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The Impacts of Control Measures on Air Pollution Trends in Sichuan Province, China

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Abstract: The atmospheric environment continues to be increasingly affected by air pollutants which are heavily released into the ambient air, especially in developing countries such as China. This has led to severe effects on public health. Sichuan Province, which is the economic centre of southwestern China, is characterised by an increasing number of industries and vehicle use. It also abounds with natural resources, high biodiversity and increased socioeconomic development. The growing number of industries, vehicle usage and exploitation of natural resources have contributed to the high levels of air pollutant concentrations in the province. However, recent analyses of air pollution parameters are scanty. This research analyses the current trend of particulate matter (PM), sulphur oxide (SO_2), nitrogen oxide (NO_2), carbon monoxide (CO) and ozone (O_3) using the recent atmospheric parameter datasets after the adoption of Chinese National Ambient Air Quality Standard (CNAAQS). Statistical and comparative of the air quality under the CNAAQS were performed. The results showed a negative (decrease) trend in $PM_{2.5}$, PM_{10}, SO_2 and CO concentrations, a positive (increase) trend for O_3 and an irregular trend for NO_2 concentrations in the province between 2015 and 2020. It is concluded that air quality has improved in Sichuan for most of the pollutants. However, proper management strategies should be taken to control O_3 and NO_2 due to their increasing and irregular trends, respectively.

Keywords: Air pollution, Pollution trend, Atmospheric pollutants, Sichuan air quality

INTRODUCTION

After China's economic reform in the late 1970s, a massive economic expansion, urbanisation, industrialisation and substantial increase in energy consumption have been experienced. The unprecedented growth together with increased energy consumption and increased vehicular usage has led to a great increase in air pollution (Economy, 2010; Wang & Hao, 2012). China is currently the world's largest energy consumer and most of its energy consumed comes from coal leading to poor air quality (Zhang & Cheng, 2009). The increase in the number of vehicle use and industrial growth has contributed to the already high concentration of air pollutants which leads to a continual deterioration in air quality, threatening human health and causing environmental damage (Muller et al., 2015). Like many other countries, particulate matter (PM), Sulphur Oxide (SO_2), nitrogen oxide (NO_2), carbon monoxide (CO) and ozone (O_3) are the major air pollutants. It has been shown that the concentration of these pollutants was very high in China's atmospheric space (Li & Liu, 2014; Muller et al., 2015; Rathi, 2018; Song et al., 2017; Wang & Hao, 2012; Zhao et al., 2008).

Though the country, in general, has reduced some of the pollutants in the atmosphere, others such as SO_2 have increased especially in the North China Plain (Li et al., 2019) while others have reduced

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only minimally or oscillated. O_3 is referred to as the new pollution crisis in China as research shows a continual increase in its concentration over the years (Rathi, 2018). Air quality reports from 155 cities indicated that there is a high annual concentration of two or more pollutants and most of these cities are located in eastern China and megacities (Han et al., 2018; Muller et al., 2015). Chengdu (Sichuan provincial capital) in southwestern China was included in the list of multi-contaminant air pollution cities in China (Han et al., 2018). WHO report shows a 17% reduction in annual $PM_{2.5}$ concentration in China from the previous year but still four times higher than WHO recommendations (WHO, 2018).

Modelled on the approaches of the Western world, modern management of environmental problems was embraced by China in the 1970s. This management of the physical environment was focused on the elimination of existing pollution. It later evolved into prevention and elimination in 1972 (He et al., 2012). Since then China has taken significant measures to prevent further deterioration caused by air pollution. In 2005 and 2011, the Chinese government implemented the desulphurisation of coal-fired plants and the installation of selective catalytic reduction systems. At the city level, policies for upgrading fuels for vehicles and banning older polluting cars were introduced. In early 1990, China started promoting the use of alternative fuels as a way of reducing fossil fuel consumption. Compared with diesel and gasoline-powered vehicles, they are considered cleaner and capable of abating the emission of air pollutants. Studies in China have however suggested that these alternative fuels could be higher emitters of gaseous pollutants (Wu et al., 2017). During the 12th FYP, China targeted reducing emissions of SO_2, NO_X (especially NO_2) and CO_2 by 8%, 10%, and 17%, respectively. In 2013, the central government established the Air Pollution Prevention and Control Action Plan to reduce heavily polluted days in China. Furthermore, in 2015, a new law on environmental protection was implemented which is considered a turning point in Chinese air pollution prevention. Studies have shown a reduction in the emission of major pollutants like SO_2 and NO_X as a result of these laws or policies (Nam et al., 2013). This improvement has been attributed to the Chinese government's effectiveness in air pollution control measures (Song et al., 2017; van der A et al., 2017; Wu et al., 2017). This includes additional policies set by the provinces and the development of further prevention and control measures to improve air quality within their provinces. These efforts have been christened the "war on pollution" in China.

In addition, the changes in the administrative structure of environmental protection also reinforced better pollution control in China. Pollution control and climate change mitigation are now the responsibilities of the new Ministry of Ecology and Environment which was created during the central government restructuring process in 2018. This restructuring is expected to improve and enforce the country's emission control policies and improve its ability to successfully implement emission standard enforcement for both the pollutants linked with adverse health outcomes and the greenhouse gasses linked to climate change (Tilt, 2019).

To further reduce air pollution, the Chinese Ministry of Environmental Protection (MEP) issued a new Chinese National Ambient Air Quality Standard (CNAAQS) in 2012, and for the first time including fine particulate matter ($PM_{2.5}$) and 8-hourly O_3 measurements. It was implemented nationwide in 2016 with a concentration limit for air pollutants set at Class I that is considered safe and acceptable for urban areas (Li & Liu, 2014; You, 2014; Zhao et al., 2016). The Class II standard was the set minimum standard to achieve within the shortest time. With the achievement of the SO_2 reduction target during the 11th Five-Year Plan (FYP), strategies for upgrading vehicle fuel and banning older polluting cars were introduced at the city level. Further studies are reporting the government's success in the reduction of NO_2 emissions as well (Song et al., 2017; Wu et al., 2017). However, these studies were conducted quite early in the implementation stages of the new CNAAQS air quality standard.

The health and welfare of people and the environment in Sichuan Province are endangered by the air pollution problem. The industries, vehicles, natural resources, high biodiversity, and increased socioeconomic development have made Sichuan the economic centre of southwestern China. They have also contributed to the high levels of PM, oxides of sulphur (SO_X) especially SO_2, and oxides of nitrogen (NO_X) especially NO_2, CO and O_3. The Sichuan provincial capital, Chengdu, was the only southwestern city included in the list of multi-contaminant air pollution cities in China (Han et al., 2018). Yet only a few studies have been conducted on air quality in the entire province. Therefore, it is important to analyse the air pollution trend that presents the status of the progress made in its control in the province. The air pollutant measurements are compared with the set limits of the CNAAQS *Class I* and *II* standards. This will enable the understanding of the nature of air quality and to what extent it has been controlled at the provincial level after the CNAAQS standard. It will also serve as a reference for further and future baseline analysis in the area.

STUDY AREA

Sichuan Province is located in the southwest of China (Figure 1). It is one of the largest provinces in the country. With a population of over 83 million people as of 2020, Sichuan is the fourth most populous province in China. It consists of 21 administrative distinct units comprising 18 prefecture-level cities and three autonomous prefectures. The 21 administrative units are simply referred to as cities.

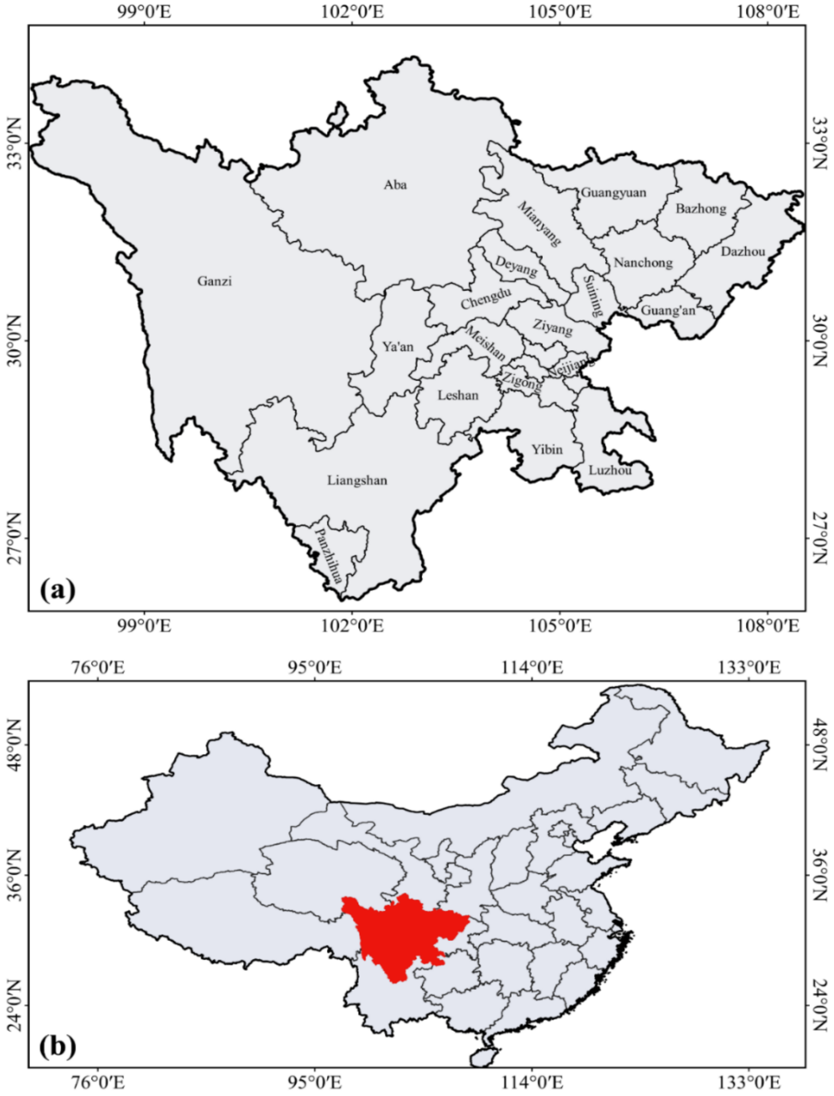


Figure 1. Map of Sichuan Province (a) and China (b) showing the location of Sichuan Province

The province is divided into two distinct geographical parts. The eastern part includes the Three Gorges and Yangtze River and the western part consists of numerous mountain ranges which form the easternmost part of the Tibetan Plateau. Western Sichuan contains the highest point of the province at 7556 m (24,790 ft) above sea level. Due to this great difference in terrain, the climate of Sichuan is very diverse and complex with noticeable differences between the east and west. The Eastern part of the province has a subtropical and humid climate while western Sichuan experiences low temperatures in winter, cool summers and frequent fog. Generally, the temperature in Sichuan is above 22^{o}C in summer and below 10^{0}C in winter. The temperature in the spring and autumn seasons ranges from 10 to 22^{0}C. The province serves as an economic passageway, connecting inner southwestern China. For this, it is considered the most important province in western China (Liao et al., 2018; Liu et al., 2018; Zhao et al., 2018). It is also one of the largest agricultural bases in China. Furthermore, industries in Sichuan are the most developed in western China and they play an important role in the country as a whole which includes in addition to agriculture, high-tech industry, nuclear industry and Chinese liquor.

Concentrating on both heavy and light industries, the coal, iron and steel industries are considered to be the leading sectors in this province. This has led to an increase in urbanisation and motorisation. Such massive development has increased the demand for energy consumption to support this infrastructure, transportation, industries, and the basic energy needs of the people (Zhao et al., 2018). With several infrastructural projects and industrial and individual activities, the air quality of Sichuan province deserves a systematic as well as scientific investigation so that proper strategies can be taken to mitigate this problem.

METHODOLOGY

Data acquisition

The daily air pollutants concentration datasets were acquired from the air quality monitoring stations from 21 cities in Sichuan for six years (2015-2020) to give a comprehensive analysis of the air quality under the CNAAQS. The concentrations of PM ($PM_{2.5}$ and PM_{10}) and gaseous pollutants (SO_2, NO_2, CO and O_3) were collected from the Air Quality Publishing System (http://www.tianqihoubao.com/lishi/). The historical and real-time air quality datasets for all State Controlling Air Sampling Sites in China are provided in the datasets. Air quality data from all monitoring stations in the 21 cities presented as citywide daily average data were analysed. The cities are Aba, Bazhong, Chengdu, Dazhou, Deyang, Ganzi, Guang'an, Guangyuan, Leshan, Liangshan, Luzhou, Meishan, Mianyang, Nanchong, Neijiang, Panzhihua, Suining, Ya'an, Yibin, Zigong and Ziyang.

The data for this analysis ranged from January 2015 to December 2020. Quality assurance and quality control of the data have been reported (Zhao et al., 2016, 2018). The data was validated based on GB 3095-2012 specifications (ME&E, 2016). To eliminate problematic data points, a sanity check was conducted on the data before calculating the average concentrations.

Data analysis

The daily citywide concentrations of atmospheric pollutants were used to analyse the air quality trend of Sichuan Province. The data were analysed using SPSS v.25 and Excel 2016. The periods with no data were excluded. The daily air quality data were then used to calculate the annual average of the pollutants in Sichuan for the study period (1st January 2015 to 31st December 2020). In addition to examining trends, further analysis was done to evaluate the attainment of Class I and II standards of the CNAAQS (Table 1) for each pollutant during the study period.

Table 1. Limits for air pollutants in the National Ambient Air Quality Standard (CNAAQS)

		Limit		
Pollutants	Averaging time	Class I	Class II	Unit
$PM_{2.5}$	Annual	15	35	μgm^{-3}
	24 Hours	35	75	
PM_{10}	Annual	40	70	μgm^{-3}
	24 Hours	50	150	
SO_2	Annual	20	60	μgm^{-3}
	24 Hours	50	150	
	Hourly	150	500	
NO_2	Annual	40	40	μgm^{-3}
	24 Hours	80	80	
	Hourly	200	200	
CO	24 Hours	4	4	mgm^{-3}
	Hourly	10	10	
O_3	Daily 8-hour maximum	100	160	μgm^{-3}
	Hourly	160	200	

RESULTS AND DISCUSSIONS

Annual correlation analysis between the air pollutants

Table 2 shows the correlation between the pollutants for the 21 cities within the study period. Over the study period, $PM_{2.5}$ has a strong positive correlation with PM_{10} ($r = 0.96$) at a 0.01 significant level. The NO_2 is strongly and positively correlated with $PM_{2.5}$ and PM_{10} ($r = 0.62$ and $r = 0.70$). This implies that NO_2 emission is accompanied by PM emissions. This is because the PMs can be formed as a result of the transformation of gaseous emissions like oxides of nitrogen (Feng et al., 2018). The SO_2 has a weak positive correlation with the PMs ($PM_{2.5}$ and PM_{10}), CO and NO_2 ($r = 0.08$, $r = 0.11$, $r = 0.28$ and $r = 27$, respectively) at 0.01 level. Furthermore, NO_2 had a moderate positive correlation with CO ($r = 0.44$) at 0.01 level which indicates that CO emission is not only characterised by the emission of PMs but the SO_2 and NO_2 as well. According to Kovač-Andrić et al (2013), CO can oxidize nitrogen oxide (NO) slowly to form NO_2. It may have led to a positive correlation between these two pollutants. The O_3 has a negative correlation with $PM_{2.5}$, MP_{10}, NO_2 and CO, implying no direct links between O_3 and the precursors (NO_2 and CO), $PM_{2.5}$ and MP_{10}.

Table 2. Pearson's correlation (annual) between air pollutants

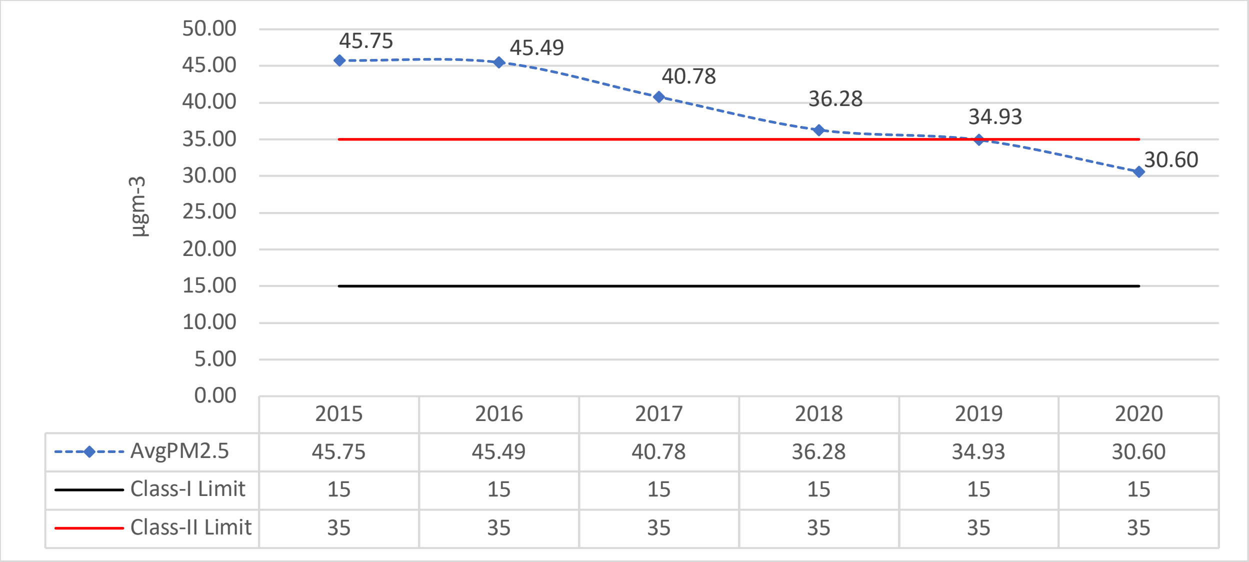
	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
$PM_{2.5}$	1					
PM_{10}	0.96**	1				
SO_2	0.08**	0.11**	1			
NO_2	0.62**	0.70**	0.27**	1		
CO	0.41**	0.41**	0.28**	0.44**	1	
O_3	-0.29**	-0.22**	0.02*	-0.30**	-0.17**	1

***$p<0.01$ and * $p<0.05$ (2-tailed)*

The trend for fine particulate matter ($PM_{2.5}$)

Figure 2 shows the average concentration of $PM_{2.5}$ pollution derived from a network of monitoring sites in the 21 cities in Sichuan from 2015 to 2020. There was a steady drop in the average $PM_{2.5}$ concentration throughout the study period. A decline from 2016 to 2019 is noticeable. A sharper decline was observed between 2019 and 2020, coinciding with the intense COVID-19 lockdown and travel restrictions and its consequential effects on vehicular movement, industrial production and other polluting activities. The result is in line with a report by Cai et al (Cai et al., 2017) and Geng et al (Geng et al., 2019) that noted a steady decline between these periods as a result of the implementation of air pollution control policies. Figure 2 also shows that the average $PM_{2.5}$ concentration in Sichuan was above the CNAAQS Class I limit (Table 1) for the entire study period. The concentration was above the Class II threshold between 2015 and 2018. The Class II threshold was attained in 2019 and even better in 2020 (Figure 2), indicating that the average concentrations of $PM_{2.5}$ have decreased significantly in the province.

The Air Pollution Prevention and Control Action Plan (APPCAP) was targeted at reducing the countrywide $PM_{2.5}$ concentrations. To execute this plan, Sichuan introduced the motor vehicle exhaust pollution control measures which in addition to the other control measures, has helped in reducing $PM_{2.5}$ in the province. This concurs with an earlier study noting that the APPCAP policy has been a milestone in the control of air pollution as it mitigates the serious levels of air pollution in China (Huang et al., 2018). Other studies have reported a decline in air pollution after the implementation of the policy in China (Cai et al., 2017; Geng et al., 2019). Correlation analysis among air pollutants has proven that $PM_{2.5}$ concentration during the study period positively correlated with NO_2 and CO (Xiao et al., 2018); both of which are mainly emitted from vehicles indicating that $PM_{2.5}$ pollution in Sichuan is largely from vehicle emission. Therefore, the control of emissions from vehicles has been a contributing factor to the decreasing trend in $PM_{2.5}$ in Sichuan.



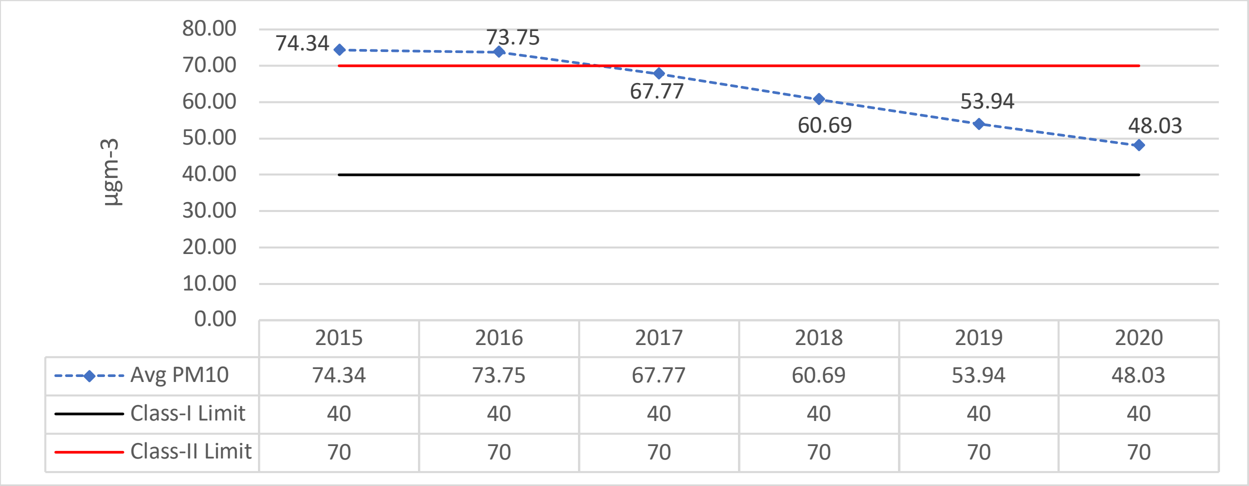
	2015	2016	2017	2018	2019	2020
AvgPM2.5	45.75	45.49	40.78	36.28	34.93	30.60
Class-I Limit	15	15	15	15	15	15
Class-II Limit	35	35	35	35	35	35

Figure 2. The average $PM_{2.5}$ trend in Sichuan between 2015 and 2020

The trend for coarse particulate matter (PM_{10})

Like the $PM_{2.5}$, Figure 3 shows a decline in the average PM_{10} from 2015 to 2020. PM_{10} concentration was above the Class I threshold in Sichuan throughout the study period. However, only concentrations in 2015 and 2016 were above the Class II limit. The PM_{10} concentrations between 2017 and 2020 were below the class II limit in the province.

Particulate matter with diameters that are generally ≤ 10 micrometres (PM_{10}) was included in the APPCAP. About 70% of total PM_{10} comes from $PM_{2.5}$ in the atmosphere (Xiao et al., 2018). As a result, a decrease in $PM_{2.5}$ concentration may lead to a decrease in PM_{10}. Furthermore, PM_{10} like $PM_{2.5}$ has a positive correlation with NO_2 and CO (Xiao et al., 2018) which implies that vehicle emission was the major source of PM_{10} concentration in Sichuan. Exhaust from diesel engines is considered to contribute to more than 50% of PM_{10} which is even higher for $PM_{2.5}$ (Thakur, 2017). Therefore, in addition to national policies (especially APPCAP), the crackdown on motor vehicle emissions in Sichuan is the contributing factor to the negative trend of PM_{10} within the province.



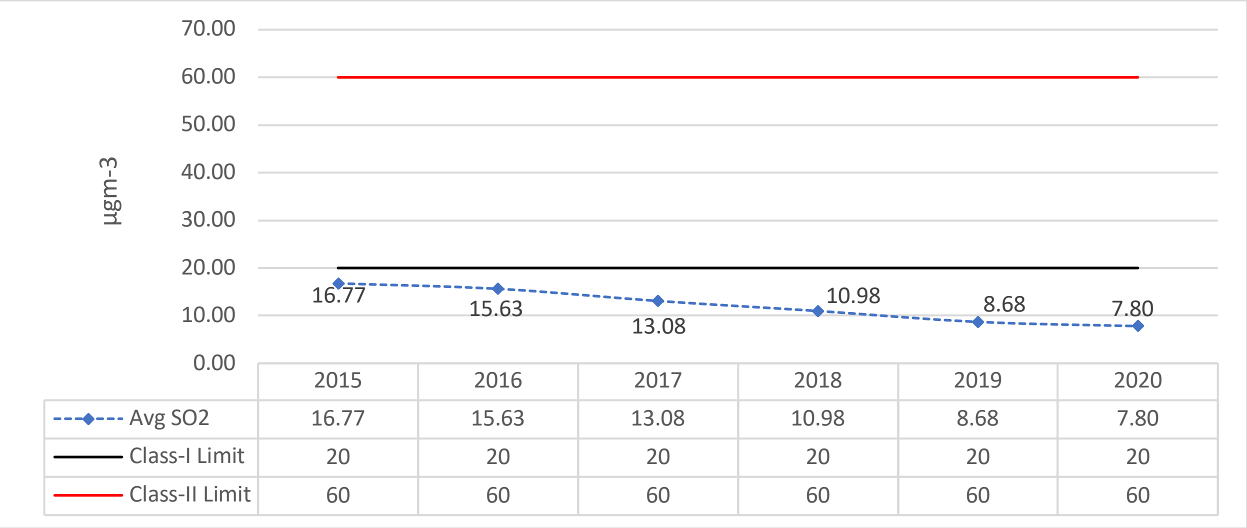
	2015	2016	2017	2018	2019	2020
Avg PM10	74.34	73.75	67.77	60.69	53.94	48.03
Class-I Limit	40	40	40	40	40	40
Class-II Limit	70	70	70	70	70	70

Figure 3. The average PM_{10} trend in Sichuan

The trend for Sulphur dioxide (SO_2)

Figure 4 shows that the annual concentration of SO_2 from the monitoring sites decreased throughout the study period in Sichuan. Unlike PM, SO_2 concentration was below the Class I and II limits set by the CNAAQS (Figure 4) throughout the study period. The decline became prominent from 2018 to 2020.

There was a 29.75% decrease in SO_2 between 2016 and 2018 and about 54% during the study period. A significant reduction in SO_2 nationwide has been reported (Song et al., 2017; Wang & Hao, 2012). The reason for the decrease in the concentration of SO_2 might be due to the several control measures instituted by the central and local governments and the deposition of SO_2 as sulphate. Higher concentrations of sulphate have been reported especially in the Sichuan Basin (Zhang et al., 2012).



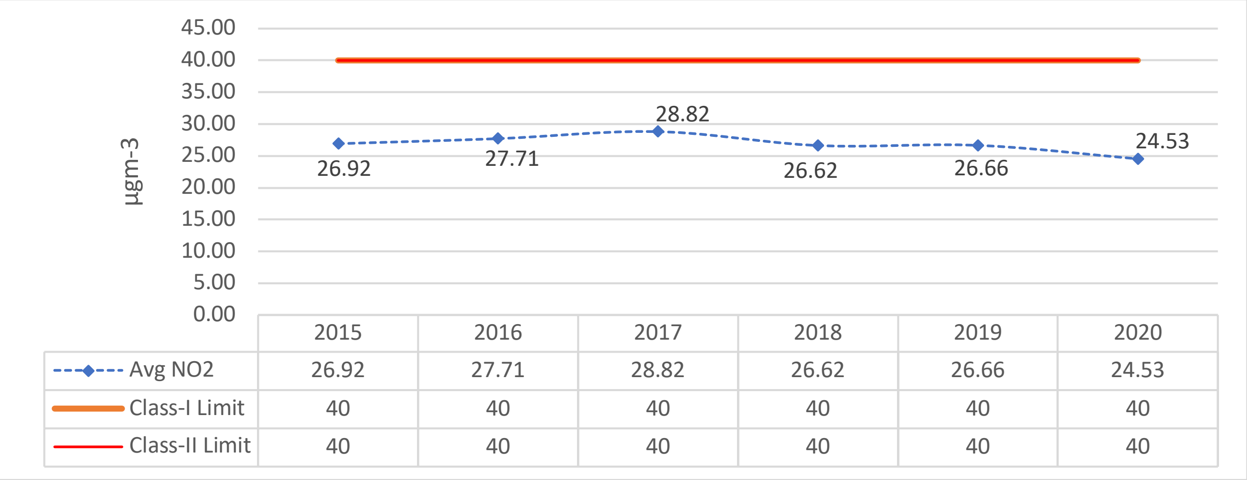
	2015	2016	2017	2018	2019	2020
Avg SO2	16.77	15.63	13.08	10.98	8.68	7.80
Class-I Limit	20	20	20	20	20	20
Class-II Limit	60	60	60	60	60	60

Figure 4. The average SO_2 trend in Sichuan

The trend for nitrogen dioxide (NO_2)

Figure 5 shows the average annual NO_2 trend in Sichuan. The trend fluctuated throughout the study period. NO_2 concentration was below the Class I and II thresholds. The thresholds for Class I and II are the same nevertheless, hence a thicker threshold line in Figure 5.

The major source of NO_2 pollution is emissions from vehicles and industries. A correlation analysis has shown a strong positive correlation between NO_2 and CO and a weak positive correlation between NO_2 and SO_2 (Table 2). This indicates that vehicle emissions more than industrial emissions influence NO_2 concentration in Sichuan. Studies have suggested that the strategies for upgrading vehicle fuel and banning older polluting cars in addition to government policies introduced at the city level have impacted the reduction of NO_X pollution (Wu et al. 2017; Song et al. 2017).



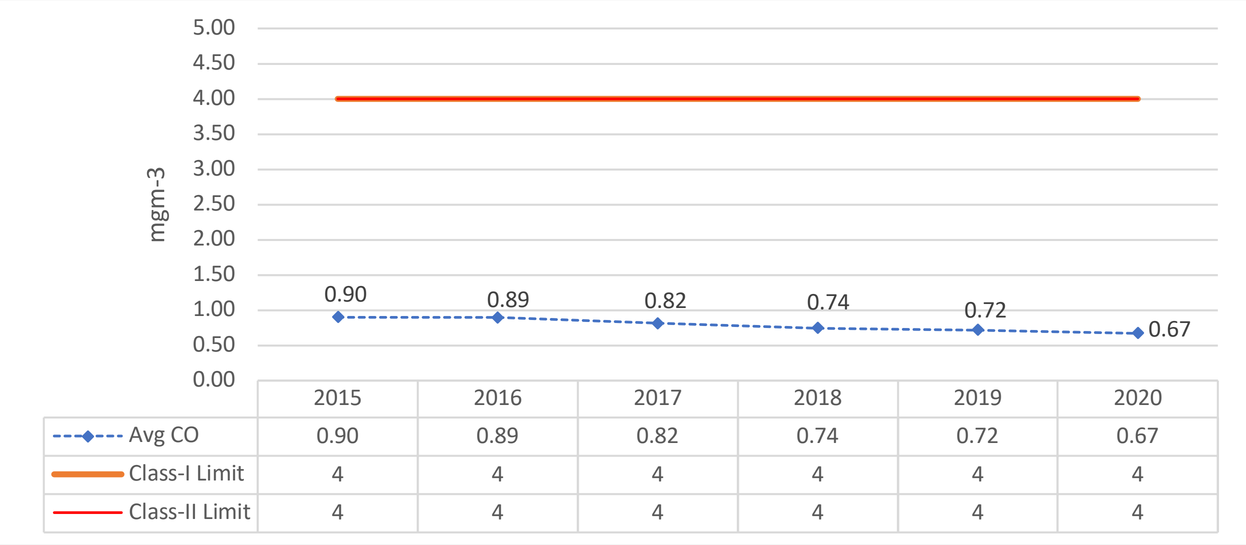
	2015	2016	2017	2018	2019	2020
Avg NO2	26.92	27.71	28.82	26.62	26.66	24.53
Class-I Limit	40	40	40	40	40	40
Class-II Limit	40	40	40	40	40	40

Figure 5. The average NO_2 trend in Sichuan. The Class I and II thresholds are the same, hence a thicker threshold line

Like SO_2, the average concentrations of NO_2 have witnessed a decreasing trend after the implementation of pollution control measures during the 12th FYP (2011-2015). In addition, Sichuan's implementation of motor vehicle emission control due to APPCAP has further reduced NO_2 concentration. However, an irregular trend was observed during the study period. Studies have shown an increase in the average concentration of NO_X in 2017 which was due to a rebound in coal consumption (Liu et al., 2017; Zhao et al., 2021). Thus, the slight increase observed in 2017 might be due to a rebound in coal consumption.

The trend for carbon monoxide (CO)

Figure 6 shows the average concentration of CO in Sichuan during the study period. The CO concentrations were below the CAAQS Class I and II standards. It also witnessed a steady decline, decreasing by 25.56% between 2015 and 2020. The major source of CO, especially from automobile exhaust and the burning of biomass. As a result, higher concentration mostly occurs in areas with traffic congestion and heavy biomass burning. This decrease should be due to improvements in combustion efficiency, recycling of industrial coal gases, and strengthened vehicle emission standards. It concurs with Li et al (2017). The results in Table 2 show a positive correlation between CO, SO_2 and NO_2. However, there was a strong positive correlation between CO and SO_2, and a weak positive correlation between CO and NO_2 (Table 2). Based on these findings, it is evident that industrial emission has a greater influence on CO concentration in Sichuan than vehicle emission. In addition to nationwide control of emissions from industries and vehicles, Sichuan's measures on the control of motor vehicle exhaust pollution might have influenced the continuous decrease in CO concentration.



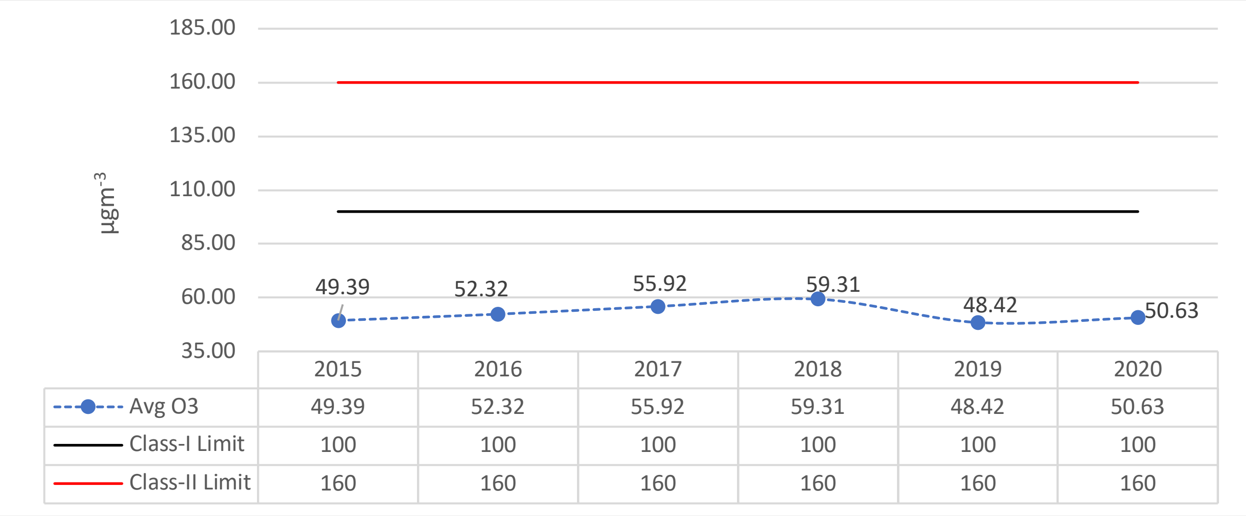
	2015	2016	2017	2018	2019	2020
Avg CO	0.90	0.89	0.82	0.74	0.72	0.67
Class-I Limit	4	4	4	4	4	4
Class-II Limit	4	4	4	4	4	4

Figure 6. The average CO trend in Sichuan. The Class I and II thresholds are the same, hence a thicker threshold line

The trend for ozone (O_3)

Figure 7 shows the average concentration of O_3 in Sichuan. Unlike other major pollutants, the result shows a continuous increase in O_3 concentration until 2018 after which a reduced and irregular trend was observed. O_3 pollution has been described as the new pollution crisis in China. This is because, unlike other pollutants, there is an increase in its concentration (Rathi, 2018). O_3 is a secondary pollutant that is formed as a result of a photochemical reaction between pollutants (mainly NO_2, volatile organic compounds and CO). Despite the negative trend in the annual concentration of its precursors, there is a positive trend in the level of O_3 in China.

Due to China's vast manufacturing sector and the continuous increase in the number of vehicles, a continuous rise in O_3 concentration was linked to both industry and transport (Rathi, 2018) which may be the case in Sichuan as well. Another reason could be due to the downward transport of O_3 from the stratosphere which acts as an additional source of ground-level O_3 (Ni et al., 2019). During hot temperatures, the environment becomes conducive for O_3 production. Results from the annual correlation analysis show a weak relationship between O_3 and the other pollutants (Table 2). Seasonal correlation analysis gives a better understanding of the pollutant, especially in spring and summer. A positive correlation occurs between O_3 and SO_2 and O_3 and CO in spring. A positive correlation occurs between O_3 and PM and O_3 and NO_2 in summer. These relationships are indications of photochemical reactions, industrial activities, and transport. This concurs with previous studies (Liu et al., 2017; Zhao et al., 2021) that the continuous increase in O_3 concentration is influenced by industry output, increasing oil consumption in chemical industries and transport, hot weather, and reduction in particle pollution levels which allows more sunlight to penetrate. It is also partially driven by preparation for the restrictions during winter which might be the case for Sichuan.



	2015	2016	2017	2018	2019	2020
Avg O3	49.39	52.32	55.92	59.31	48.42	50.63
Class-I Limit	100	100	100	100	100	100
Class-II Limit	160	160	160	160	160	160

Figure 7. The average O_3 trend in Sichuan

Though the results showed that air quality is improving in China, there is still room for improvement, especially for the PMs. Another pollutant needing reduction strategies is the O_3 which has shown a steady increase during the study period. Engaging the public in environmental management and awareness could help improve air pollution management. However, the level of public participation in environmental management and governance in China is still in its infancy (Zhang et al., 2021). Thus, this needs to be strengthened and sustained. This is because public participation has been shown to have a significant positive impact on the control of air pollution by strengthening the supervision of environmental law enforcement and influencing the formulation of environmental policies (Zhang et al., 2021). This will enable holistic management of environmental and air pollution in the country. Also, the inter-regional transport of pollutants has been reported (Gautam et al., 2021). Thus, control measures to locally reduce emissions may not be sufficient. The control measures and strategies should also address the inter-provincial pollution problem.

CONCLUSION AND RECOMMENDATIONS

The average concentration of $PM_{2.5}$ in the study area shows a decreasing trend annually. The decreasing trend may be due to China's effort to control the concentration of pollutants in the atmosphere. Nevertheless, the concentrations are still above the CNAAQS Class I limits throughout the study period. Concentration was above the Class II limit between 2015 and 2019, falling below the threshold between 2019 and 2020. The high concentration of $PM_{2.5}$ may be linked to vehicle emission, biomass burning, and re-suspension of road dust. The unfavourable meteorological conditions for pollutants are also an inducing factor for $PM_{2.5}$ accumulation in the study area. Thus, China has a task to sustain the recent decreasing $PM_{2.5}$. PM_{10} concentration was above the Class I limit in Sichuan throughout the study period. Unlike the Class I limit, only concentrations in 2015 and 2016 were above the Class II limit. The PM_{10} concentrations from 2017 to 2020 were below the class II limit, indicating better ambient air quality within the period. The concentration of SO_2 was below both standards throughout the study period. Therefore, Sichuan is safe from SO_2 pollution. Generally, it can be concluded that NO_2 pollution in Sichuan is slightly good in comparison with pollutants like PM. Like the entire country in general, NO_2 concentration in Sichuan is highly dependent on coal consumption as evidenced by its irregular trend. CO had a decreasing concentration and was far below the maximum limit under the CAAQS specifications, implying a safer environment during the study period. O_3 was far below the standard in the study area. It seems to not only depend on its precursors, namely CO and NO_2 as there was an increase in O_3 concentration with the decreasing concentration of its precursors. Although its concentration falls within the standard throughout the study period, there was a continuous increase in O_3. The increase in concentration may be attributed to the downward transport of O_3 from the stratosphere in addition to the emission of its precursors due to urbanisation, high elevation, and strong ultraviolet (UV) radiation.

From the observations above it may be concluded that air quality has improved in Sichuan. However, proper management strategies should be taken to control $PM_{2.5}$, PM_{10} and O_3 as these pollutants either crossed the prescribed standard or have an increasing trend in the study area. Statistical analysis (Table 2) shows that the transport and industrial sectors might be the major source of atmospheric degradation in the study area. As a result, the following management strategies can be taken for the study area to reduce the pollution level and to make the province a cleaner, safer, and sustainable environment for all.

- Technological measures such as environmentally friendly fuels like liquefied natural gas (LNG), compressed natural gas (CNG) and emission control from new and in-use vehicles may reduce emissions from the transport sector.
- Shifting to electric and hydrogen vehicles and promoting shared mobility like carpooling and public transport may help reduce vehicle emissions.
- Introduce pedestrianisation in city centres to reduce vehicle density in these centres.
- Increase the charges for road space and parking to discourage the use of private vehicles.
- Reducing road space for private cars and increasing it for public transport should contribute to discouraging the use of private vehicles.
- Pollution control at the source such as the use of devices like electrostatic precipitators to control the emission of PM.
- Encourage major cities in the province to adopt landuse changes such as the relocation of industries that are higher emitters of air pollutants to reduce industrial emissions in cities and near human habitation.
- Beautification of urban centres may reduce the need for travel as well as filter the air in these cities, hence, improving air quality.
- Environmental audits of small-scale industries should be done to help maintain clean air in their surroundings.
- Environmental impact assessment (EIA) should be carried out from the planning stage and site selection for the industrial location to effectively reduce pollution load and effects on public health.
- Ultimately, the Strategic Environmental Assessment (SEA) that seeks to evaluate the environmental implications of a proposed policy, plan or programme should be taken firmly at the decision-making stages of industrial and economic development. SEA provides a means for looking at cumulative effects and appropriately addressing them at the earliest stage of decision-making alongside environmental, economic, cultural and social considerations.

Finally, though most of the gaseous pollutants are monitored in this study including CO and NO_2 which are precursors of O_3, the volatile organic compounds (VOCs) should also be monitored in future studies to understand their role in O_3 formation in Sichuan. Considering that regional pollution is embedded in China, attempts to reduce emissions may not be enough. Hence, future studies and policies should focus on inter-provincial pollution analysis for effective control measures.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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