

## Recollection

## Clean Air Actions and Air Quality Improvements — Beijing-Tianjin-Hebei and Surrounding Areas, China, 2013–2019

Shijie Liu<sup>1</sup>; Yangxi Chu<sup>1</sup>; Jingnan Hu<sup>1,†</sup>

Severe air pollution has brought great challenges to the economic and social development of China, and in response, the Action Plan for the Prevention and Control of Air Pollution was issued and a mix of air pollution prevention and control measures has been released since 2013 such as ultra-low emission retrofitting in thermal power industry, dealing with the small coal-fired boilers, household clean heating programs, and severe pollution mitigation. In addition, the National Research Program for Key Issues in Air Pollution Control was conducted for Beijing-Tianjin-Hebei (BTH) and surrounding areas, which supported significant air quality improvements. This paper reviews the main air pollution prevention and control measures released for BTH and surrounding areas. Moreover, the improvements in air quality and the evolution of air pollution characteristics in this region are also evaluated.

### Actions to Prevent and Control Air Pollution

Rapid economic growth based on intensive energy consumption over the past decades has led to serious air pollution across China. At the beginning of 2013, Beijing Municipality, Tianjin Municipality, Hebei Province, and some other regions in China suffered from a persistent haze. Large parts of North and East China were ravaged by haze for more than 20 days, which had a severe effect on human health and economic and social development.

In the same year, the Action Plan for the Prevention and Control of Air Pollution was issued by the State Council, which declared the commencement of intensive air pollution prevention and control. A series of laws, regulations and measures were issued or amended, such as the Environmental Protection Law of the People's Republic of China, the Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution, etc. The National Ambient Air Quality Standard (GB 3095-2012) was also revised identifying the major air pollutants (PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>,

NO<sub>2</sub>, CO, and O<sub>3</sub>) (1). Two additional technical regulations and guidance (HJ 633-2012 and HJ 663-2013) were released to standardize the assessment and management of air quality and provide health guidance to the general public (2–3). The so-called “ground-aerial-space” integrated monitoring system was established to comprehensively monitor the atmospheric environment (4), including the satellite remote sensing system, the national air quality, regional particulate, and photochemical composition monitoring networks, etc. A mix of emission mitigation measures had been established and implemented since 2013. A series of emission standards for key industries have been released or revised. Upgrading and renovation programs for pollution control facilities in key industries have been pushed forward. An ultra-low emission and energy-saving retrofitting of coal-powered venues and pilot programs for clean household heating in northern China were launched. Small coal-fired boilers (below 10 t/h) in urban areas were eliminated. For mobile sources, the standards for gasoline and diesel fuel quality were strengthened twice in five years, and high-emission vehicles, especially heavy-duty diesel trucks, were under strict supervision.

Due to serious air pollution, BTH and surrounding areas were selected as the key region for air pollution prevention and control. In addition to the policies and measures mentioned above, the National Joint Research Center for Tackling Key Problems in Air Pollution Control was established in 2017. More than 2,000 scientists and researchers were organized to investigate the causes of heavy air pollution and provide solutions for 28 cities in BTH and surrounding area (known as “2+26” cities, including Beijing, Tianjin, Shijiazhuang, Tangshan, Baoding, Langfang, Cangzhou, Hengshui, Handan, Xingtai, Taiyuan, Yangquan, Changzhi, Jincheng, Jinan, Zibo, Liaocheng, Dezhou, Binzhou, Jining, Heze, Zhengzhou, Xinxiang, Hebi, Anyang, Jiaozuo, Puyang, and Kaifeng). A total of 28 expert teams were dispatched to “2+26” cities, and investigation on the

“Customized strategy for each city” campaign was conducted. A comprehensive mechanism for responding to heavy pollution was also established for BTH and surrounding areas, including air quality forecast, expert joint-meetings, heavy pollution warnings, instant emission reduction, and supervised enforcement, which significantly improved the capabilities of local governments to tackle the heavy pollution problem.

### Trends in Air Quality Improvement

The comprehensive air pollution prevention and control measures have led to sustained improvements in air quality in BTH and surrounding areas (5–7). Figure 1 shows the trends of the annual evaluation concentrations for major pollutants, namely the annual average concentrations of PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, the annual 95<sup>th</sup> percentile of the daily average concentrations of CO, and the annual 90<sup>th</sup> percentile of the maximum daily 8-h average (MDA8) concentrations of O<sub>3</sub> (3). As some of the cities in Shanxi Province and Henan Province were not included in national air quality monitoring network in 2013 and 2014, the concentrations of CO, O<sub>3</sub> and PM<sub>2.5</sub> were not measured in those cities. The cities

with missing data were listed in Supplementary Table S1. The concentrations of major pollutants, except for O<sub>3</sub>, showed continuous decreases from 2013 to 2019. Compared to 2013, the mean annual evaluation concentrations of PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, and CO in “2+26” cities in 2019 decreased by 50%, 41%, 79%, 20%, and 53%, respectively. SO<sub>2</sub> and CO, with the greatest concentration decrease among basic pollutions in “2+26”, showed the remarkable effects of coal consumption control. For Beijing, most notably, the concentration of PM<sub>2.5</sub> in Beijing dropped from 89.5 µg/m<sup>3</sup> in 2013 to 42 µg/m<sup>3</sup> in 2019.

The Air Quality Index (AQI) also showed similar annual improvements in BTH and surrounding areas as illustrated in Figure 2. From 2013 to 2019, the days of heavy and serious pollution (Grade V and VI according to HJ 633-2012 (2), respectively per year had decreased from 88 days to 20 days on city average. In particular, the days of serious pollution dropped from 31 days in 2013 to 2 days in 2019, reflecting the great progress in emission mitigation efforts in the region. Additionally, days with good and excellent air quality for each year have significantly increased and nearly doubled from 2013 to 2019.

PM<sub>2.5</sub>, PM<sub>10</sub>, and O<sub>3</sub> are the main pollutants in

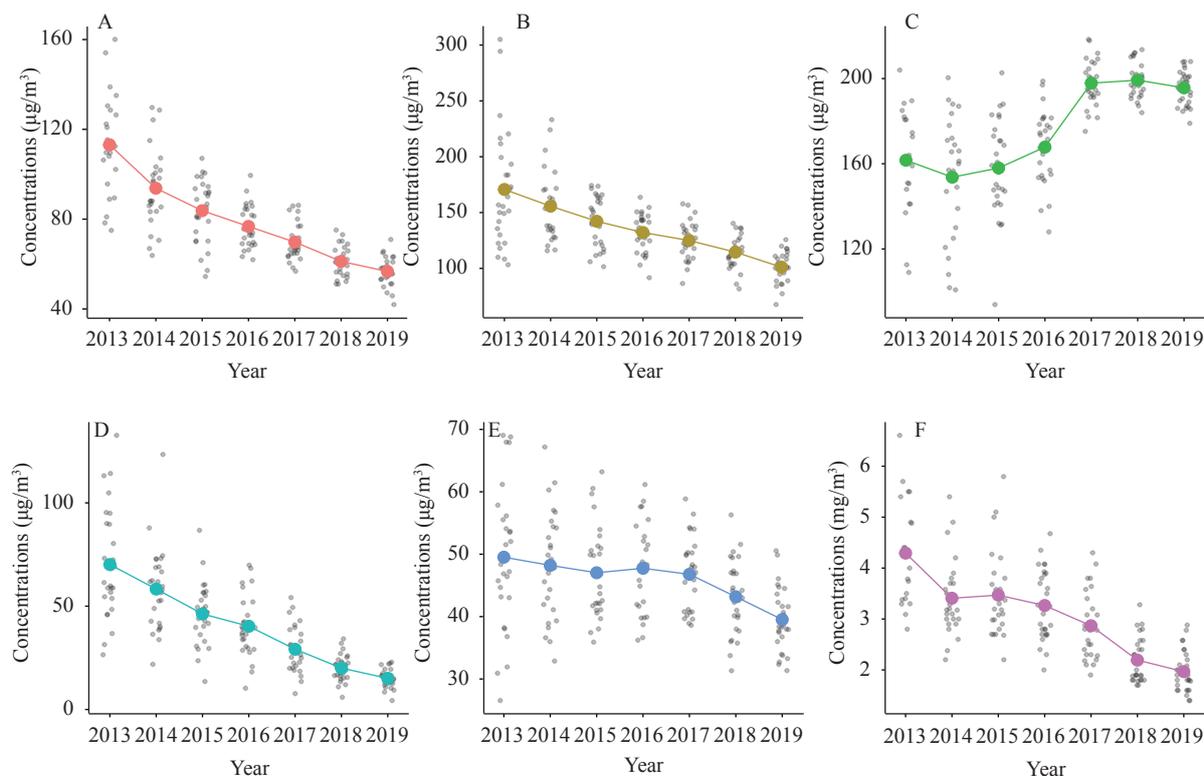


FIGURE 1. Trends of annual evaluations of concentrations of (A) PM<sub>2.5</sub>, (B) PM<sub>10</sub>, (C) O<sub>3</sub>, (D) SO<sub>2</sub>, (E) NO<sub>2</sub>, and (F) CO in “2+26” cities from 2013 to 2019.

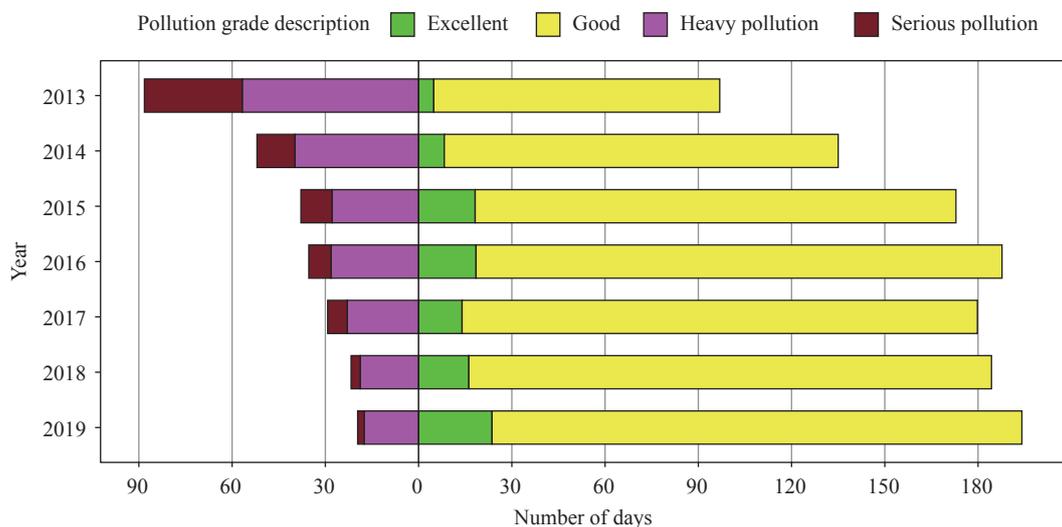


FIGURE 2. Average number of days per year with air quality levels of excellent, good, heavy pollution, and serious pollution in “2+26” cities from 2013 to 2019. The number of days with air quality levels of mild and moderate pollution were not included in the statistics.

polluted days in “2+26” cities. Between 2013 and 2019, the number of polluted days with  $PM_{2.5}$  as the chief pollutant decreased continuously (from 189 to 73 days), while the days with  $O_3$  as the chief pollutant increased rapidly from 20 to 80 days. Moreover,  $O_3$  has replaced  $PM_{2.5}$  as the most important pollutant in days of chief pollutant from 2018 (Figure 3).

### Evolution of Air Pollution Characteristics

As the  $PM_{2.5}$  concentrations in BTH and surrounding areas decrease, the  $PM_{2.5}$  chemical compositions have undergone significant changes over the years. Table 1 shows the changes of major  $PM_{2.5}$  components concentrations in the studied region over the years. The most notable change was the reduction in sulfate and organic matter, which decreased by 42% and 31%, respectively, from the 2016–2017 autumn-winter seasons (October 2016–March 2017) to 2018–2019 autumn-winter seasons (October 2018–March 2019). This is due to effective control of coal consumption including household coal replacements, the elimination of small coal-fueled boilers, etc. in BTH and surrounding areas. Emission inventory statistics revealed that households consumed less than 5% of coal in the “2+26” cities but accounted for >20%  $SO_2$  and >30% organic matter emissions. From 2016 to 2018, coal in 8.6 million households were substituted by natural gas and electricity, which reduced emissions of  $SO_2$  and organic matter significantly. On the contrary, the reduction in nitrate concentration (11%) was relatively lower than those of sulfate and organic matter. As a result, the nitrate-to-

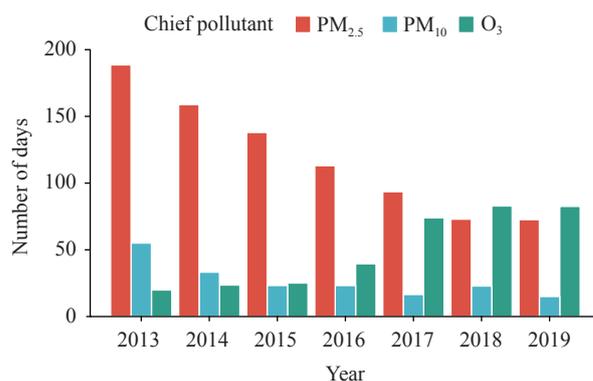


FIGURE 3. The number of air polluted days with different chief pollutants from 2013 to 2019.

sulfate mass ratio increased from 1.2 in 2016–2017 autumn-winter seasons to 1.8 in 2018–2019 autumn-winter seasons. Given the decrease in  $PM_{2.5}$  concentrations, the mass fraction of nitrate increased to 19.6% in 2018–2019 autumn-winter seasons, and the extent of mass fraction increase (3.4%) is larger than any other species. This highlights the importance of tackling nitrate pollution in the studied region. Ammonium is the major cation in  $PM_{2.5}$  to balance the anions charge-wise, and its concentration decreased by 22.4%, which is between the decrease in sulfate and nitrate. Considering the fact that the concentration of ammonia is in excess over those of acidic species (e.g. sulfuric acid and nitric acid gases) in the atmosphere in the studied region, reduction of ammonia emission alone might not lead to substantial air quality improvement without drastic changes (7).

TABLE 1. Concentrations and mass fractions of PM<sub>2.5</sub> components in BTH and surrounding areas in the 2016–2017 and 2018–2019 autumn-winter seasons.

PM <sub>2.5</sub> component	2016–2017 autumn-winter		2018–2019 autumn-winter	
	Concentration (µg/m <sup>3</sup> )	Mass fraction (%)	Concentration (µg/m <sup>3</sup> )	Mass fraction (%)
Elemental carbon	4.0	2.6	4.6	4.1
Organic matter	46.3	30.4	31.8	28.3
Nitrate	24.7	16.2	22.1	19.6
Sulfate	21.2	13.9	12.4	11.0
Ammonium	14.5	9.5	11.2	10.0
Chloride	5.9	3.9	4.0	3.6
Crustal matter	4.7	3.1	7.2	6.4
Trace elements	4.2	2.8	2.6	2.3
Others	26.9	17.6	16.5	14.6

Furthermore, studies revealed that the MDA8 surface O<sub>3</sub> concentration during April–September increased in BTH and surrounding areas (8). During the seasonal transition period, PM<sub>2.5</sub> and O<sub>3</sub> complex pollution can occur in the studied region. For instance, on April 30 and May 1, 2020, both daily PM<sub>2.5</sub> and MDA8 ozone levels exceeded the National Ambient Air Quality Standards (1–2) in cities such as Beijing and Tangshan (Supplementary Figure S1 available in <http://weekly.chinacdc.cn/>). The results show that secondary pollutants such as particulate nitrate, secondary organics, and O<sub>3</sub> had become prominent in recent years, implying the importance and urgency of controlling their precursors such as nitrogen oxides and volatile organic compounds.

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# Corresponding author: Jingnan Hu, [hujn@caes.org.cn](mailto:hujn@caes.org.cn).

<sup>1</sup> Institute of Atmospheric Environment, Chinese Research Academy of Environmental Sciences, Beijing, China.

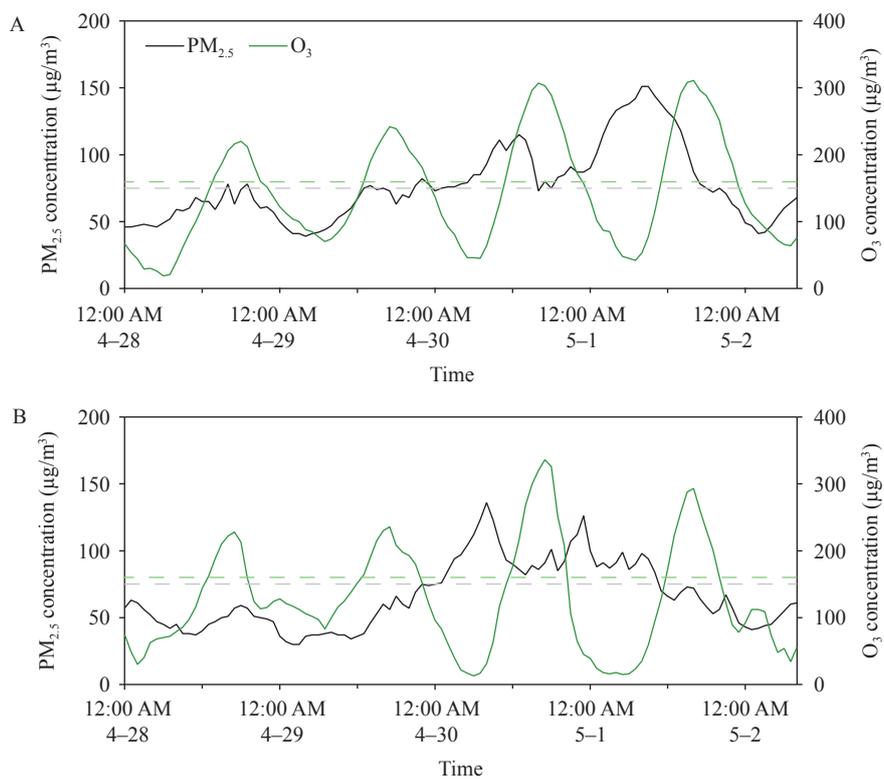
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## REFERENCES

1. Ministry of Environmental Protection. GB 3095-2012 Ambient air quality standards. Beijing: China Environmental Science Press, 2016. <http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqhjzlbz/201203/W020120410330232398521.pdf>. (In Chinese).
2. Ministry of Environmental Protection. HJ 633-2012 Technical regulation on ambient air quality index (on trial). Beijing: China Environmental Science Press, 2016. <http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/201203/W020120410332725219541.pdf>. (In Chinese).
3. Ministry of Environmental Protection. HJ 663-2013 Technical regulation for ambient air quality assessment (on trial). Beijing: China Environmental Science Press, 2013. <http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/201309/W020131105548549111863.pdf>. (In Chinese).
4. Liu WQ, Chen ZY, Liu JG, Xie PH. Stereoscopic monitoring technology and applications for the atmospheric environment in China. *Chin Sci Bull* 2016;61(30):3196–207. <http://engine.scichina.com/doi/10.1360/N972016-00394>. (In Chinese).
5. Cai SY, Wang YJ, Zhao B, Wang SX, Chang X, Hao JM. The impact of the “Air Pollution Prevention and Control Action Plan” on PM<sub>2.5</sub> concentrations in Jing-Jin-Ji region during 2012–2020. *Sci Total Environ* 2017;580:197–209. <http://dx.doi.org/10.1016/j.scitotenv.2016.11.188>.
6. Zhang Q, Zheng YX, Tong D, Shao M, Wang SX, Zhang YH, et al. Drivers of improved PM<sub>2.5</sub> air quality in China from 2013 to 2017. *Proc Natl Acad Sci USA* 2019;116(49):24463–9. <http://dx.doi.org/10.1073/pnas.1907956116>.
7. Liu MX, Huang X, Song Y, Tang J, Cao JJ, Zhang XY, et al. Ammonia emission control in China would mitigate haze pollution and nitrogen deposition, but worsen acid rain. *Proc Natl Acad Sci USA* 2019;116(16):7760–5. <http://dx.doi.org/10.1073/pnas.1814880116>.
8. Lu X, Zhang L, Wang XL, Gao M, Li K, Zhang YZ, et al. Rapid increases in warm-season surface ozone and resulting health impact in China Since 2013. *Environ Sci Technol Lett* 2020;7(4):240–7. <http://dx.doi.org/10.1021/acs.estlett.0c00171>.

SUPPLEMENTARY TABLE S1. The cities missing the concentration data of CO, O<sub>3</sub>, and PM<sub>2.5</sub>.

Pollutant	2013	2014
CO	Anyang, Hebi, Jiaozuo, Jincheng, Kaifeng, Puyang, Xinxiang, Yangquan, Changzhi	Hebi, Puyang, Xinxiang
O <sub>3</sub>	Anyang, Hebi, Jiaozuo, Jincheng, Kaifeng, Puyang, Xinxiang, Yangquan, Changzhi	Hebi, Puyang, Xinxiang
PM <sub>2.5</sub>	Anyang, Hebi, Jiaozuo, Kaifeng, Puyang, Xinxiang	Hebi, Puyang, Xinxiang



SUPPLEMENTARY FIGURE S1. PM<sub>2.5</sub> and O<sub>3</sub> hourly concentrations in (A) Beijing and (B) Tangshan from April 28 to May 2, 2020. The grey and light green dashed lines indicate the secondary standards of daily PM<sub>2.5</sub> concentration (75 µg/m<sup>3</sup>) and MDA8 O<sub>3</sub> level (160 µg/m<sup>3</sup>), respectively.