants is different as the daily rainfall changes, and the ability of precipitation to remove atmospheric pollutant of PM_{10}, NO_2, $PM_{2.5}$, SO_2 decreases successively. This conclusion is basically the same as that of Liuxing [7]. It can be seen that rainfall has strong clearance capability for PM_{10} and NO_2. The author believes that PM_{10} has a large self-weight relative to the $PM_{2.5}$, whose particle size is smaller, and it is more likely to land on the ground under water erosion. While the performance of NO_2 is unstable with water, and NO_2 is well removed due to chemical reaction in the rain.Compared with the NO_2, the ability of rainfall to remove SO_2 is relatively weak because the water solubility of SO_2 is poor.

3.4. Effect of rainfall intensity on the removal of atmospheric pollutants

The removal efficiency of atmospheric pollutant is measured by the atmospheric pollutant removal rate before and after rainfall. The effects of rainfall intensity on atmospheric pollutant removal were analyzed by monitoring the different rainfall intensity of rainfall events of 17 March, 29 May, 16 June, 3 July, 16 July and 30 September in 2015 and the changes of atmospheric pollutant concentration before and after rainfall, as is shown in Fig.4.

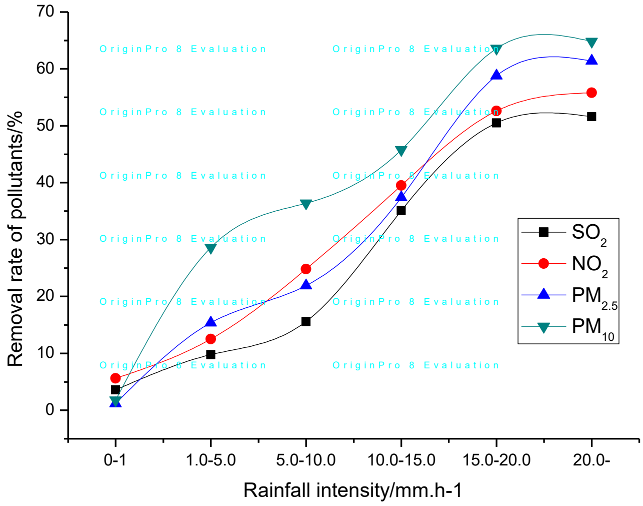

Fig.4 Influence of rainfall intensity on atmospheric pollutant removal ability

IOP Conf. Series: Earth and Environmental Science **153** (2018) 062015 doi:10.1088/1755-1315/153/6/062015

It can be seen from Fig.4 the effect of rainfall on atmospheric pollutants is limited and the clearance rate of SO_2, NO_2, $PM_{2.5}$ and PM_{10} is below 5% when the rainfall intensity is less than 1mm/h.The effect of rainfall on the removal of atmospheric pollutants is obviously enhanced with the increase of rainfall intensity, and the higher the rainfall intensity, the better the effect of rainfall on atmospheric pollutant removal. Rainfall has good clearance effect on SO_2, NO_2, $PM_{2.5}$ and PM_{10} and the clearance rate remains above 35% when the rainfall intensity exceeds 10mm/h. After the rainfall intensity reaches 20mm/h, the effect of rainfall on atmospheric pollutants tends to be stable and the clearance rate of SO_2, NO_2, $PM_{2.5}$ and PM_{10} is maintained at 50-65%.

The reason for the above results may be raindrops in size and density are small when the rainfall intensity is lower and rainfall has a weak ability to capture, scour and dissolve atmospheric pollutants, and the result is that rainfall has a poor scavenging effect on atmospheric pollutants. While as the rainfall intensifies, the size and density of raindrops gradually increase, and the ability to capture, erosion and corrosion of atmospheric pollutants is enhanced and it presents a good cleaning effect on atmospheric pollutants. But because it is limited by atmospheric contaminant background concentration, the effect of rainfall on atmospheric pollutants tends to be stable when the intensity of rainfall increases to an extreme value.

3.5. Effect of rainfall duration on the removal of atmospheric pollutants

The concentration of atmospheric pollutants during rainfall on September 30, 2015 is monitored in cultural and educational area and the effects of rainfall duration on the removal of atmospheric pollutants were analyzed, as is shown in Fig.5.

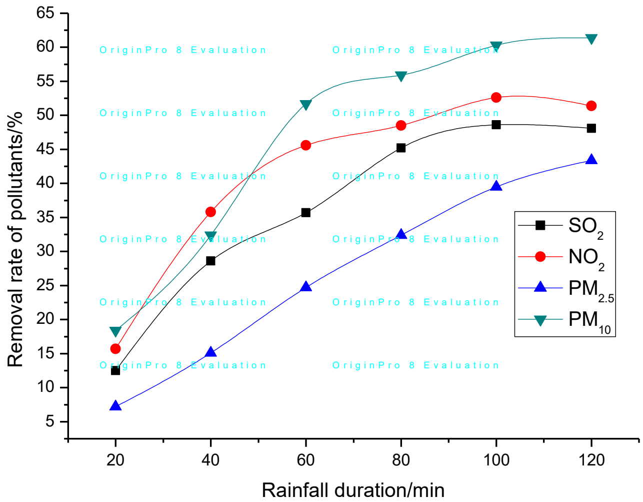

Fig.5 Influence of rainfall duration on atmospheric pollutant removal ability

It can be seen from Fig.5 the clearance rate of SO_2, NO_2, $PM_{2.5}$ and PM_{10} increases significantly during the time of 20 to 40 minutes after the onset of rainfall; SO_2, NO_2, $PM_{2.5}$ and PM_{10} have a certain amount of pollutants removed quickly. The effect of rainfall on NO_2 and PM_{10} tends to be stable after 60 minutes of rainfall, while the effect of rainfall on SO_2 tends to be stable after 80 minutes of rainfall. With the increase of rainfall duration, the effect of rainfall on the removal of $PM_{2.5}$ is not obvious compared with other atmospheric pollutants. It may be that SO_2 and NO_2 are soluble in water for above phenomenon and SO_2 , NO_2 are quickly cleared under the common action of scouring and dissolution. Although PM_{10} is not easy to dissolve, it can be quickly cleared under rain scouring because of its large particle size and self-weight. On the contrary, because of its small particles, $PM_{2.5}$ is not easily scoured and captured by rainfall in the atmosphere, which affects its removal efficiency.

In a word, the effect of rainfall on the removal of atmospheric pollutants increases with the increasing of the rainfall duration when the intensity of rainfall remains constant.This shows that rainwater has sufficient time to capture, flush and dissolve atmospheric pollutants when the duration of rainfall is longer, and accordingly, the effect of rainfall on atmospheric pollution is increased, and the increase of rainfall duration is beneficial to the removal of atmospheric pollutants.

4. Conclusion

1. In the mining cities, the atmospheric pollutants concentration of SO_2, NO_2, $PM_{2.5}$ and PM_{10} varies from spring to winter, and the background concentration of 4 kinds of atmospheric pollutants in summer and autumn is lower than that in winter and spring.

2.The concentration of atmospheric pollutants varies significantly with spatial distribution in different functional areas of mining cities; the pollutant concentration of SO_2 and NO_2 is higher in the coal-chemical industry areas and light industrial areas, and then it is in the mining area, the commercial district, the cultural district and the scenic spot in turn. The concentration of $PM_{2.5}$ and PM_{10} show little difference in each functional area and are 40.8$\mu g \cdot m^{-3}$~54.8$\mu g \cdot m^{-3}$, 68.9$\mu g \cdot m^{-3}$~84.6$\mu g \cdot m^{-3}$ respectively.

3.As the daily rainfall, rainfall intensity and rainfall duration increase, the effect of rainfall on atmospheric pollutants is gradually improved. The removal capacity of all atmospheric pollutants tends to be stable after the daily rainfall exceeds 30mm and the rainfall intensity reaches 20mm/h. The effect of rainfall on the removal of $PM_{2.5}$ is slightly worse than that of other atmospheric pollutants, and the rainfall duration lasts to 60min, 60min and 80min respectively when the removal effect of rainfall on NO_2, PM_{10} and SO_2 tends to be stable.

References

[1] Chen xunlai, Fan shaojia, Li jiangnan, etal. The typical weather characteristics of the air pollution in Hongkong area. [J]. Journal of tropical meteorology. 2008. 4(2): 195-199.
[2] Hu chunmei, Liu de, Chen daojin. Index of meteorological conditions for pollutant diffusion in chongqing. [J]. Meteorological Science and Technology. 2009. 37(6). 665-669.
[3] Liu yongqi, Li dapeng, Ni changjian. The analysis of atmospheric pollution feature and affecting factors in chongqing. [J]. Sichuan Environment, 2009. 28(3): 28-32.
[4] Zhou guobin, Wang shigong. Research on weather characteristics of air pollution in chongqing. 2010. 19(11): 1345-1349.
[5] Xie peng, Huo mingqun, Sun qian, etal. Contributions of washout process of particles to ion concentrations in rainwater. [J]. Journal of Peking University. 2009(1). 70-75.
[6] Guo wei, Cheng yan, Fanwei, etal. Characteristics and affecting factors of atmospheric pollutants in Xi’an. [J]. Journal of Earth Environment. 2014. 5(4). 235-242.
[7] Liu xing, Huanghong, Zuojia, etal. Scavenging of rainfall on air pollutants in summer. [J]. Environmental Pollution &Control. 2016. 38(3). 20-24.