Urban air quality management in Xi'an

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Xi'an, also known as Chang'an in ancient times, is the most famous historical and cultural city in China. Established as the capital city about 1200 years ago, Xi'an is also the eastern terminal of the Silk Road. Today, it is the biggest and principal city of Northwestern China, with a population over 8 million. Air pollution has always been a serious problem in Xi'an. The air quality in Xi'an is often ranked among the top 10 worst cities in China. The heavy air pollution could cause a great impact on its residents' health and life quality. An effective air pollution control is a pressing demand and requirement for the city.

Status and causes of Xi'an air quality

Since 2013, when the Chinese central government have established a law on air quality regulation and national air quality standard for air pollution control, the air quality of Xi'an has been improving continuously. In 2013, 'Good' air quality days were numbered as 138, 211 days in 2014 and 251 days in 2015. In 2016, due to meteorological reasons (including dust storm events, El Niño impact, etc.), the air quality was affected, and the number of 'Good' days declined to 192. During 2013–2015, five of the six ambient air pollutants, PM_{10}, $PM_{2.5}$, SO_2, NO_2 and CO pollutants, showed a declining trend every year; however, the ambient ozone concentration has been on the rise annually since 2013.

Traditionally, the particle pollution in winter in Xi'an is more critical and is usually characterized by severe haze pollution events (Huang et al., 2014).[1] Air-borne dusts (e.g. from construction and dust storm), coal burning from power station or heating system, biomass burning (e.g. from cooking and heating in rural areas) and secondary pollutants (e.g. from traffic vehicles and industries) are the major sources of $PM_{2.5}$ pollution in heavy haze events reported in Huang et al.'s study.[1] In spring, Xi'an is occasionally affected by dust activities and dust storms. In recent years, ozone (O_3) pollution produced as a by-product of photochemical reactions of volatile organic compounds (VOCs) from fossil fuel and combustion products, NO_x, emitted from motor vehicles, has become a particular concern during summer that could seriously affect ambient air quality in Xi'an.

The $PM_{2.5}$ pollution in Xi'an mainly consists of carbonaceous components: organic carbon (OC) and elemental carbon (EC), sulphate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+) and dusts. Comparison studies on winter and summer pollution of 2003 and 2013[2,3] show that Xi'an has the highest winter $PM_{2.5}$ concentration among the 14 sampled cities reported in their studies. Also, Xi'an is within the top three cities where the highest summer concentration of $PM_{2.5}$ was monitored.[3] In 2003, average $PM_{2.5}$ concentration in Xi'an was $356\,\mu g\,m^{-3}$ in winter and $102\,\mu g\,m^{-3}$ in summer.

Fortunately, over the past 10 years, $PM_{2.5}$ concentration in Xi'an has been declining significantly, about 43% in winter and 41.6% in summer. Compared to the recent record with 2003 measurements, sulphate concentration in Xi'an has been reduced by 47%, while nitrate has been slightly increased. The concentration of OC and EC in Xi'an has been reduced by 30% and 50% (which is the biggest EC decrease trend in 14 cities), respectively. Comparing 2013 NH_4^+ concentration to 2003 concentration in Xi'an, the concentration has been reduced by nearly half. A comparison of winter SO_4^{2-}/NO_3^- ratio in 14 cities during the period between 2003 and 2012 shows a decline from 1.9 to 0.9 in Xi'an indicating that since the government's 11th five-year plan (year 2006–2010), the environmental control of SO_2 emission has achieved remarkable result; however, NO_x emission reduction would still need to be reinforced in Xi'an's urban air quality management (AQM).

The poor air quality in Xi'an is mainly caused by the huge quantity of pollutants emitted into the air, for example, in 2012, the total amount of industrial

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emissions in Xi'an reached 104.3 billion m^3, 83,072 tons of sulphur dioxide emissions, 41,862 tons of nitrogen oxide emissions and 17,462 tons of industrial dust emissions. The emissions of these pollutants into the ambient air would be the major cause of pollution in Xi'an.

In addition, Xi'an is located in the Guanzhong area, the terrain is high in the southeast, low in northwest, Qinling Mountains blocks the airflow to its south and the Loess Plateau holds its northern position, with a relative height difference in land level of up to 600–800 m, similar to Basin topography and valley terrain, and this would be very detrimental to effective diffusion of air pollutants in the urban area of Xi'an. On the other hand, the primary dominant wind direction of Xi'an in the region is north-easterly, secondary dominant wind direction is south-westerly, the frequency of static winds (<1 m/s) is 35% (up to 45% in winter) and the annual average wind speed is 1.7 m/s. These factors, therefore, could greatly impede the effective dispersion of air pollutants in Xi'an.

Urban air quality management in Xi'an

Xi'an AQM system was first established in 1979 due to requirements of the National Environmental Protection Management. Currently Xi'an Environmental Protection Bureau is in charge of the city's management of air quality, being operated directly by supporting 'Iron fist on haze pollution' (IFH) Office and Atmospheric Environment Division. The Xi'an Environmental Monitoring Centre is responsible for environmental data monitoring. The Xi'an Environmental Protection Research Institute is responsible for environmental science research and engineering management. The Xi'an Environmental Education and Information Centre is responsible for public education and promotion of awareness of environmental science and policy. The Xi'an Motor Vehicle Exhaust Monitoring Centre is responsible for motor vehicle management. In the Xi'an municipal government, about 100 staff are currently being engaged in specialized AQM of the city.

In accordance with requirements of the National Environmental Protection Agency, the Xi'an Atmospheric Particulate Matter Monitoring Project has been progressing from the initial total suspended particle (TSP) monitoring started in 1979 to PM$_{10}$ monitoring after 2000, and started PM$_{2.5}$ monitoring since 2013. During the 1996–1999 period, the United Nations Development Programme (UNDP) funded a national project 'Capacity Development for Xi'an Atmospheric Particulate Pollution Control' to help Xi'an to establish advanced AQM system.[4] Currently, the air monitoring network in Xi'an has 13 stations, monitoring pollutants including PM$_{10}$, PM$_{2.5}$, SO$_2$,

NO$_x$, O$_3$ and CO. The hourly real-time concentrations of these pollutants can be found and freely downloaded from the website: http://www.xaepb.gov.cn/ajax/comm/pm25/newMapindex.jsp

The dominant sources of air pollution in Xi'an has been shown by a previous study[3]: (1) Fugitive dust: Xi'an is located in a semi-arid region and is close to the northwest desert dust source area, which is posing a serious dust pollution in the city. Meanwhile, a large number of construction sites within the city also emit a considerably large amount of dust particles. (2) Raw coal and biomass combustion: burning of raw coal and biomass burning are common in Xi'an for winter heating. There are more than 200 thousand tons of raw coal and a large quantity of biomass being burned in winter. (3) Motor vehicular emission: There has been a huge surge in the number growth of motor vehicles, which is about fivefold growth in 10 years. The existing motor vehicle number has reached 2.8 million. (4) VOCs emission: Small scattered high pollution enterprises that include coating plants, paint processing plants, etc. emit high quantity of VOCs into the atmosphere. There are also high levels of emissions of fossil fuel vapours from motor vehicles and from fuel refilling stations, tankers and oil depots.

Targeting the control measures on the above sources of pollution, the Xi'an municipal government has been implementing six major air quality management control strategies since 2013: reduction on reliance on coal burning, control of motor vehicles, suppression of dust release from construction, industry source control, restriction of burning of biomass substances and establishment of afforestation.

Firstly, 'coal reduction': since 2013, 2.3 million tons of coals have been cut back by eliminating outdated production capacity, reducing key enterprise coal consumption, transforming these enterprises into the use of energy-saving technology and clean energy. High-polluting fuel-restricted areas were further enhanced in management. During 2013–2016, a total of 1544 coal-fired boilers for heating were dismantled, and 135 thousand households that have been using briquettes were successfully converted to clean energy heating systems (e.g. gas boilers).

Secondly, 'vehicle control' by providing subsidies and applying strict regulation for accelerating the discard of 'Yellow Label' and aged vehicles. In the past four years, about 190 thousand 'Yellow Label' and aged vehicles were discarded and over 5000 new energy-saving cars and over 1400 new energy-saving buses (natural gas vehicles) have been introduced. Citizens are encouraged to buy and use highly efficient fuel combustion vehicles. Since 1 October 2014 onward, the government of Xi'an has been implementing the full supply of State V Standard petrol and diesel policy,

which is three years ahead of the National Gasoline upgrading schedule.[5,6]

Thirdly, 'dust suppression': Construction industries have been implementing a wet operation on their construction sites. Six dust control measures are being implemented: e.g. 'sprinkling, hardening, washing, covering, blocking and afforestation' to ensure almost 100% prevention of dust release into the atmosphere. The number of mechanized cleaning equipment has been increased every year. Currently, the city holds 539 various types of mechanical sweepers in all districts, among which 316 cleaning vehicles were purchased and commissioned since 2013. At the same time, 101 small road cleaning vehicles and 44 mist cannon were added for street cleaning operations. The mechanized cleaning rate for major roads has reached 99% in Xi'an. The city's overall mechanized cleaning rate has reached 86%.

Fourth, 'source control'; 438 sets of coal-fired boilers have been upgraded to a new standard. Thermal power units that are over 300 thousand kilowatts would have ultra-low emissions, and those that are less than 300 thousand kilowatts units would have to comply with the special emission limit requirement.[7] Since 2013, the Xi'an Government has carried out engineering management of organic waste gas from key industrial enterprises, including petrochemical, paint spraying, printing and paint processing industries, and has completed the emission management of 82 companies. Additionally, secondary gasoline vapour recovery unit has been installed in 475 gas stations, 5 oil depots and 645 tankers.

Fifth, 'burning restriction'; the Xi'an Government has been implementing a grid management on pollution control since the beginning of 2015, including one Level I grid, 20 Level II grids, 221 Level III grids, 3243 Level IV grids and 228 basic level environmental management stations/workstations, and over 8000 grid officers have been employed. By the end of October 2016, more than 17,000 scattered pollution incidents of burning sources were treated. In addition, the Xi'an Government has enforced the restriction on straw burning in summer and autumn and realized the 'zero fire point' for many years.

Sixth, 'afforestation'; the Xi'an Government has actively implemented major ecological projects such as the 'Qinling Mountain Ecological Protection', 'Eight Rivers Circle Xi'an' and so on to improve ecological environment. Within the city, the government has actively promoted urban roof gardening, vertical gardening and afforestation on exposed land, as well as constructed multiple sections of water bodies to constantly increase the urban environmental capacity. A total of 360 thousand acres of afforestation, 30 new parks, 363 green squares, 19.31 million m^2 of newly developed urban green land, 9573 acres of ecological water body and 21,000 acres of wetland area have been developed in the city. Green park area per capita in Xi'an has been increased from $9.5\,m^2$ to $11.6\,m^2$ over these years.

In order to further strengthen the air pollution management in Xi'an, in March this year, the Xi'an municipal government has launched an 'IFS $1 + 1 + 9$' action programme (http://news.163.com/17/0310/22/CF6VISUB00014AEE.html), which includes 'Xi'an city IFS – Defending blue Sky' Implementation Plan + Interim Measures for Evaluation and Accountability Assessment + Special Action Programme for Coal reduction + Special Action Programme for Coal-fired Boiler Demolition + Special Action Programme for Volatile Organic Compounds Pollution Management + Special Action Programme for Environmental Monitoring and Enforcement for Waste Gaseous-related Pollution Sources + Special Action Programme for Remediation of Small Scattered Pollution Companies + Special Action Programme for Remediation of Low-speed and Diesel Freight Car Pollution + Special Action Programme for Straw and Other Biomass Comprehensive Utilization + Special Action Programme for Prevention and Control of Construction site Dust Pollution + Special Action Programme for Grid Management of Environment. These special action programmes were proposed and implemented to ensure that the annual 'Good' days are not less than 220 days in Xi'an. The Xi'an Government has a special budget of a few billion RMB to invest in the planned air pollution control, air quality management this year.

Although the Xi'an municipal government has spent significant efforts in pollution control, the improvement of air quality has still not been totally satisfactory. There is still a gap to meet expectations of the people. In the past, a great deal of work had been done on the above six initiatives, but not so much in the aspect of long-term measures. The following areas have been recommended for the future implementation:

- Effectively change the coal-based energy structure in Xi'an, reduce the usage of coal and to lower the usage of coal by 30% within the primary energy supply and gradually implement the commissioning of new clean energy structure that is mostly based on natural gas and electricity.
- Reduce as much as possible the number of chemical industries, spray coating and other industrial enterprises within the urban city. Promote the growth of low-emission or zero-emission industries such as high-tech, design, cultural tourism, finance industry in the proportion of GDP of Xi'an.

- Take the opportunity of Xi'an-Xianyang amalgamation process, implement as soon as possible, the high-performance, rapid and convenient urban public transportation system. Construct intelligent city management system and slow down the growing number of private cars.
- Construct novel air pollution management system with $PM_{2.5}$ management as the core focus. Engage all sections and stakeholders to participate, involving the government, to encourage participation of economic, legal and science and technology stakeholders, so to achieve the goal of achieving good ambient air quality in Xi'an within 15–20 years.
- We recommend the government to support a range of high-level scientific research to monitor and record accurately the air pollution control measures and to identify the long-term improvement requirements in Xi'an. The main research directions should include: the establishment of high-precision pollutant source inventory, dynamic analysis of pollution sources; the establishment of early warning and forecasting system of Xi'an air pollution and the establishment of air pollution comprehensive intelligent management platform and heavy pollution emergency management system.

Authors' contribution

Junji Cao and Chuck Yu designed the study and drafted the manuscript. Junji Cao and Yan Cheng collected the data, coordinated the data-analysis.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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