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

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ABSTRACT

In 2018, four air pollutants in Qingdao and Shenzhen were comprehensively analyzed and evaluated according to the standards. According to the results, PM\textsubscript{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 maximum index of ambient air quality was used to evaluate the above pollutants, the air pollutant in Shenzhen was NO\textsubscript{2} from May to September and PM\textsubscript{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\textsubscript{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 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\textsubscript{2} de mayo a septiembre y las PM\textsubscript{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).

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, Guangzhou, Shenzhen and Dongguan. 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 (SO₂), nitrogen dioxide (NO₂), inhalable particulate matter (PM₁₀), fine particulate matter (PM₂.₅), carbon monoxide (CO) and ozone (O₃). This study only compared and analyzed SO₂, NO₂, PM₁₀ and PM₂.₅ 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:

\[ B_i = \frac{(C_i - S_i)}{S_i} \] (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:

\[ D_i(\%) = \left(\frac{A_i}{B_i}\right) \times 100 \] (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:

\[ I_i = \frac{C_{i, m}}{S_{i, a}} \] (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:

\[ I_{\text{max}} = \max(I_i) \] (4)

Comprehensive index of ambient air quality (CIAAQ) formula:

\[ I_{\text{sum}} = \sum(I_i) \] (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: SO₂ annual average 60 μg/m³, NO₂ annual average 40 μg/m³, PM₁₀ annual average 70 μg/m³, and PM₂.₅ annual average 35 μg/m³.

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
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\textsubscript{2}, NO\textsubscript{2}, PM\textsubscript{10}, and PM\textsubscript{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\textsubscript{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\textsubscript{2} in June to October, NO\textsubscript{2} in June to September, and PM\textsubscript{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\textsubscript{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\textsubscript{2}, PM\textsubscript{10}, and PM\textsubscript{2.5}, which exceeded.
the standard 1.25, 1.69, and 1.89 times, respectively. NO₂, PM₁₀, PM₂.₅ exceeded their standards in November and December; NO₂ exceeded its standard by multiples of 1.3 and 1.05, respectively; PM₁₀ exceeded its standard by multiples of 1.3 and 1.41; and PM₂.₅ exceeded its standard by multiples of 1.34 and 1.54. When evaluating the monthly compliance probability in Qingdao, the compliance probabilities of NO₂, PM₁₀, and PM₂.₅ were 75.0%, 50.0%, and 58.3%, respectively, and the MAMC of SO₂ over the whole year reached the standard. Among the pollutants, PM₁₀ and PM₂.₅ both exceeded their standards by the highest multiples in January.

**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 °C, 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 were 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 SO₂ considered in one category, PM₁₀ considered in one category, and NO₂ and PM₂.₅ 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, NO₂ and PM₂.₅. 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, SO₂ was considered in one category, PM₁₀ was considered in one category, and NO₂ and PM₂.₅ were considered in one category, which was similar to the calculation of the MIAAQ.

**Correlation analysis between the air pollutant PM₂.₅ and the other pollutants in Shenzhen and Qingdao**

PM₂.₅ 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 PM₂.₅ 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 PM₂.₅, O₃ and NO₂, and approximately 75% of the pollution was caused by the increase in PM₂.₅ concentration...
(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$_{10}$
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\textsubscript{2} and the other three pollutants was in the order of PM\textsubscript{2.5} > PM\textsubscript{10} > NO\textsubscript{2}, showing that the sources of environmental air pollutants in Qingdao may be diverse and mainly related to energy combustion.

**CONCLUSION**

In 2018, PM\textsubscript{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\textsubscript{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\textsubscript{2} from May to September and PM\textsubscript{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 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**


