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The Impact of Alter for Heavy Air Pollution Policy on Air Quality in Beijing, a Case Study on Neighborhood

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Abstract: Accompanied with socio-economic development, Beijing has been suffering a severe haze in recent years, which has caused wide public concern. A four-tier warning system for air pollution is implied, in which different degrees restrictions on enterprises operation, gasoline standard and license plates based traffic restriction would be implied to ameliorate the air quality. Based on per-hour time precision real time monitoring data set of five kinds of air pollution (CO, NO, NO_2, NOx, and $PM_{2.5}$) and traffic volume at neighborhood scale during haze frequent period in Beijing from December 19 to 31 in 2015 and 2016, the timeliness, effect duration and effectiveness of different levels of policy, and the response from diverse pollutants were evaluated. Red, orange and yellow alter for heavy air pollution policy do have positive roles in preventing worsening air quality and reducing the concentration of air pollutions with a time-lag effect from 12 hours to 72 hours. At neighborhood scale in downtown Beijing, the red alter has a significantly higher efficacy than orange and yellow alerts, and no significant difference between the efficacies of orange alter and yellow alter is found caused by the urban function and traffic restrictions. As for the pollutant response, these alters had the greatest effect on $PM_{2.5}$, followed by NO, CO, NOx and NO_2. Red alter emergency responses would cause 31.99% decrease of total non-public transport vehicle volume and 11.4%~25.4% decrease of air pollutant emissions respectively. Statistically, there is significant correlation vehicle emission atmospheric pollutant concentration with R^2 up to 93.5%, which is most significant during red alter, followed by orange alter and off-policy period.

Keywords: Air Pollution, Traffic, Neighborhood Scale, Policy, Beijing

1. Introduction

Accompanied with vigorous socio-economic development, serious air pollution problems beset China for a long time, especially Beijing, the capital of China. The air quality in Beijing, the capital of China, which has been suffering a serious and persistent air pollution issue since 2000s [1]. With the rapid development of industrialization, urbanization and motorization [2], energy consumption and the resulting multiple pollutant emissions in Beijing were increasing year by year, which had increasingly adverse impacts on not only regional and urban air quality but also human health and eco-environment air quality, human health and eco-environment [3]. The air quality in Beijing is becoming a focus of public attention [6].

Large amount of the researches in this field have been primarily theoretical, with a focus on methodology [8], and has not been applied to anthropogenic disturbance. Chinese government has recognized that it is a key task to prevent and control air pollution in China. Correspondingly, a series of policies, regulations and laws on prevention and control of air pollution have been formulated and promulgated [9], which have showed their impact on air quality, such as the air quality during Olympic Games in 2008 [10] and APEC in 2014 [12]. The necessity for research on air pollution under specific circumstances and in specific regions have been emphasized [14].

The local emissions are the main contributors to the severe haze, such as the local emission of Beijing contributed about

64–72% to its $PM_{2.5}$ mass concentration with vehicle, coal combustion, industries, and suspended dust as the largest contributors [16]. By the end of 2016, Beijing's total vehicle population reached 5.72 million (http://www.askci.com/news). The growth in vehicle populations and the resulting exhaust emissions would have substantial impacts on urban air quality. Correspondingly, many studies have confirmed that Beijing urban air pollution has shifted from being dominated by coal burning to a mix of coal burning and vehicle emissions [17]. Therefore, Beijing enacted relevant policies abiding the traffic on road to control the air pollution level. There is a four-tier warning system for air pollution in China: blue, yellow, orange and red, in rising severity (Table 1). The measures stopped or limited the production of many industrial enterprises, implemented traffic restrictions on motor vehicles, and took control of coal enterprises and heating plants to guarantee that emissions of waste gases and other pollutants complied with national standards.

Table 1. *Mandatory emission reduction measures of different alters for heavy air pollution policy.*

Degree	Activating signal	Mandatory emission reduction measures
Red	Severe pollution is forecast for the next 3 days	(1) Light-duty gasoline vehicles at national Ⅰ and II emission standard stay off the road, the motor vehicles at national III and above are allowed on the roads on alternate days, depending on whether their license plate number ends in an odd or even number; as for the official business vehicles, additional 30% are banned on road. (2) Construction refuse, residue and sand transport vehicles are prohibited from driving. (3) 30% industrial operations are suspended according to the list of industrial enterprises stop and limit plan. (4) Increase more than 2 times of road cleaning and cleaning frequency and reduce dust. pollution; reduce excavation scale of earthwork construction; construction demolition and other construction must take effective coverage, watering and other dust control measures. (5) Fireworks and firecrackers are forbidden to be set up in the whole city.
Orange	Alternating severe pollution or heavy pollution is expected for 3 days	(1) Light-duty gasoline vehicles at national Ⅰ and II emission standard stay off the road. (2) Construction refuse, residue and sand transport vehicles are prohibited from driving. (3) 30% industrial operations are suspended according to the list of industrial enterprises stop and limit plan. (4) Increase 1 time of road cleaning and cleaning frequency and reduce dust pollution; reduce excavation scale of earthwork construction; construction demolition and other construction must take effective coverage, watering and other dust control measures. (5) Fireworks and firecrackers are forbidden to be set up in the whole city.
Yellow	Severe pollution is expected in the next 1 days or heavy pollution is expected for 3 days	Increase 1 time of road cleaning and cleaning frequency and reduce dust pollution; reduce excavation scale of earthwork construction; construction demolition and other construction must take effective coverage, watering and other dust control measures.
Blue	Heavy pollution is expected in the next 1 days	None

The improvement in air quality in Beijing after each alter for heavy air pollution policy on air quality was obvious and significant (http://news.youth.cn/jsxw/201512/t20151223_7450573.htm). How long would the diverse level alter policies take effect respectively, whether were such measures affected all pollutants, to what extent could the anthropogenic emission perturbation impact altering the air quality remain questions.

Owing to the spatiotemporal variability and uncertainty of different anthropogenic air pollution sources, it is difficult to attribute emission uncertainties to specific sectors in complex bottom-up emission inventories. To mitigate the influence of the anthropogenic activities variation caused by spatial variability and realize urban refinement management, a typical post-live mixing zone was taken as study area, the land-use type in which is mostly residential land and education research land, also with a small proportion of commercial land scattering along the street and no industrial land. This kind of land-use type is widely distributed, especially in the downtown area of Beijing.

Hourly data from pollution monitoring stations was used to measure the effect of these policy on air quality at neighbor scale in the downtown area of Beijing to compare the pollution levels are before and after the different degree policy application during the late December of 2015 and 2016. And the per half-hour traffic volumes of the main roads in the study area, Linda North Road and Shuangqing Road, on Monday (the first working day, rush hour day), Wednesday (the middle working day, traffic flat hump day), Saturday (weekend) were videoed and counted during the period from 19 to 31 in December, 2016. To guarantee the data accuracy, data were checked again by the data check group, and the result showed that the accuracy is above 90%.

In urban area, main air pollution comes from road traffic, and is comprised of a mixture of airborne particulate matter (PM), oxides of sulfur (SO_x), oxides of nitrogen (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and ozone. This study presents per-hour time precision real time monitoring data set of five kinds of air pollution (CO, NO, NO_2, NO_x, $PM_{2.5}$) and traffic volume at neighborhood scale during haze frequent period in Beijing. The dynamic varying pattern of traffic volume and air pollution concentration and their relationship during different degrees of the restriction policies were analyzed, the effects of different degree alter for heavy air pollution policies were evaluated and some optimizing suggestions were proposed.

2. Research Methodology

Several methods have been developed which detect the concentration of various pollutants at the roadside [19]. The paper also contributes, more broadly, to a growing literature using high-quality data and credible identification techniques to better understand the impact of government policies on air quality.

The analysis meters, model 42i, 48i, TEOM 1405, made by Thermo Fisher, were used to monitor the concentration of nitric oxide, CO and PM2.5 respectively. To ensure the accuracy of experimental data, the filter membrane of PM2.5 was replaced once every 2 weeks, monthly for gas path flow validation, sampling apparatus intake cutting head cleaning and replacement; replace separator filter cartridge unregularly; calibrate K0 value every semi-annual. As for the monitoring equipment for other pollutants, zero correction and cross point calibration and replacement of the instrument filter film and other accessories and consumables were carried out every week; multi-point calibration of the instrument was performed every six months or a year.

Based on monitoring per half-hour traffic flow of the main roads in the study area, Linda North Road and Shuangqing Road, on Monday (the first working day, rush hour day), Wednesday (the middle working day, traffic flat hump day), Saturday (weekend) were videoed and counted during the period from 19 to 31 in December, 2016. MOVES, the U.S. Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator, was used to simulate the air pollution emitted from motor vehicles. The purpose of MOVES is to provide an accurate estimate of emissions from cars, trucks and non-highway mobile sources under a wide range of user-defined conditions. Previous studies have shown that concentrations of primary pollutants in vehicular emissions are elevated near busy roadways but then decrease to background levels within several hundred meters due to dilution and reactions [21]. The factors that impact the magnitude and extent of distance-decay gradients include traffic conditions, wind speed and direction, topography, atmospheric stability, and mixing height [22]. The highest pollutant concentrations were measured within 0-50 m of I-93 with distance-decay gradients varying depending on traffic and meteorology. the highest NOx concentrations were measured in the 0-50 m bins on either side of I-93 and the concentrations decayed to background levels within ~ 200 m [27]. 450m decay to the background level. particle mass (PM2.5), particle-bound polycyclic aromatic hydrocarbons, black carbon, carbon monoxide, nitric oxide and total nitrogen oxides. In this research, 500 meter was set as the contribution radius.

3. Results

3.1. The Altering Pattern of Air Pollution Concentration

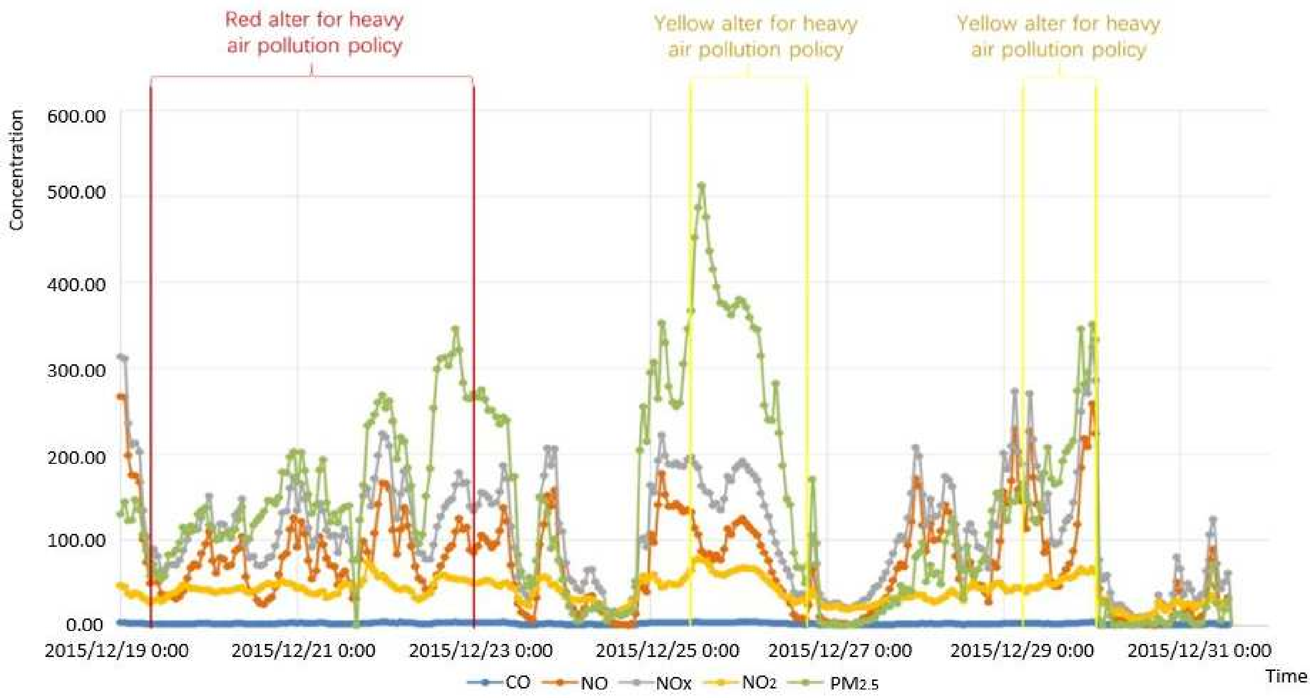
In order to evaluate the impact of emission control measures on air quality during the different levels of alter policy, three periods of each policy are defined in this study, the pre-policy period, the policy period and the post-policy period. For the purpose of comparative analysis, the mean concentration of each air pollutant in each period are calculated (Table 2). The fluctuation rules of $PM_{2.5}$, NO_x, NO, NO_2, CO concentration present similar pattern, on which the impact of the policy implementation are significant. Except the unusually high concentration of NO and NOx, pollutants generally show higher concentrations during the implementation of the policy and lower concentrations before and after the implementation of the policy. This means that the intervention period of the policies at all levels were previous to the rapid increase of pollutant concentrations, playing a preventive role. The concentrations decrease after the policies proved the positive role of the alter for heavy air pollution policy on air quality at neighborhood scale.

Table 2. *The Mean Concentration of Each Air Pollutant in Different Period.*

	Period	Time	CO (PPb)	NO (PPb)	Nox (PPb)	NO_2 (PPb)	$PM_{2.5}$ (μg/m^3)
Dec. 2015	Pre-Red Alter	19th 0:00~7:00	2.67	192.38	230.98	38.60	129.30
	Red Alter	19th 7:00~22nd 24:00	2.27	75.15	119.08	43.93	161.29
	Post-Red & Pre-Yellow Alter I	22nd 24:00~25th 11:00	1.92	66.91	106.04	39.13	137.74
	Yellow Alter I	25th 11:00~26th 19:00	3.07	78.11	133.52	55.41	308.27
	Post-Yellow I & Pre-Yellow II	26th 19:00~29th 5:30	1.37	65.34	97.83	32.49	58.98
	Yellow Alter II	29th 5:30~30th 0:00	2.30	118.49	170.31	51.82	196.43
	Post-Yellow Alter II	30th 0:00~31st 24:00	1.03	30.57	53.45	22.88	27.40
Dec. 2016	Red Alter	19th 0:00~22nd 0:00	5.97	91.51	163.10	71.59	239.58
	Post-Red Alter & Pre-Orange Alter	22nd 0:00~30th 0:00	1.80	30.83	65.20	34.37	50.10
	Orange Alter	30th 0:00~31st 24:00	4.12	77.91	137.04	59.13	186.76

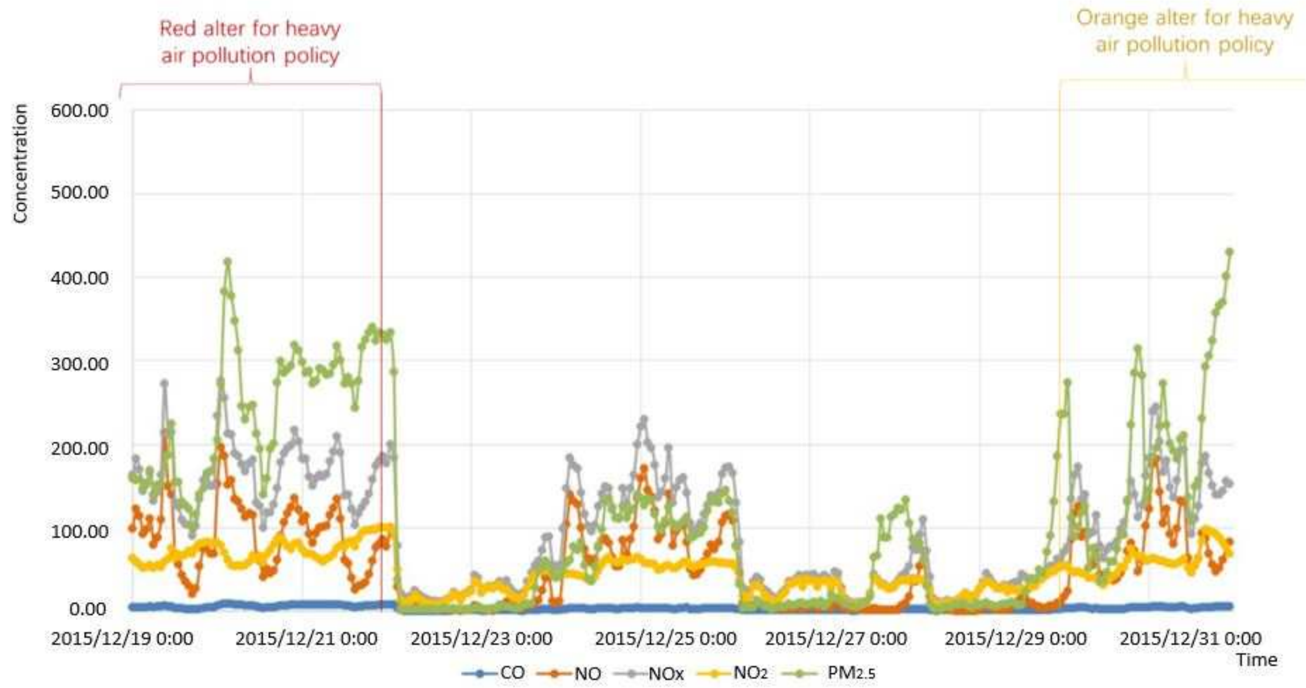
3.2. The Time-lag Effect of the Policies

Figure 1 and Figure 2 depict the hourly atmospheric pollutant concentrations of the study area monitoring station. At the beginning of red alert, orange alert and yellow alter, although the pollutant concentrations do not show a significant decline immediately, they present a modest increase or plateau status, which means although the emergency measures cannot quickly reverse the situation of heavy pollution, it has obvious effect on alleviating the aggravation of air pollutant concentration. The effect of reducing emissions over time has been shown and enhanced.



(The unit of $PM_{2.5}$ is μg/m^3, the units of the other four air pollutants are PPb)

Figure 1. *The concentration of air pollution in the late December 2015.*



(The unit of $PM_{2.5}$ is μg/m^3, the units of the other four air pollutants are PPb)

Figure 2. *The concentration of air pollution in the late December 2016.*

The alter for heavy air pollution policies have time-lag effect, and the time of the emergency measure implementation should be appropriately advanced. Under heavy air pollution condition, pollutants would accumulate in the atmosphere and are likely to be accompanied by secondary conversion, leading to a hardly obvious decrease in a short period. The period of the most obvious effect, where the concentration of pollutant drops fastest, of the red alert and orange alert is from 36 to 72 hours after implementation, which of yellow alter is from 12 to 24 hours. The limit of $PM_{2.5}$ average concentration in 24 hours is 75μg/m^3 in accordance with the environmental air quality standard (GB 3095-2012). It will cost 72 to 96 hours to reach the standard after the implementation of red and orange alters and 24 to 36 hours for yellow alters. To guarantee the air quality in downtown Beijing, the best intervention time should be 36-48 h before the rapid increase of atmospheric pollutant concentration. Early warning measures can better prevent the occurrence of atmospheric heavy pollution, but requires the higher accuracy of atmospheric pollutant concentration prediction.

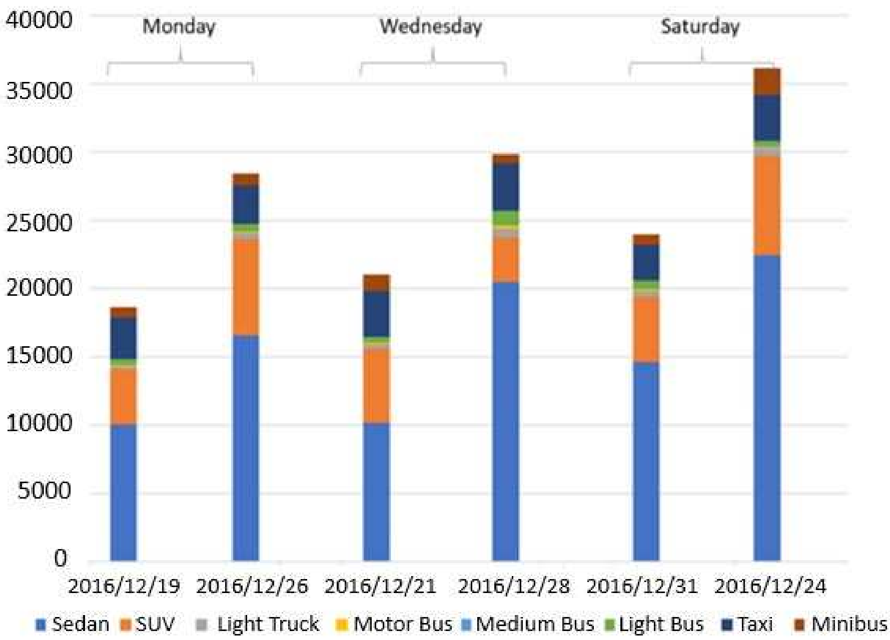


Figure 3. *The concentration of air pollution in the late December 2016.*

3.3. The Relationship Between Traffic Emissions and Concentration

From Figure 3, under air red alert policy, non-public transport vehicles reduced by about 31.99% over weekdays in the study area, among which the number of car and SUV fell the most (37.5%), and the number of taxis remained unchanged. Therefore, the emission of CO_2, CO, NO, NOx, NO_2, and $PM_{2.5}$ emission decreased by about 20.2%, 21.7%, 12.0%, 12.0%, 11.4%, and 16.5% respectively.

Comparing the temporal variations of atmospheric pollutant concentrations and the vehicle pollutant emissions are showed in Figure 4. The short-time temporal variations of atmospheric pollutant concentrations show similar rule to that of traffic pollutant emissions. Compared with the non-air pollution warning period, the coordinated changes are more obvious in the air pollution warning period. This is because that the climate of Beijing is characterized by stagnant weather with weak wind and relatively low boundary layer height, leading to the favorable atmosphere conditions for accumulation, formation and processing of aerosols [28].

Also, the nighttime was a special period. Although the traffic volume during the nighttime dramatically decrease and its related air pollution emissions approximate to zero, the air pollution concentrations are higher during the nighttime than the daytime, because although traffic-related emissions is a major infector of air pollution concentration at downtown area, the climate constitution will cause great impaction [29], especially during the nighttime in winter, the enhanced emission for heating and relatively low the boundary layer [30].

4. Discussion

4.1. Comparison of the Effectiveness of Different Policies on Diverse Air Pollutants

Based on the study period division in Table 2, the coefficient of variation was introduced to reflect the effect of different grades of alter policies and the response degree of different atmospheric pollutants. As a dimensionless statistics, coefficient of variation is used to measure the degree of variation in the observed values. Different from the standard deviation, the variation coefficient can be used to eliminate the effects of units and/or averages on the comparison of two or more data variations in the comparison of two or more data variation degrees to Increase the credibility of the comparison results. In this case, the higher coefficient of variation of different air pollutant in each period means the higher response of the pollutant and high effectiveness of the policy.

The corresponding degree of different pollutants to the policy varied from case to case due to relative activating signal, such as the red alter in 2015 was triggered by the extreme high concentration of nitrogen oxide, which lead to a high corresponding degree of NO, NO_2 and NOx, but a general rule can be generalized. Based on the coefficients of variation (Table 3). $PM_{2.5}$ fluctuated most, followed by NO, CO, NOx, and NO_2. This indicated that the alter for heavy air pollution policy measures had the greatest effect on $PM_{2.5}$ concentrations and lowest effect on NO_2.

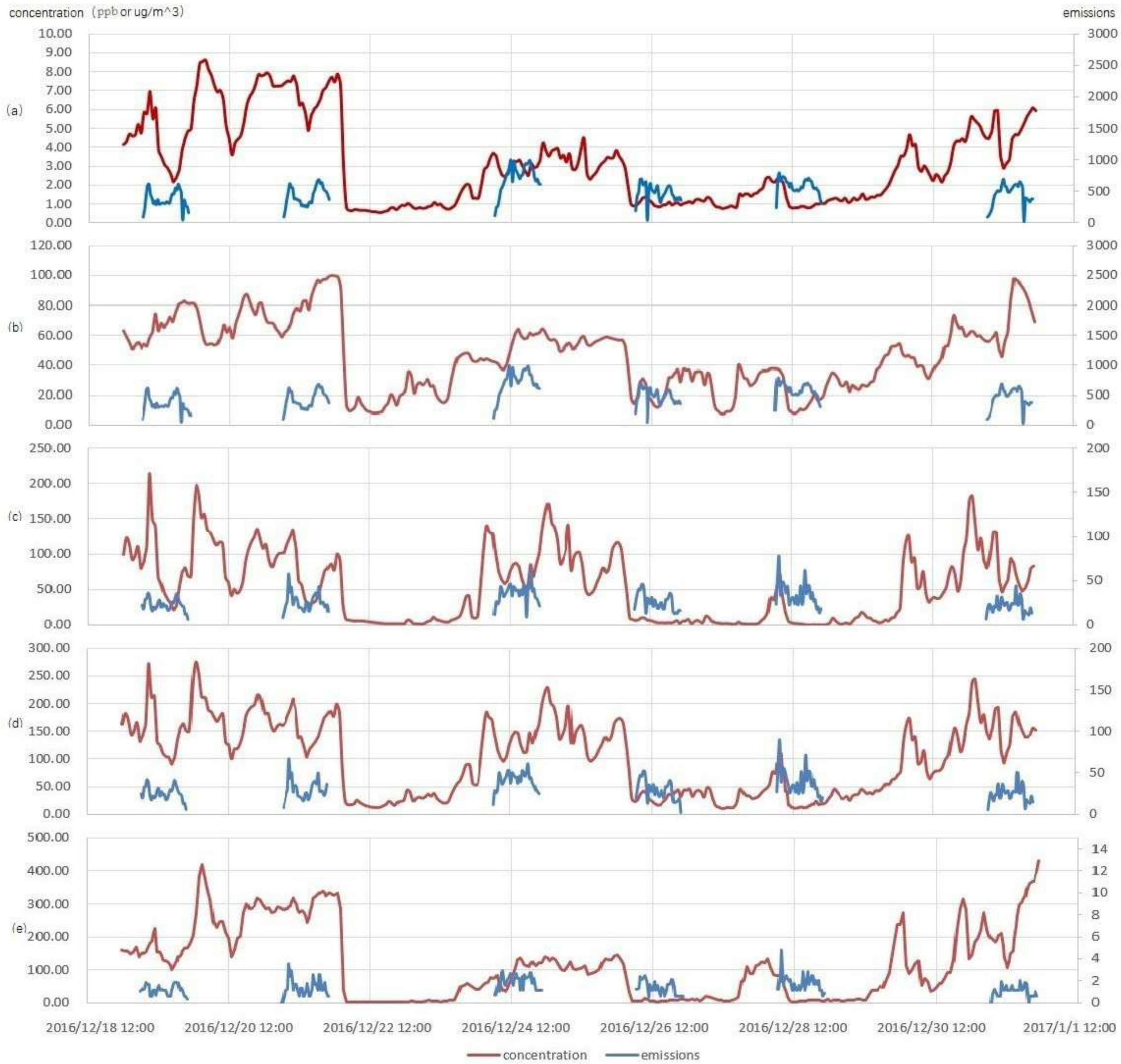


Figure 4. *The temporal variation of air pollution concentration and traffic air pollution emissions in the late December 2016. The red lines separately present the air pollution concentration and the blue lines separately present the traffic air pollution emissions: CO (a),* NO_2 *(b), NO (c), NOx (d),* $PM_{2.5}$ *(e).*

Table 3. *The Coefficient of Variation of different air pollutant in each period.*

	CO	NO	NOx	NO_2	$PM_{2.5}$
Red Alter in 2015	0.164	0.630	0.452	0.072	0.116
Red Alter in 2016	0.759	0.702	0.606	0.497	0.925
Orange Alter in 2016	0.555	0.612	0.502	0.374	0.816
Yellow Alter I in 2015	0.409	0.099	0.166	0.279	0.757
Yellow Alter II in 2015	0.422	0.620	0.550	0.412	0.953

Take the maximum of the coefficient of variation of each pollutant under each alter degree as the the maximum control ability to each pollutant under each alter degree (Figure 5). At neighborhood scale in downtown Beijing, the red alter has a significantly higher efficacy than orange and yellow alerts. And there is not a significant difference between the efficacies of orange alter and yellow alter, which is caused by its function and traffic restrictions in urban areas of Beijing. Since 1995, the 72 industrial pollution sources have been managed and relocated and a large secondary industry was weed out of Beijing. By 1999, industrial enterprises had been cleaned up and the no industrial land located in inner city. As for the traffic restriction, according to the rule made by Beijing Municipal

Bureau of Communications, the road within the trucks are prohibited from driving on the road with the fifth ring road (excluding) from 6:00 to 23 every day, and trucks loading 8 tons or above are prohibited from driving on the fifth ring road. These measures have led to the ineffectiveness of the measures in orange alter other than yellow alter in downtown Beijing. And more specific and scientific measures in orange alter are urged.

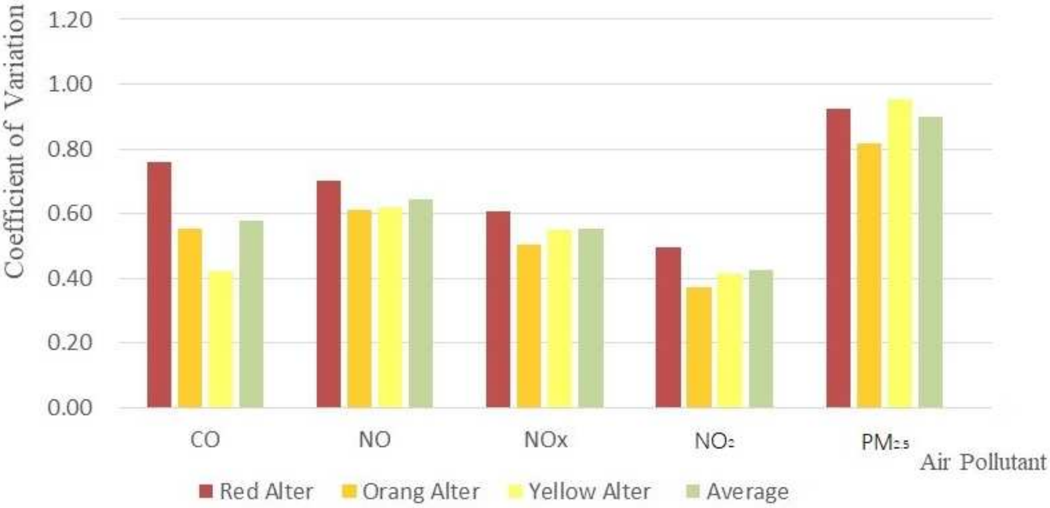


Figure 5. *Maximum Coefficient of Variation of air pollutants at different policy levels.*

4.2. The Effectiveness of Traffic Restrictions

Table 4 shows the correlation analysis result between cumulative traffic emissions within the day and the air pollution concentration. The higher correlation coefficient showed that combustion-related processes such as fuel combustion and vehicle exhaust emission, had direct relationship with air pollution. The traffic pollutant emissions can affect the air quality at neighborhood scale, the degree of which is influenced by multi-factors such as the chemical properties of pollutants. Statistically, there is significant correlation vehicle emission atmospheric pollutant concentration with R^2 up to 93.5%. During red alter period, affected by adverse meteorological conditions (stagnant weather with weak wind and relatively low boundary layer height), the effect of pollutant emission on air pollutant concentration is most significant, followed by orange alter and Off-policy period. This further illustrates the need to restrict travel during the early warning period. In the study of [31], the authors pointed out that Beijing's transportation policy is related to reducing air pollutant concentrations. But in stark contrast to [32], who followed similar policies in Mexico and observed no reduction in daily air pollution levels. There are two possible explanations for these differences. One is that different cities have different environments, so similar policies do not necessarily produce the same effect; Secondly, Mexico has increased the use of a second vehicle, which is usually more polluting.

Table 4. *Regression Analysis Result of diverse policies and air pollutions.*

Policy		Red Alter						Orange Alert		
Data		20161219			20161221			20161231		
		R	R-squared	Sig.	R	R-squared	Sig.	R	R-squared	Sig.
	CO	.597	.356	.000	.227	.051	.212	.318	.101	.076
	NO	.548	.300	.001	.600	.360	.000	.572	.327	.001
Air Pollution	NO_2	.943	.889	.000	.967	.935	.000	.794	.631	.000
	NOx	.390	.152	.027	.309	.096	.085	.018	.000	.923
	$PM_{2.5}$	.329	.108	.066	.579	.335	.001	.833	.695	.000
Policy		None								
Data		20161224			20161226			20161228		
		R	R-squared	Sig.	R	R-squared	Sig.	R	R-squared	Sig.
	CO	.076	.076	.897	.368	.135	.038	.708	.501	.000
	NO	.032	.001	.860	.717	.514	.000	.779	.606	.000
Air Pollution	NO_2	.859	.738	.000	.421	.177	.016	.544	.296	.001
	NOx	.410	.168	.020	.175	.031	.338	.694	.482	.000
	$PM_{2.5}$	.786	.617	.000	.264	.070	.144	.680	.463	.000

4.3. Other Influence Factors

From the perspective of policy, this study studied the effect of different levels of alter policy, especially different levels of traffic restrictions, on the concentration of atmospheric pollutants. Other influence factors might also have great influence on the policy-making, such as climate condition and social-economic factors.

In this study, Beijing is located in the north of the north China plain, west of the Taihang mountains west hill, north and northeast of Yanshan mountains, where the terrain is not conducive to the spread of pollution. Meteorological conditions, such as cold air transit and air humidity decease have evident effects on air pollution degree, leading to some influences on the accuracy of the results.

Meanwhile, in order to guarantee the air quality in Beijing, the optimal intervention time of early warning and control measures are suggested to be advanced to 36 to 48 hours before the atmospheric pollutant concentration fast-rising. However, the close down of relevant factories and enterprises, the increase of municipal clean frequency, the traffic restrictions, etc., will undoubtedly bring great social and economic costs, cause reduction of residents convenience and increasing of travel cost. Quantitative evaluation the relationships among social-economic cost, residents' willingness and social welfare benefits from pollutant concentration decrease, would have indispensable assistance to making scientific alter for heavy air pollution policy.

5. Conclusion

The article evaluates the response of five air pollution to different levels of policies by measuring the air pollutants on Beijing's main roads during the late December of 2015 and 2016. The main conclusions are follows:

(1) Air pollutants show higher concentrations during policy implementation and lower concentrations before and after policy implementation. When the policy is expected to be earlier than the rapid increase in pollutant concentration, its policy can play a preventive role.
(2) Severe pollution has a significant time lag effect. For Beijing, the best intervention time should be 36-48h before the severe pollution.
(3) For Beijing, transportation has a significant effect on pollutant emissions. With the implementation of the red alert, non-public transport has declined and the number of taxis has remained unchanged. During the period of air pollution, the short-term changes in air pollution concentrations have a similar pattern to traffic pollutant emissions.

The article further discusses the impact of different Beijing policies on air pollutant emissions. Changes in severe pollution policies and measures have the greatest impact on $PM_{2.5}$ concentration and the least impact on NO_2. The effectiveness of the red alert is significantly greater than that of the orange and yellow alerts. Due to a series of emission reduction policies in Beijing, there is no significant difference between the orange and yellow alerts. There is a high correlation between traffic emissions and air pollution concentrations. During the red warning period, the impact of traffic emissions and air pollution concentrations was most significant, followed by orange and non-policy periods.

In order to protect Beijing's air quality, Beijing can take some measures. Including control warning time, it will advance rapidly rising atmospheric concentration of 36-48h. The adoption of relevant policies will cause some factories and enterprises in the city to close, increasing socioeconomic costs. Therefore, the Beijing Municipal Government is required to introduce scientific policies to promote social stability and sustainable environmental development.

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