Rev. Int. Contam. Ambie. 38 (Sustainable Architecture and Urban Environment) 13-22, 2022
https://doi.org/10.20937/RICA.54354

THE DIFFERENCE IN AIR POLLUTANTS IN TYPICAL NORTHERN AND SOUTHERN CHINA COASTAL CITIES-TAKING SHENZHEN AND QINGDAO AS EXAMPLES

Diferencia en los contaminantes atmosféricos de dos ciudades costeras típicas del sur y el norte de China. El caso de Zhenzen y Qingdao

Zike ZHAO[1], Chunliang CHEN[1], Lirong ZHAO[2]* and Bo YANG[3]

[1] Analysis and Test Center, Guangdong Ocean University, Zhanjiang city 524088, China.
[2] School of Chemistry and Environment, Guangdong Ocean University, Zhanjiang city 524088, China.
[3] Shenzhen Institute of Guangdong Ocean University, Shenzhen city 518114, China.

*Author for correspondence: zlrsms@163.com

(Received: March 2021; accepted: November 2021)

Key words: air pollutants, coastal cities, correlation analysis

ABSTRACT

In 2018, four air pollutants in Qingdao and Shenzhen were comprehensively analyzed and evaluated according to the standards. According to the results, $PM_{2.5}$ exceeded its standard by multiples of 1.11 and 1.03 in January and February, respectively, in Shenzhen, and the no-exceedance probability was 84.6%. However, the no-exceedance probability in Qingdao was only 50%. When the maximun index of ambient air quality was used to evaluate the above pollutants, the air pollutant in Shenzhen was NO_2 from May to September and $PM_{2.5}$ in other the months, but the pollutants in Qingdao were different each month. The distribution patterns of the monthly average mass concentration of the pollutants in Shenzhen and Qingdao were consistent with the seasonal distribution. The particulate matter in the air was still the focus of the government in Shenzhen. The sources of air pollutants in Qingdao were diverse, and most pollutants were related to energy combustion.

Palabras clave: contaminantes atmosféricos, ciudades costeras, análisis de correlación

RESUMEN

En 2018, cuatro contaminantes del aire en Qingdao y Shenzhen fueron analizados y evaluados exhaustivamente de acuerdo con las normas. Según los resultados, las $PM_{2.5}$ superaron su estándar por múltiplos de 1.11 y 1.03 en enero y febrero, respectivamente, en Shenzhen, y la probabilidad de no superación fue del 84.6 %. Sin embargo, la probabilidad de no superación en Qingdao fue de sólo el 50 %. Cuando se utilizó el índice máximo de calidad del aire ambiental para evaluar los contaminantes mencionados, el contaminante del aire en Shenzhen fue NO_2 de mayo a septiembre y las $PM_{2.5}$ en otros meses, pero los contaminantes en Qingdao fueron diferentes cada mes. Los patrones de distribución del promedio mensual de la concentración de masa de los contaminantes en Shenzhen y Qingdao fueron consistentes con la distribución estacional. Las partículas atmosféricas en el aire siguen siendo el foco del gobierno en Shenzhen. Las fuentes de contaminantes atmosféricos en Qingdao fueron diversas, y la mayoría de los contaminantes estaban relacionados con la combustión de energía.

INTRODUCTION

With the continuous development of China's social economy and the acceleration of industrialization, the wide range and high frequency of severe air pollution have gradually emerged in large and medium-sized cities. People have begun to realize the importance of air quality to health. Studies have shown that even a low level of air pollution may cause discomfort to some sensitive people (He et al. 2014). Serious air pollution could lead to disease, allergies and even death (Bert 2007). Air pollution affects not only quality of life and city views but also the investments, production, business environment and industrial development of cities.

Both Shenzhen and Qingdao are located along the coast of China (**Fig. 1**). With their unique geographical locations and climatic environments, these coastal cities have great advantages in terms of economic development, urban construction, and talent attraction, but they are also facing environmental problems. First, the rapid growth of the population has led to an increase in cars, coal-fired heating activity, domestic waste incineration, and emissions of sulfur dioxide, nitrogen dioxide and other pollutants in the air. Second, the number of urban construction activities increased, and the dust and fugitive dust generated during construction were discharged in unmanaged manner. Third, the rapid development of urban construction has led to an obvious urban heat island effect, and harmful substances have flowed rapidly with the air in the city. Because dust and sulfur dioxide discharged from industrial production are very easily adsorbed on water vapor, hindering sunlight, the air has become a "collection place" of pollutants. Affected by specific factors such as monsoons, ocean currents and air humidity, air pollution in coastal cities has complex causes, wide diffusion ranges and long durations (Zhang and Ren 2019).

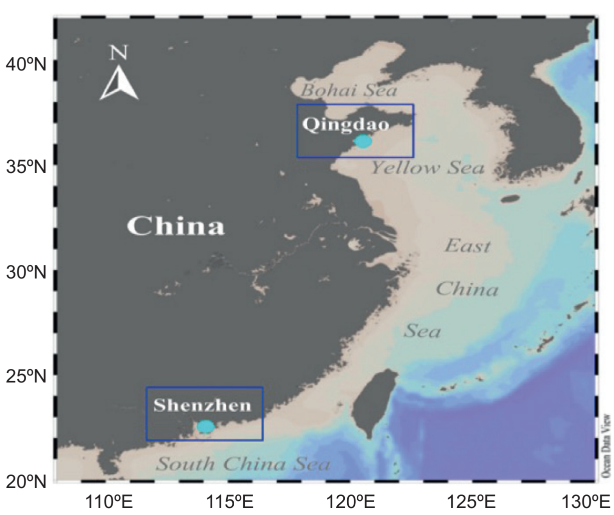

Fig. 1. Location of Shenzhen and Qingdao.

During the period of China's reform and opening-up, Shenzhen had a permanent resident population of 13.0266 million in 2018 and a GDP of 2422.198 billion RMB. It is one of the most active regions in China and even the world. The annual average temperature in Shenzhen was 23.4 ºC, and the average annual precipitation was 1957.2 mm. The sunshine hours were 1905.5 hours in the Shenzhen Statistical Yearbook of 2018. (2019). The eastern part of Shenzhen is mainly an ecological protection zone dominated by natural mountains, and the coastal area in the central and western parts is a coastal plain. The Pearl River Delta includes large international cities with tens of millions of people, such as Hong Kong, Guang zhou, Shen zhen and Dong guan. Due to the dual effects of atmospheric circulation and chemical reactions between various air pollutants, haze occurs more frequently in these areas. Qingdao is an important international port and tourist city in northern China, with a permanent resident population of 9.3948 million in 2018 and a GDP of 1200.152 billion RMB. Qingdao is the main node city of the economic corridor of the new Eurasian Continental Bridge and an important global city as the strategic fulcrum of maritime cooperation. The city's annual average temperature was 13.3 ºC, the average annual precipitation was 722.7 mm, and the number of sunshine hours was 2083 hours in the Qingdao Statistical Yearbook of 2018 (2019). Qingdao is in the south of Shandong Peninsula, bordering the Yellow Sea in the east and south. It is in the northern temperate monsoon region, with a temperate monsoon climate. The southeastern monsoon, ocean currents and water masses from the ocean surface are affected by the mountain barriers, and air pollutants in the undulating hills in the coastal and mountainous areas of Qingdao easily accumulate and are difficult to disperse (Li 2001).

In 2018, the proportion of primary, secondary and tertiary industries in Shenzhen was 0.1%, 41.1% and 58.8%, respectively, of which the gross industrial product was 996.195 billion RMB, including strategic emerging industries such as new generation information technology, the digital economy, high-end equipment manufacturing, green and low-carbon industries, the marine economy, new materials, and biological medicine, accounting for a total amount of 915.518 billion RMB. In 2018, Shenzhen had 3.36 million cars and consumed 8 705 861.69 tons of raw coal and 16 1243.00 tons of crude oil. The sea freight was 327.64 million tons, and the port throughput was 251.27 million tons (Shenzhen Statistical Yearbook of 2018). The proportion of Qingdao's primary, secondary and tertiary industries in 2018 was 3.2%, 40.4% and 56.4%, respectively, of which the gross industrial product was 1138.978 billion RMB. The main industrial products included appliances, rubber tires, flat glass, crude steel, and automobiles. The consumption of raw coal was 11 437 971.31 tons, the consumption of crude oil was 15 422 450.59 tons, the sea freight was 25.02 million tons, the throughput of the port was 542.5 million tons, and the number of cars was 2 690 558 (Qingdao Statistical Yearbook of 2018). The special marine geographical environment, continuous economic development and population growth of Qingdao and Shenzhen have led to increasingly serious air pollution problems. Since 2019, Qingdao has regarded Shenzhen as a benchmark for economic development (Jiang and Wang 2019). Due to the differences in geographical location and industrial layout, the level of economic development and environmental protection policies of Qingdao and Shenzhen have their own characteristics, which provide a model for studying the economic development and environmental protection of coastal cities in China. Based on the annual ambient air quality data for Shenzhen and Qingdao in 2018, this paper determined the differences in the air pollution between Shenzhen and Qingdao to provide a reference for environmental managers of various coastal cities.

DATA SOURCES AND EVALUATION METHODS

The general factors of ambient air quality assessed included sulfur dioxide (SO_2), nitrogen dioxide (NO_2), inhalable particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), carbon monoxide (CO) and ozone (O_3). This study only compared and analyzed SO_2, NO_2, PM_{10} and $PM_{2.5}$ between the two cities. Numerical decimal places, the degree the standard was exceeded, the monthly no-exceedance probability, and the comparison of ambient air quality and other methods were determined in accordance with the Technical Regulation for Ambient Air Quality Assessment (on trial) (TSAAQA) (HJ633-2013). In addition, the relevant formulas involved in this article from the TSAAQA (HJ 633-2013) are as follows:

Exceeded standard for pollutants formula:

$$B_i = (C_i - S_i)/S_i \tag{1}$$

B_i represents the exceeded multiple of the item i; C_i indicates the mass concentration of exceeded item i; S_i stands for the mass concentration limit standard of the exceeded item i, and the first-class and the second-class exceedance standards were adopted for the first-class and second-class areas, respectively.

Calculation method used to determine the monthly no-exceedance probability:

$$D_i\,(\%) = (A_i/B_i)\times 100 \tag{2}$$

D_i represents the no-exceedance probability of evaluation item i; A_i indicates the number of months that evaluation item i reached the standard within the evaluation period; B_i represents the effective monitoring months of the evaluation of item i in the evaluation period.

Single index formula:

$$I_i = C_{i,m}/S_{i,a} \tag{3}$$

$C_{i,m}$ represents the monthly average mass concentration (MAMC) of item i; $S_{i,a}$ indicates the secondary standard limit of the annual average mass concentration of pollutant i.

Maximum index of ambient air quality (MIAAQ) formula:

$$I_{max} = MAX(I_i) \tag{4}$$

Comprehensive index of ambient air quality (CIAAQ) formula:

$$I_{sum} = SUM(I_i) \tag{5}$$

where I_i represents a single index of item i.

According to the quality requirements of the ambient air function zone, Shenzhen and Qingdao belong to the second-class area, which is applicable to the secondary mass concentration limit. The basic limits of the secondary mass concentrations of the four pollutants were as follows: SO_2 annual average 60 μg/m^3, NO_2 annual average 40 μg/m^3, PM_{10} annual average 70 μg/m^3, and $PM_{2.5}$ annual average 35 μg/m^3.

Systematic cluster analysis is a quantitative method used to study the classification of multiple factors. Systematic cluster analysis can be divided into Q-type clusters and R-type clusters. Q-type clustering is the classification of samples (cases) in which cases

TABLE I. MAMC DISTRIBUTION OF THE MAIN AIR POLLUTANTS IN SHENZHEN AND QINGDAO IN 2018 UNIT (μg/m^3).

Month	Shenzhen	Qingdao	Shenzhen	Qingdao	Shenzhen	Qingdao	Shenzhen	Qingdao
	SO_2		NO_2		PM_{10}		$PM_{2.5}$	
January	8	19	37	50	61	118	39	66
February	8	15	27	32	54	76	36	40
March	7	11	30	32	47	86	28	45
April	8	11	28	30	53	94	29	34
May	7	7	26	27	31	62	18	28
June	7	6	25	16	29	48	17	23
July	7	5	23	12	26	37	13	16
August	7	6	29	14	33	41	20	14
September	8	7	30	29	36	49	24	18
October	9	7	29	37	54	63	32	23
November	7	10	31	52	51	91	31	47
December	7	16	31	42	50	99	29	54

with common characteristics are clustered to analyze different types of samples. R-type clustering is the clustering of variables, which are clustered based on common characteristics to analyze different types of variables. In this paper, different months in Shenzhen and Qingdao were used as the cases, and different air pollutants, such as SO_2, NO_2, PM_{10}, and $PM_{2.5}$, were used as the variables to carry out cluster analysis. Finally, the linear correlation between two pollutants can be measured by a simple linear correlation coefficient, which reflects the correlation between two pollutants.

RESULTS

Overview of major air pollutants in Shenzhen and Qingdao in 2018

To compare the MAMC of ambient air pollutants simply and intuitively in Shenzhen and Qingdao in 2018, a histogram of the MAMC was drawn according to **table I**, as shown in **figure 2**. It can be seen from **figure 2** that only the $PM_{2.5}$ in Shenzhen exceeded the standard in January and February, with it exceeding the standard by multiples of 1.11 and 1.03, respectively, and the no-exceedance probability for the monthly evaluation was 84.6%. Comparing the analysis results for the other pollutants, it could be seen that the SO_2 in June to October, NO_2 in June to September, and $PM_{2.5}$ in August to October in Shenzhen were higher than those in Qingdao, when economic activities in Shenzhen were frequent. Most of the mass concentrations of the four air pollutants in Qingdao were higher than those in Shenzhen. Compared with other pollutants, PM_{10} was much higher in Qingdao than in Shenzhen, and the highest level was 1.93 times that in Shenzhen in January. The air pollutants exceeding the standard in Qingdao in January were NO_2, PM_{10}, and $PM_{2.5}$, which exceeded

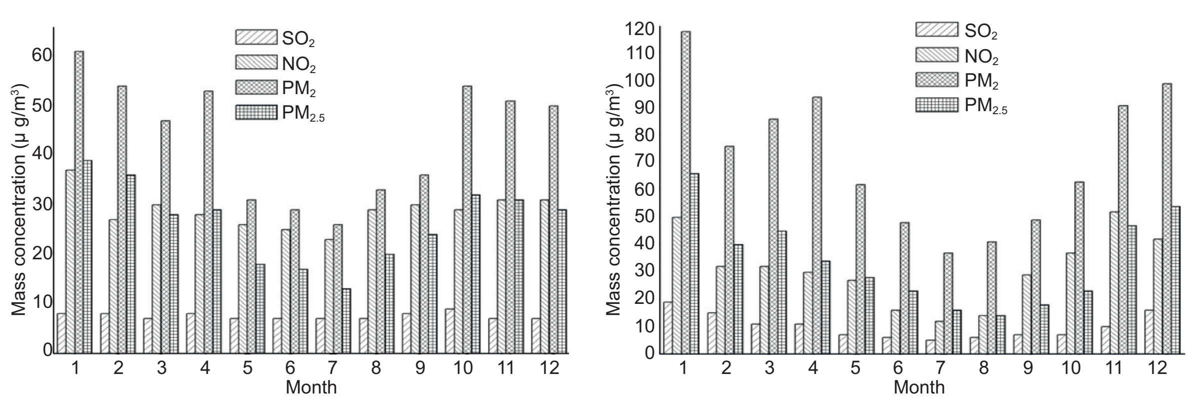

Fig. 2. MAMC distribution of the main air pollutants in Shenzhen (right) and Qingdao (left) in 2018.

the standard 1.25, 1.69, and 1.89 times, respectively. NO_2, PM_{10}, $PM_{2.5}$ exceeded their standards in November and December; NO_2 exceeded its standard by multiples of 1.3 and 1.05, respectively; PM_{10} exceeded its standard by multiples of 1.3 and 1.41; and $PM_{2.5}$ exceeded its standard by multiples of 1.34 and 1.54. When evaluating the monthly compliance probability in Qingdao, the compliance probabilities of NO_2, PM_{10}, and $PM_{2.5}$ were 75.0%, 50.0%, and 58.3%, respectively, and the MAMC of SO_2 over the whole year reached the standard. Among the pollutants, PM_{10} and $PM_{2.5}$ both exceeded their standards by the highest multiples in January.

Relevant air index evaluation of Shenzhen and Qingdao in 2018

Air pollution in Shenzhen tended to occur under conditions with no rain or weak rainfall, a weak north wind and relatively high humidity (Wang et al. 2018). **Figure 3** shows that the air quality evaluation results obtained by comparing the MIAAQ with the CIAAQ are similar. When the four pollutants were evaluated by the MIAAQ, the air pollutants present in Shenzhen were NO_2 from May to September and $PM_{2.5}$ in the other months. The target pollutants obtained by using the MIAAQ in Qingdao were different each month. Among the pollutants, $PM_{2.5}$ was present from January to March and from November to December, the main air pollutant from April to August was PM_{10}, and the main air pollutant from September to October was NO_2. When the four pollutants were evaluated by CIAAQ, the I_4 of Shenzhen was slightly greater than that of Qingdao in July, August, and September, and the I_4 value of the other months in Shenzhen was lower than that of the other months in Qingdao.

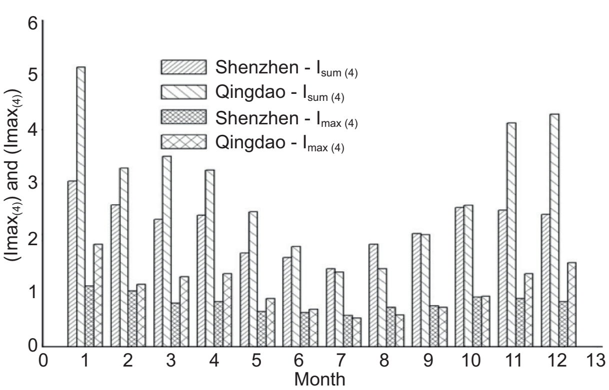

Fig. 3. Monthly distribution of the MAAQI and the CIAAQ in Shenzhen and Qingdao in 2018.

Analysis of air pollutants in Shenzhen and Qingdao by systematic cluster analysis

According to the 2018 Shenzhen Climate Bulletin, the average monthly temperature in Shenzhen ranged from 15.7 to 28.7 ºC, and the precipitation was less than 77.7 mm in February, March, April, October, November, and December and greater than 85.1 mm in other months (Climate Bulletin of Shenzhen in 2018). As shown in **Fig. 4**, May, June, July, August, and September were considered in one category. January was considered in one category, and February, March, April, October, November, and December were considered in another category. The MAMC distributions of the above pollutants was consistent with the temperature and precipitation distributions in Shenzhen. When studying the distribution of pollutant sources in Shenzhen and dividing them into three categories, the results were like those calculated by the MIAAQ, with SO_2 considered in one category, PM_{10} considered in one category, and NO_2 and $PM_{2.5}$ considered in one category. This result further verified that the emissions of motor vehicles in Shenzhen led to an increase in the concentrations of two pollutants, NO_2 and $PM_{2.5}$. **Figure 5** shows that when the MAMC of the pollutants in Qingdao was studied and divided into three categories, May, June, July, August, September, and October were considered in one category, and January was considered in one category. February, March, April, November, and December were considered in one category, which was similar to the results of Bi W (Bi et al. 2015), who found that moderately and highly haze-polluted weather in Qingdao occurred from December to January of the next year. When studying the distribution of pollutants in Qingdao and dividing them into three categories, SO_2 was considered in one category, PM_{10} was considered in one category, and NO_2 and $PM_{2.5}$ were considered in one category, which was similar to the calculation of the MIAAQ.

Correlation analysis between the air pollutant $PM_{2.5}$ and the other pollutants in Shenzhen and Qingdao

$PM_{2.5}$ is a particulate with a diameter less than 2.5 μm and includes oxides, minerals, bacteria, and other components that are mainly derived from dust generated on the ground and through building construction. Another source of $PM_{2.5}$ is the conversion of sulfur and nitrogen oxides produced by the combustion of fossil fuels such as petroleum and coal (Li et al. 2018). The main pollutants in Shenzhen were $PM_{2.5}$, O_3 and NO_2, and approximately 75% of the pollution was caused by the increase in $PM_{2.5}$ concentration

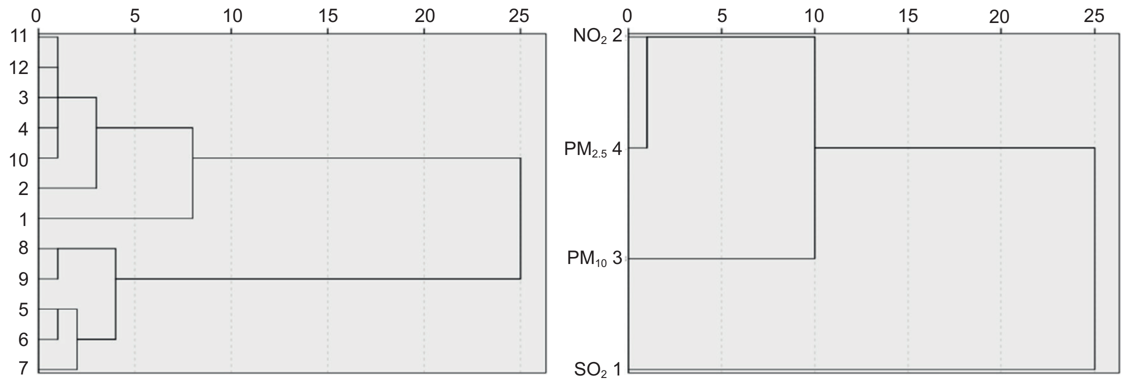

Fig. 4. Q-type cluster analysis and R-type cluster analysis of four air pollutants in Shenzhen.

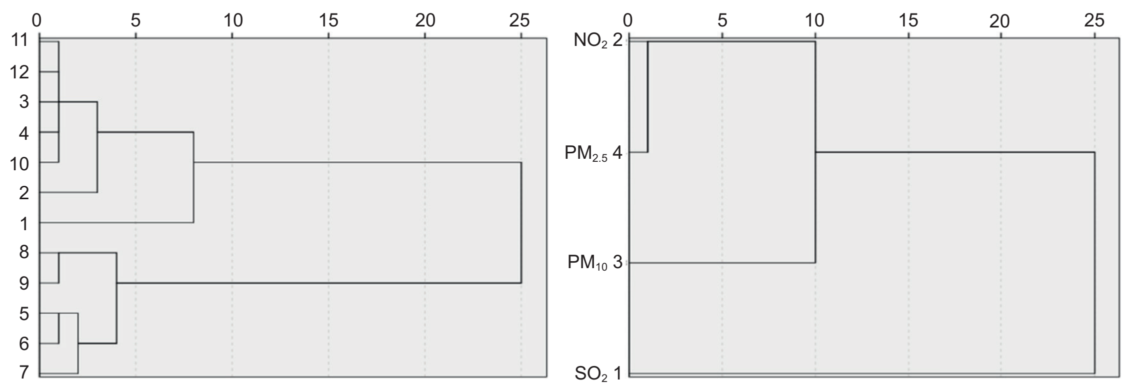

Fig. 5. Q-type cluster analysis and R-type cluster analysis of four air pollutants in Qingdao.

(Wang et al. 2018). To study the relationship between $PM_{2.5}$ and NO_2, PM_{10}, and SO_2 in the two cities, a scatter plot was drawn, as shown in **figure 6**, and correlation analysis, as shown in **tables II** and **III**, was used for further study. **Fig. 6** shows that only $PM_{2.5}$ and PM_{10} in the ambient air of Shenzhen had an approximately linear relationship. **Table I** shows that the ratio of MAMC between $PM_{2.5}$ and PM_{10}

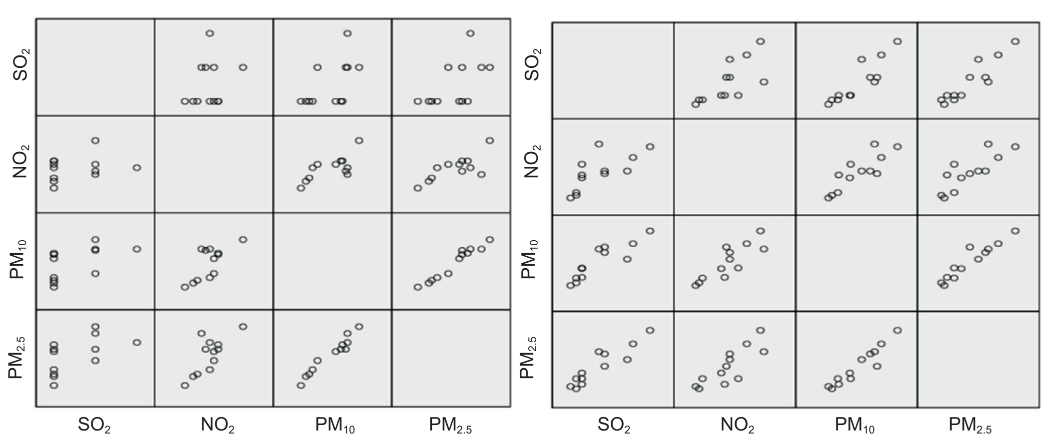

Fig. 6. Scatter plots of four air pollutants in Shenzhen (left) and Qingdao (right).

TABLE II. CORRELATION ANALYSIS RESULTS FOR FOUR AIR POLLUTANTS IN SHENZHEN.

		SO_2	NO_2	PM_{10}	$PM_{2.5}$
SO_2	Pearson correlation	1	.265	.559	.573
	Significance (two-tailed)		.405	.059	.052
NO_2	Pearson correlation	.265	1	.715**	.751**
	Significance (two-tailed)	.405		.009	.005
PM_{10}	Pearson correlation	.559	.715**	1	.974**
	Significance (two-tailed)	.059	.009		.000
$PM_{2.5}$	Pearson correlation	.573	.751**	.974**	1
	Significance (two-tailed)	.052	.005	.000	

** at a 0.01 level (two-tailed), the correlation is significant.

TABLE III. CORRELATION ANALYSIS RESULTS FOR FOUR AIR POLLUTANTS IN QINGDAO.

		SO_2	NO_2	PM_{10}	$PM_{2.5}$
SO_2	Pearson correlation	1	.715**	.889**	.920**
	Significance (two-tailed)		.009	.000	.000
NO_2	Pearson correlation	.715**	1	.851**	.827**
	Significance (two-tailed)	.009		.000	.001
PM_{10}	Pearson correlation	.889**	.851**	1	.951**
	Significance (two-tailed)	.000	.000		.000
$PM_{2.5}$	Pearson correlation	.920**	.827**	.951**	1
	Significance (two-tailed)	.000	.001	.000	

** at 0.01 level (two-tailed), the correlation is significant.

in Shenzhen in 2018 was more than 50%, and the maximum ratio was 66.7%. The four pollutants in Qingdao's ambient air all generally had a linear relationship.

DISCUSSION

SO_2 from June to October, NO_2 from June to September, and $PM_{2.5}$ from August to October in Shenzhen were higher than those in Qingdao. Li and CAO et al. (Li et al. 2008, Cao et al. 2012) found that the main air pollutant in winter (December to February in the second year) was $PM_{2.5}$ in Shenzhen. Meteorological conditions play an important role in the diffusion, dilution, transportation, and transformation of pollutants (Zhao et al. 2016); for example, strong winds and precipitation can remove air pollutants such as $PM_{2.5}$ (Wang et al. 2014, Kang et al. 2013). Because it was dry in autumn and cold in winter, the energy consumption in autumn and winter was relatively high, and the atmospheric diffusion condition was poor, which made it easy to accumulate pollutants. The area of Shenzhen area is much smaller than that of Qingdao, which may result in the concentrations of SO_2, NO_2, and $PM_{2.5}$ in some areas of Shenzhen to increase. Before 2018, Nanshan and Bao'an of Shenzhen were areas with high energy consumption, intensive industrial enterprises, and frequent economic activities. These two areas are adjacent to Guangzhou and Dongguan, and the air quality was greatly affected by the surrounding cities, where the emission sources were mainly local motor vehicle exhaust and the combustion of industrial sources, thermal power plants and biomass in the surrounding cities (Tan and Chen 2012).

Qingdao has a monsoon climate, with distinct seasons, a dry climate, a short sunshine duration, low temperatures, minimal precipitation, and a long heating period in winter. PM_{10} in Qingdao was much higher than that in Shenzhen because of the high amount of coal dust there, which was consistent with the conclusion obtained by Li et al. (2012). The mass concentrations of $PM_{2.5}$ and PM_{10} in Qingdao's atmosphere substantially exceeded the standard concentrations, and the values in the warm season were higher than those in the cool season. This result is consistent with the conclusion obtained by Wu Hong et al. (2013) that atmospheric particulate concentrations change significantly among seasons, with high concentrations in spring and winter and low concentrations in summer and autumn. Thus, Qingdao needs to pay attention to both urban dust and coal pollution.

The systematic cluster analysis results for the air pollutants in Shenzhen and Qingdao were similar to the calculation results of the MIAAQ, and the classification difference in their pollutants may be related to the distribution of the main production activities in each location. Although Shenzhen has good atmospheric diffusion conditions, Shenzhen's industrial and environmental protection policies are important factors in terms of changing Shenzhen's air quality. The service industry was also dominated by electricity in Shenzhen and supplemented by fuel oil, and residents' lives were mainly fueled by natural gas (Huang et al. 2009). When the four pollutants were evaluated by the MIAAQ, the air pollutant in Shenzhen was NO_2 from May to September and $PM_{2.5}$ in the other months. Therefore, Shenzhen should continue to promote motor vehicle emission reductions, including taking actions such as vehicle cancellation, vehicle transfer out, traffic restriction with "yellow label" vehicle restrictions that do not meet the emission requirements, and promotion of new energy vehicles and other methods, to achieve the pollutant emission reduction target to the greatest extent. In addition, the management of construction dust should be included when assessing urban construction. The environmental protection department should strictly address the behavior of ultrahigh and overloaded transportation of clay trucks and charge dust emissions from construction. On the other hand, Qingdao has experiences issues related to an unsustainable energy structure and industry distribution, coupled with its adverse geographical conditions and climate, resulting in severe nonpoint source pollution. PM_{10} is the pollutant that contributes the most to air pollution, followed by $PM_{2.5}$ and NO_2. Soot pollution and motor vehicle and ship exhaust pollution were the main sources of air pollutants in Qingdao. Shenzhen has been implementing its clean energy policy for a long time, and it formed a clean energy structure dominated by electricity and liquefied natural gas. Due to the specific geographical location and social development stage of Qingdao, this economic structure cannot be changed in the short term (Chen 2021).

Studies have shown (Yan et al. 2013) that reducing the emissions of nonpoint sources, ships and key industries could effectively reduce SO_2. Similarly, reducing the emissions of motor vehicles could effectively reduce NO_2, and reducing the emissions of road dust, building dust and motor vehicles could effectively reduce PM_{10}.

As seen in **Table II**, $PM_{2.5}$ in Shenzhen in 2018 most likely originated from the same source as PM_{10}, which was mainly produced from road dust sources, nonpoint sources and motor vehicle sources. The correlation analysis showed that the correlation coefficient between $PM_{2.5}$ and PM_{10} in Shenzhen was 0.974, and the correlation between SO_2 and the other three pollutants in Shenzhen was not significant. Thus, it was inferred that the PM_{10} and $PM_{2.5}$ in Shenzhen were not from the burning of fossil fuels such as oil and coal but from other sources such as dust from construction sites and road fly ash. Therefore, reducing the emissions of PM_{10} could also reduce $PM_{2.5}$ pollution. In addition, $PM_{2.5}$ in Shenzhen has not been ruled out as being derived from long-distance transmission from surrounding cities. The correlation coefficient between $PM_{2.5}$ and NO_2 in Shenzhen was 0.751, and the correlation coefficient between PM_{10} and NO_2 was 0.715. There was a significant correlation between NO_2 and PM_{10} and $PM_{2.5}$, which was consistent with the increase in NO_2 concentration in Shenzhen caused by the combustion of motor vehicles, as previously mentioned. Therefore, the air pollution was caused by dust from construction sites, road fly ash, and motor vehicle exhaust, as noted drawn by Lin et al. (2017), and was still the focus of the government in Shenzhen. At the same time, the four pollutants in Qingdao's ambient air generally occurred in a linear relationship, which showed that the sources of air pollutants in Qingdao were diverse, and the situation was more complex than that in Shenzhen. This difference was mainly due to the different climates, geographical environments, and regional distributions of economic activities between Qingdao and Shenzhen. The concentration of particulate matter in Qingdao varied significantly with season and was higher in spring and winter and lower in summer and autumn. Similarly, it can be seen from **Table III** that the various air pollutants in

Qingdao had obvious correlations, and the correlation between SO_2 and the other three pollutants was in the order of $PM_{2.5}$> PM_{10}> NO_2, showing that the sources of environmental air pollutants in Qingdao may be diverse and mainly related to energy combustion.

CONCLUSION

In 2018, $PM_{2.5}$ exceeded the standard only in January and February in Shenzhen, and the mass concentrations of the four air pollutants in Qingdao were mostly higher than those in Shenzhen, where PM_{10} was much higher than that in Shenzhen. The two cities should place great importance on the comprehensive treatment of dust and reducing motor vehicle exhaust and urban dust are still the major goals in the two cities in the future. Qingdao should increase investment in the desulfurization project for coal-fired power plants and the "oil to gas" for oil-fired power plants, shutting down small thermal power units.

The pollutants determined using MIAAQ in Qingdao were different in each month. Based on the above results, it was concluded that the sources of various air pollutants in Qingdao were diverse and that the air pollution in Qingdao showed obvious seasonal characteristics. However, the economic development level and climate conditions in Qingdao are not conducive to effectively improving Qingdao's air pollution status in a short time. Qingdao should formulate a set of environmental development policies that are applicable to Qingdao and the current industrial development status to gradually improve air quality.

At the same time, Qingdao should also gradually pay attention to special air pollutants, such as volatile organic compounds (VOCs).

As Shenzhen completed industrial transformation, the air quality generally became stable and improved. Shenzhen experienced NO_2 from May to September and $PM_{2.5}$ in other months when the four pollutants were evaluated by the MIAAQ. In the future, Shenzhen should cooperate with Dongguan, Hong Kong, Macao, and other cities to explore the impact mechanism of mixed air pollutants on the respiratory tract to provide a theoretical basis for preventing damage from pollutants to human health. The above urban agglomerations should develop solar energy, nuclear energy, wind energy and biomass energy at a large scale to reduce composite air pollutants and pay attention to emerging pollutants such as VOCs. Shenzhen's achievements in air pollution prevention and governance show that economic development and clean air can achieve a win–win situation.

REFERENCES

Bert B. (2007). Health effects of air pollution observed in cohort studies in Europe. Journal of Exposure Science & Environmental Epidemiology 17 (2), 61-65. https://doi.org/10.1038/sj.jes.7500628

Bi W., Wan F.J., Lu X., Zhang K.J., Sun M., Gao S. (2015). Analysis on the weather characteristics of haze pollution in Qingdao area. Journal of Ocean University of China (Natural Science Edition), 045 (005), 11-18. https://doi.org/10.16441/j.cnki.hdxb.20140292

Cao J.J., Shen Z.X., Chow J.C., Watson J.G., Lee S.C., Tie X.X., Ho K.F., Wang G.H. and Han Y.M. (2012). Winter and summer $PM_{2.5}$ chemical compositions in fourteen Chinese cities. Journal of the Air & Waste Management Association 62 (10), 1214-1226. https://doi.org/10.1080/10962247.2012.701193

Chen S.Q. (2021). Analysis on the implementation of the pilot policy of paid use and trading of coal rights based on environmental protection - a case study of Qingdao. Modern Salt and Chemical Industry 48 (2), 124-125. https://doi.org/:10.3969/j.issn.1005-880X.2021.02.057

He B.J., Li Y. and Ye M. (2014). Strategies for creating good wind environment around Chinese residences. Sustainable Cities & Society 10, 174-183. https://dx.doi.org/10.1016/j.scs

Huang X.Y., Li J., Wan Z.H. and Song L.H. (2009). Air quality assessment for Shenzhen city based on pollution harm index method. Environment and Ecology in the Three Gorges 2 (4), 41-45. http://10.3969/j.issn.1674-2842.2009. 04.013

Jiang W. J. and Wang Q. X. (2019). Build one belt, one road international cooperation platform: Interview with Wang Qingxian, member of Shandong Provincial Committee and Qingdao Municipal Committee. China Finance (16), 9-12.

Kang H., Zhu B., Su J., Wang H.L., Zhang Q.C. and Wang F. (2013). Analysis of a long-lasting haze episode in Nanjing, China. Atmospheric Research 120/121, 78-87. https:// 10.1016/j.atmosres.2012.08.004

Lin C.X., Chen J.Y., Li H.X., Xu W.J., You Y, Xu J. Z. and Li S.P. (2017). Study on $PM_{2.5}$ concentration characteristics and statistical forecast in Shenzhen. Environmental Engineering 35 (5), 87-92. https://10.13205/j.hjgc.201705019

Li J., Zhuang G.S., Huang K., Lin Y.F., Wang Q.Z., Guo Y.H. and Guo J.H. (2008). The chemistry of heavy haze over Urumqi central Asia. Journal of Atmospheric Chemistry 61, 57-72. https://10.1007/s10874-009-9124-7

Li R.Q. (2001). Plain discussion on pollution prevention and treatment of ambient SO_2 of Qingdao Proper. Jiangsu Environmental Science and Technology 14 (2), 28-29. https://10.3969/j.issn.1674-4829.2001.02.013

Li X.Z., Sheng L.F., Xu H. and Qu W.J. (2012). Study on the elemental composition and source of atmospheric $PM_{2.5}$ in Qingdao. Environmental Science 32(5), 1438-1445. https://10.13227/j.hjkx.2012.05.015

Li Y, Chiu Y.H. and Lu L.C. (2018). Energy and AQI performance of 31 cities in China. Energy Policy 122, 194-202. https://10.1016/j.enpol.2018.07.037

SZMB (2019). Climate Bulletin of Shenzhen in 2018. Meteorological Bureau of Shenzhen. Bulletin. Shenzhen, China, 27pp.

PRC MEP (2013). Technical regulation for ambient air quality assessment (on trial). Ministry of Environmental Protection of the People's Republic of China. Laws. Beijing, China, 14 pp.

QDSB (2019). Qingdao Statistical Yearbook of 2018. Statistics Bureau of Qingdao Municipality. Manual. Qingdao, China, 424 pp.

SZSB (2019). Shenzhen Statistical Yearbook of 2018. Statistics Bureau of Shenzhen Municipality. Manual. Shenzhen, China, 443 pp.

Tan D.S. and Chen J.M. (2012). Analysis of air quality and diffusive conditions of contaminants in Shenzhen from 2004 to 2009. Journal of Nanchang University (Natural Science), 36 (3), 301-306. https://10.3969/j.issn.1006-0464.2012.03.020

Wang M.J., He J.J., Wang S.X. and Zhang L. (2018). Analysis of air pollution characteristics and typical circulation situation in Shenzhen based on AQI. Journal of Ecological Environment 27(2), 268-275. https://10.16258/j.cnki.1674-5906.2018.02.010

Wang X., Chen J., Sun J.F., Li W.J., Yang L.X., Wen L., Wang W.X., Wang X.M., Jeffrey L., Collett J., Shi Y., Zhang Q.Z., Hu J.T., Yao L., Zhu Y.H., Sui X., Sun X.M. and Mellouki A. (2014). Severe haze episodes and seriously polluted fog water in Ji'nan, China. Science of the Total Environment 493, 133-137. https://10.1016/j.scitotenv.2014.05.135

Wu H., Zhang C.Y., Wang J., Yi Z.F., Chu C.J., Feng Y.C. and Xu H. (2013). Comparison of pollution characteristics and sources of PM_{10} and $PM_{2.5}$ in Qingdao ambient air. Environmental Science Research 26(6), 583-589. https://10.13198/j.res.2013.06.4.wuh.011

Yan M., Li H.C., Liang Y.X., Yu B. D. and Liu B.Z. (2013). The impact of pollution emissions from local and surrounding areas on summer air quality in Shenzhen. Environmental Science Guide 32(2), 88-91. https://10.3969/j.issn.1673-9655.2013.02.023

Zhang X. and Ren N.W. (2019). Preliminary study on the prevention and control of air pollution in coastal cities of China in the New Era. Journal of Heilongjiang Vocational Institute of Ecological Engineering 32 (3), 9-10. https://10.3969/j.issn.1674-6341.2019.03.003

Zhao H., Zheng Y.F., Xu J.X. and Sun J. (2016). Analysis on the characteristics of temporal and spatial variation of atmospheric pollutant concentration in typical cities in China. Earth and Environment 44 (5), 549-556. https://10.14050/j.cnki.1672-9250.2016.05.010