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## ► To cite this version:

Ling Sun, Jingyi Zhang, César Ducruet, Hidekazu Itoh, Xiangqi Liu. The impact of shipping activities on air quality and residents' health in China's port cities. *Journal of Transport Geography*, 2024, 123, pp.104099. 10.1016/j.jtrangeo.2024.104099 . halshs-04838170

**HAL Id: halshs-04838170**

**<https://shs.hal.science/halshs-04838170v1>**

Submitted on 14 Dec 2024

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# The impact of shipping activities on air quality and residents' health in China's port cities

*Pre-final version of the article published in Journal of Transport Geography (2024), 123: 104099*

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**Abstract.** Shipping activities emit pollutants such as NOX, SOX, and PM, which are detrimental to air quality and to the health of local residents. As one of the major shipping nations, China's population and port-related industries concentrate in coastal areas. However, an interesting phenomenon is that the average life expectancy of coastal port cities in China has not significantly decreased in the past few decades, but has instead shown an upward trend, and often higher than that of non-port cities. To explain this, this paper uses panel data from 36 port cities in China from 2001 to 2019. The relationship between shipping activities, air quality, and average life expectancy is investigated through a nonlinear mediation effect model, which is used to study the impact of shipping on health, as well as the mediating role of air quality. Main results underline that except for average turnaround time, other indicators representing shipping intensity are positively correlated with air quality index and average life expectancy, indicating that the economic benefits of ports are closely related to their operational efficiency. Shipping activities have a significant negative impact on the health level of port cities. This impact is influenced by the mediating variable of air quality and has a partial mediating effect. However, the impact of air quality on health presents a complex nonlinear relationship, with an inverted N-shaped curve, and the two inflection points are about 68 and 120 respectively. Our research provides guidance for the sustainable development of port cities, in order to achieve the balance between shipping activities and environment and health.

**Keywords:** Shipping activity; Air pollution; Public health; Port city; China

## Acknowledgements

The research leading to these results has received funding from the French National Research Agency (ANR) project No. [ANR-22-CE22-0002] "MAGNETICS". This work was also supported by the Soft Science Research Program of Shanghai (No.24692107200).

## 1 Introduction

Maritime transportation is an efficient and low-cost way to transport bulk commodities and raw materials (Liu et al., 2019), and more than 80% of global trade volumes are carried by sea (UNCTAD, 2022). Owing to globalization and trade growth, the total volume of shipping transportation has witnessed a steady increase, from 3.7 billion tons in 1980 to 12 billion tons in 2021 (UNCTAD, 2022). Shipping activities include maritime navigation, port handling operations, and ship turnover (Jahangiri et al., 2018), linked with other segments of the value chain (Robinson, 2002). However, while such activities significantly contribute to social and economic development worldwide (Verschuur et al., 2022), they also cause significant releases of air pollutants. Pollutants generated by the combustion of fuel in shipping activities contain harmful substances such as NO<sub>x</sub>, SO<sub>x</sub>, and PM, which seriously harm air quality near ports and other transport infrastructures (Colville et al., 2001; Kopela, 2017). According to the literature, nearly 70% of the ships' exhaust emissions occur within 400 km from the coastline (Corbett et al., 2007). Multiple case studies have already shown that ship and port emissions have among the principal pollution sources in local areas (Garbatov & Georgiev, 2022; Zhao et al., 2013; Zhao et al., 2022). Long-term severe air pollution not only poses a threat to the natural environment, it also has a negative impact on the physical and mental health of the local population – residents and workers (Chen et al., 2019; Sofiev et al., 2018). In addition, due to the dense population in most coastal areas, the impact of port activity emissions on public health is much higher than that of emissions from sea transportation processes (Mueller et al., 2023).

As the world's largest product exporter and importer, China is one of the shipping countries with the largest cargo throughput and the largest port scale globally (Chen et al., 2019). In 2022, total port throughput reached 15.68 billion tons, and port container throughput reached 296 million Twenty-Foot Equivalent Units (TEUs), ranking first in the world in both indicators (MOT, 2023). Among the top ten world ports in terms of total throughput and container throughput, the ports in China occupy 8 and 7 positions respectively. At the same time, China has a large and unevenly distributed population, with densely populated coastal regions (Guo & Zhang, 2019). In 2021, over 430 million residents were living in coastal port cities in China, including megacities such as Shanghai, Shenzhen, Tianjin, and Guangzhou, each with a population exceeding tens of millions of inhabitants (NBS, 2021). This exposes China to more severe air pollution and health risks associated with maritime activities than other maritime countries.

However, while air pollution caused by shipping activities has been widely discussed, Chinese coastal port cities exhibit a higher-than-average life expectancy (Wu et al., 2020). This has sparked extensive attention and a series of debates emerged in academia and society (Crippa et al., 2019; Lindgren, 2021). Scholars underlined possible causes of such a phenomenon, such as economic development, resource allocation, climate, lifestyle, diet, and social factors. Therefore, it is necessary to conduct in-depth research on the impact of port city development and shipping industry on the environment and public health. What is the correlation between different types of shipping activities and air quality and health in port cities? Does the development of shipping in port cities have a positive or negative impact on residents' health? What mechanism is it achieved through? These are important questions that not only involve issues of environmental protection and sustainable development, but also directly relate to the living environment and life quality of residents in port cities.

Therefore, this study conducts an empirical analysis based on panel data on 36 port cities in

China from 2001 to 2019. Following the relevant theories of panel models, we used nonlinear mediation effect tests to verify the impact of shipping activities on residents' health levels as well as the mediating role of air quality, and determine the two inflection points of the impact of air quality on residents' health. This study addresses the impacts of different shipping activities on the economy, environment and health, and how port cities should develop the shipping industry at different stages. It provides strong evidence and scientific suggestions for decision-makers and city planners, promoting the balance between shipping activities, ecological environment and public health, thereby contributing to the sustainable development of port cities.

The remaining sections are organized as follows: Section 2 conducts a review of previous literature research, Section 3 presents the data and methods, Section 4 reports and discusses the results, and Section 5 provides the main conclusions and policy implications.

## **2 Literature Review:**

### **2.1 The impact of shipping activities on environment**

#### **2.1.1 Pollution caused by shipping activities**

Shipping activities are known to affect the environment in several ways. Shipping pollutes marine waters through the discharge of pollutants from domestic sewage (Chen et al., 2022; Ytreberg et al., 2020), bilge water (Tiselius & Magnusson, 2017), and scrubber water (Koski et al., 2017), resulting in the eutrophication and acidification of water bodies. In addition, the toxicization of water bodies caused by oil/chemical leakage and the spread of invasive species from hulls or ballast water are also harmful to marine ecosystems (Aydin et al., 2021; Havel et al., 2015). Another major impact of shipping on the environment is noise. During loading and unloading operations, as well as ship repair or dismantling, high airborne noise levels may be radiated (Fredianelli et al., 2022), to such an extent that Badino et al. (2016) considered shipping as a significant contributor to the "soundscape" of port cities.. However, compared to the types of pollution mentioned above, air pollution caused by shipping activities is currently the most mature monitoring and research field, and this article will also mainly focus on it.

Air emissions of shipping may be categorized amongst emissions causing air pollution and emissions contributing to climate change. The first category includes emissions of SO<sub>x</sub>, NO<sub>x</sub>, PM, CO and VOC, and the second includes CO<sub>2</sub>, HCFC, and CH<sub>4</sub> (Chatzinikolaou et al., 2015). The focus of this study is on the former. According to Ramacher et al. (2019), the annual NO<sub>x</sub> emitted by ships can reach 5-10% of total global emissions, and some regions like Denmark and Norway can even reach 30-40%. Shipping emissions of SO<sub>x</sub> account for about 4-9% of global total emissions (Jonson et al., 2019). Some studies also estimated the contributions of ship emissions to particulate matter (PM) concentration through the application of source apportionment methods, with an average of 5-15 %, and in some specific harbor areas in Asia, ships can contribute up to 26 % (Chen et al., 2019; Y. Zhang et al., 2022). Chen et al. (2019) showed that air pollution levels from shipping sources are expected to increase in the future due to global trade growth, maritime transport, and ship traffic demand.

#### **2.1.2 Impact of shipping activities on coastal air quality**

Both global- and regional-scale calculations show that for PM<sub>2.5</sub> and depositions of oxidized nitrogen and sulfur, the effects of ship emissions are much larger when emissions occur close to the shore rather than at open seas (Jonson et al., 2020). In port areas, ships sailing offshore and ships

parked at berth will cause a large amount of air pollution (Jahangiri et al., 2018). Fameli et al. (2020) showed that most of the ship emissions in the ports occur during berthing, while maneuvering itself only lasts 15-20 minutes. Most studies on the contribution of port emissions to air pollution have been based on measurements or simulations. Some studies consisted in on-site measurements near ports to determine the contribution of ship traffic emissions (Mamoudou et al., 2018; Shen et al., 2022), while other studies have simulated the diffusion of air pollutants based on ship emission inventories (Gan et al., 2023; Toscano et al., 2021; Yang et al., 2021). However, existing research mostly focuses on ports rather than cities, and the impact of shipping activities on air quality at the city level is fiercely lacking, as less than ten peer-reviewed articles dealt with residents' health in port cities in the last two decades. Instead, a recent study across the OECD area showed that port regions emit more greenhouse gases (GHG) than non-port regions (Ducruet et al., 2024). This study also underlined the existence of two main types of port regions. Metropolitan port regions concentrate GHG emissions, PM<sub>2.5</sub>, population, GDP per capita, and container traffic, while industrial port regions carry more solid and liquid bulk traffic and have higher-than average mortality rates.

It is also worth noting that the emissions from non-ship factors, such as port operating machinery on terminals and transportation vehicles to/from the hinterland, are considered important, but seem to have been relatively ignored (Mueller et al., 2023; Rowangould et al., 2018). Only a few studies have evaluated the pollution caused by other factors such as cargo loading machinery, heavy vehicles, and trains at ports (Merico et al., 2019; Sorte et al., 2021; Kara et al., 2021). In addition, various port industries also have an impact on air quality, such as shipbuilding and maintenance, heavy industry, energy production and so on (Lecue & Darbra, 2019; Yuan et al., 2022).

## **2.2 The impact of shipping activities on health**

Although many studies have focused on the impact of shipping activities on the environment in recent years, few have studied the resulting health impacts. Lloret et al. (2021) pointed out in their study that from the health perspective, affected people include crew, residents living near ports, those in the pathways of long-range air and marine global pollution, and workers in shipyards. Discharge of wastewater from ships may contribute to the introduction of pathogens to non-endemic areas, which consequently increases the number of waterborne diseases, compromising human health (Chen et al., 2022; Endres et al., 2018). The studies of Murphy and King (2014) and Fredianelli et al. (2022) shows that environmental noise have the potential to be significant public health concerns, triggering mental stress and mental illness. Ship collisions and explosions of dangerous cargoes can also pose a serious threat to the safety and health of port workers (Hua et al., 2021; Khan et al. 2023). Finally, the threat of air pollution from shipping to the health of residents in port cities remains the most widely studied area. The transportation, loading and unloading of goods, navigation and berthing of ships, as well as ship maintenance and dismantling activities, which emit a large amount of air pollutants and toxic substances, posing a significant threat to the respiratory and cardiovascular systems of coastal residents (Zhang et al., 2021; Barregard et al., 2019; Chen et al., 2019; Lloret et al., 2021). Ducruet et al. (2024) reviewed the handful of papers dealing explicitly with the health impacts of ports, such as the higher mortality from all cancers and neurological diseases near the port in Civitavecchia (Bauleo et al., 2019), the increasing unplanned hospital admissions for people living under winds carrying PM<sub>10</sub> and NO<sub>2</sub> from the port and industrial areas in Brindisi (Gianicolo et al., 2013), and the higher number of hospital, heart-related,

and psychiatric visits for Black people than for white people when living near ports in U.S. counties (Gillingham and Huang, 2021).

International shipping emissions were responsible for 16%, or about 60,000, of global transportation-related premature deaths from 2010 to 2015 (Anenberg et al., 2019). Lin et al. (2018) used a time series Poisson model to quantify the association of cardiovascular mortality with shipping pollution emission indices in Guangzhou, China, and identified it as an important risk factor. Tang et al. (2020) studied the impact of shipping emissions on human health in the Gothenburg area, and estimated a mean loss of the life expectancy of 0.015 years/person associated with shipping related PM<sub>2.5</sub> exposure and 2.6 premature deaths/year associated with shipping-related NO<sub>2</sub> exposure. More recently, Mueller et al. (2023) conducted a review of relevant literature on the Health Impact Assessment (HIA) of global shipping/port air pollution, which provided us with an understanding of how to assess the associated health burden so far, as well as the possible implications for policy and research. These studies suggest that shipping emission is an important detrimental factor of illness and mortality, and should be emphasized in air pollution control and management in order to protect public health. Without effective emission control measures, as shipping demand increases, ship emissions will continue to increase, leading to more health problems (Chen et al., 2019).

### **2.3 Summary**

Ship emissions have a significant impact on the environment and health, and will continue to do so in the future. Although scholars have explored the impact of shipping activities on the environment, especially on air quality, from multiple perspectives, there are few studies on the health effects, which often remain only implicit. The principal focus of current research is on ports rather than cities, although it would better involve sustainable development. Ports have gradually shifted away from cities due to port growth, urban growth, and environmental issues (Hoyle, 1989), but many of them still remain “urban”, so that air pollution in their vicinity tends to cause greater health losses. Moreover, many studies have focused on the impact of shipping activities on local air quality, typically based on different methods, including experimental observations, numerical modeling, and emission inventory analysis, and systematic analyses from econometric or statistical perspective remain relatively scarce. The current analysis of 36 port cities in China, from a statistical perspective, is thus relatively new, and can potentially contribute to the literature on ports, shipping, environment, and health.

## **3 Data and methodology**

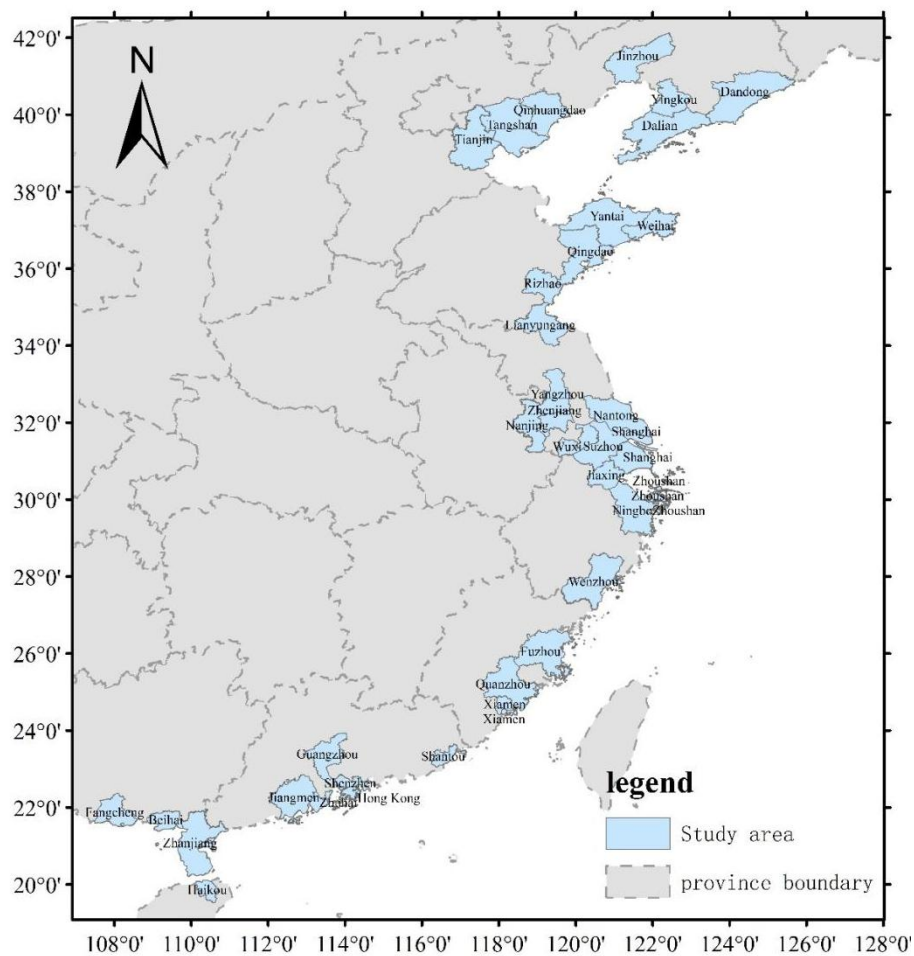
### **3.1 Study area**

China has over 50 coastal port cities, which corresponds to five main port clusters, from north to south, namely the Bohai Rim, the Yangtze River Delta, the Southeast, the Pearl River, and the Southwest. Due to the availability of data and the representativeness of samples, we selected 36 port cities from different port clusters in China as the research sample (Figure 1). In 2019, the total throughput of these port cities accounted for over 95% of the total throughput of Chinese ports. The specific criteria for selecting samples include: 1. Data availability. Ensure the openness and completeness of environmental, economic, and policy data in these cities. 2. Regional representativeness. The samples cover five major port clusters, with a balanced number of port cities belonging to each cluster to reflect regional differences. 3. Functional diversity. The samples cover

different port types such as commercial ports, industrial ports, transit ports and so on. 4. The scale of shipping activities. Selected cities have different levels of shipping development and economic scale to make the results more representative.

As a port city may contain multiple port areas, we matched the geographical location of port areas with the jurisdiction scope of the port cities, in order to merge the ports at the city level. For example, in addition to Shenzhen port area, Shekou, Yantian and Chiwan port areas also belong to the port city of Shenzhen (see Wang, 2016 for a recent overview of port-city dynamics in China).

It should be noted that as a special administrative region of China, Hong Kong enjoys a higher degree of autonomy, which sets it apart from other China's port cities in terms of health and environment. As an international financial, trade, and shipping hub, Hong Kong is one of the most densely populated cities in the world, and high population density and international exchanges lead to some special challenges, such as limited land resources, public health management, and disease transmission risks. Despite all this, the government allocated significant resources to environmental protection, resulting in lower levels of environmental pollution and better air quality. Secondly, Hong Kong boasts a well-developed healthcare system that covers the entire population, making its average life expectancy among the highest in the world, far higher than the average of other Chinese port cities.



**Fig. 1.** Geographic distribution of selected Chinese port cities

### **3.2 Variable selection and data processing**

#### **3.2.1 Independent variables: Shipping activities**

Appropriate variables need to be selected to represent the intensity of shipping activities onshore and offshore at port cities, in order to gain a more comprehensive understanding and evaluation of their potential impacts on air quality and residents' health. In this paper, taking into account the actual needs of port operations as well as the availability of existing research and data, we selected the following five indicators to represent different aspects of shipping activities in the port:

(1) Number of vessel calls: It refers to the number of times a vessel stops at a berth and loads and unloads goods. A higher number of calls means that more ships choose this port as the loading and unloading point for goods. So it indicates the level of attractiveness and busyness of the port, which to some extent represents the importance of the port's geographical location in the maritime transportation network (Ducruet et al., 2020; Nguyen et al., 2022).

(2) Weighted average turnaround time: It refers to the turnaround time a vessel spends at a port divided by its tonnage, which is crucial for evaluating the operational efficiency and congestion situation of ports. For ships of the same size, a shorter turnaround time usually means higher efficiency and better resource utilization, while a longer turnaround time may indicate potential problems such as slow loading and unloading of goods, port equipment failures, or port processes that are not smooth enough (Ducruet & Itoh, 2022).

(3) Maximum deadweight tonnage: It refers to the maximum ship load capacity that a port can accept, which can reflect the port's facilities and carrying capacity. A larger maximum deadweight tonnage means that the port can accommodate larger ships, which is of great significance for handling large amounts of cargo, but it may lead to higher pollution emissions and traffic congestion (Chang, 2016).

(4) Ship traffic volume: It corresponds to the product between ship capacity (gross registered tons) and number of calls on a yearly basis of each port city. In various shipping activities, the pollution at offshore section mainly comes from the discharge of ships, so it represents the overall scale and attractiveness of port city shipping activities at sea (Ducruet et al., 2024).

(5) Cargo throughput: It refers to the total amount of cargo handled by a port within a specific time frame. This variable reflects the port's handling capacity, the momentum of port cargo logistics, and the level of trade activity (Wang et al., 2020), including transshipment as well as import-export traffic. It is not only related to the operational strength of port machinery, but also closely related to the land transportation activities.

By selecting these five indicators, we can comprehensively evaluate the intensity of port shipping activities from multiple aspects such as frequency, efficiency, capacity, scale, and logistics. These dimensions complement each other, providing a comprehensive perspective that helps to scientifically analyze the impact of shipping activities on air quality and residents' health.

#### **3.2.2 Dependent variable: Average life expectancy**

This indicator represents the expected average lifespan of people born in a specific region, country, or population. It is calculated based on the age distribution of survival and death for a specific population, usually measured in years. Higher average life expectancy is usually associated with better health conditions. Lower incidence rate, fewer chronic diseases, and lower rates of premature death often lead to longer life expectancy. Average life expectancy is an internationally



recognized indicator for evaluating the overall health level of residents, and has been widely applied in previous studies on residents' health (Zheng et al. 2022; Kim et al. 2021).

### 3.2.3 Mediating variable: Air Quality Index

Air Quality Index (AQI) is a composite indicator for detecting the state of total air pollution, which is applied to represent actual air pollution people experience (coming from the Ministry of Ecology and Environment of the People's Republic of China (<https://www.mee.gov.cn/>)). It simplifies the concentration of monitored air pollutants into a single conceptual index based on the environmental air quality standards and the impact of six major atmospheric pollutants (PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub>, CO) on human health, ecology, and the environment. In general, the higher the air quality index, the more severe the air pollution.

AQI is a widely used index across countries, but each country uses different equations. Due to the fact that the research units of this article are all Chinese port cities, the calculation standards for AQI are uniformly referred to the "Technical Regulation on Ambient Air Quality Index" (MEE, 2012). The specific calculation process is as follows: compare the graded concentration limits of each pollutant, and calculate the Individual Air Quality Index (IAQI) based on the measured concentration values of each pollutant.

$$IAQI_P = \frac{IAQI_{Hi} - IAQI_{Lo}}{BP_{Hi} - BP_{Lo}}(C_P - BP_{Lo}) + IAQI_{Lo}$$

where:  $IAQI_P$ —— the air quality sub-index of pollutant item  $P$ ;

$C_P$ —— the mass concentration value of pollutant item  $P$ ;

$BP_{Hi}$ —— The high value of pollutant concentration limit values similar to  $C_P$ ;

$BP_{Lo}$ —— The low value of pollutant concentration limit values similar to  $C_P$ ;

$IAQI_{Hi}$ —— The air quality sub index corresponding to  $BP_{Hi}$ ;

$IAQI_{Lo}$ —— The air quality sub index corresponding to  $BP_{Lo}$ ;

Then select the maximum value from the IAQI of each pollutant to determine as AQI, and determine the pollutant with the highest IAQI as the primary pollutant:

$$AQI = \max \{IAQI_1, IAQI_2, IAQI_3, \dots, IAQI_n\}$$

Where,  $AQI$ ——Air Quality Index;

$n$ ——Pollutant projects.

### 3.2.4 Control variables

Due to differences in operating modes, transportation methods, and pollutant emissions among various ship/cargo types and port types, their impact on air quality and public health in port cities may also vary. To ensure the accuracy of this research, we added these influencing factors as control variables to the model. Specifically, for ship or cargo types, we use the proportion of traffic volume for different ship types (liquid bulk, solid bulk, general cargo, containers) to reflect the cargo structure of each port city. For port types, we define three binary variables: IMV indicates whether the port is an intermodal port (1 for yes, 0 for no), TGV indicates whether the port is a transshipment or gateway port (1 for transshipment port, 0 for gateway port), and ICV indicates whether the port

is an industrial or commercial port (1 for industrial port, 0 for commercial port).

Moreover, the control variables also include six socioeconomic factors: GDP per capita, Railway freight volume, Highway freight volume, Population density, Industrial output, Doctor density; and two natural factors: Elevation and Wind speed. GDP per capita and Industrial output are important indicators of a city's level of economic development, which will bring pollution but also improve people's living standards, so they have multifaceted impacts on health (Ye, 2022). Compared to shipping activities far from the city, railway and highway transportation emissions have a more significant impact on air quality and residents' health in urban areas (Liu et al., 2021). As observed by Gibbs (2014) in the case of Felixstowe container port in UK, hinterland trucking can represent twice the amount of emissions of the port. Population density refers to the concentration of people within a certain geographic area. A denser population means more pollutant emissions, but also means more complete public facilities (Xing, 2020). Doctor density is usually used to measure the supply of medical resources in a country or region, which is the ratio between the number of doctors and the total population (Jin et al., 2015). Elevation and wind speed may be related to the deposition, transformation, and dissipation of pollutants; thus they can have an impact on air quality and health (Yan et al., 2021; Yang et al., 2020; Linares et al., 2021).

### 3.2.5 Data processing

It should be noted that the sample scope of this study is made of relevant data for various ship types for 36 coastal cities in China from 2001 to 2019, including container ships, bulk carriers, general cargo ships, oil tankers, and so on. To show the overall intensity of shipping activities in different port cities, we should assign weights to each indicator and calculate a comprehensive score. The common methods include subjective and objective weighting methods. Subjective weighting methods mainly determine weights based on experts' assessments of each indicator, which rely heavily on subjective awareness (Guo et al., 2022). And they have little transparency and reappearance (Yu, 2021). Objective weighting methods used in previous studies mainly include Principal component analysis (PCA) and entropy weighting method. But the former is mainly used for dimensionality reduction, and the extracted main components may be difficult to explain directly, making it unsuitable for weight allocation (Yu, 2021). Therefore, we ultimately decided to only use the entropy weight method to calculate the weight of each indicator. The entropy weight method assigns weight values to each indicator based on the amount of information contained in the data, which is particularly useful in dealing with multi-indicator decision-making problems. According to Zhou et al. (2015) and Tomal (2021), the calculation steps are as follows:

Step 1. To eliminate the influence of different measurement units and magnitudes on each indicator for calculating the comprehensive score of shipping activities, the initial indicator data needs to be normalized. For this, the min-max normalization method is used to transform the initial data to fall within the range of [0,1]:

$$u_{ijt} = \begin{cases} (x_{ijt} - \min_{it}(x_{ijt})) / (\max_{it}(x_{ijt}) - \min_{it}(x_{ijt})), & \text{if } u_{ijt} \text{ is a positive indicator} \\ (\max_{it}(x_{ijt}) - x_{ijt}) / (\max_{it}(x_{ijt}) - \min_{it}(x_{ijt})), & \text{if } u_{ijt} \text{ is a negative indicator} \end{cases} \quad (1)$$

where  $u_{ijt}$  is the normalized value of indicator  $j$  for city  $i$  in year  $t$  ( $x_{ijt}$ ). For a positive

indicator, the higher the indicator value, the higher the level of the just transition.

$$e_j = -\frac{1}{\ln(km)} \sum_{t=1}^k \sum_{i=1}^m p_{ijt} * \ln(p_{ijt}) \quad (2)$$

Step 2. Calculate entropy value ( $e_j$ ) for indicator  $j$ :

$$p_{ijt} = u_{ijt} / \sum_{t=1}^k \sum_{i=1}^m u_{ijt} \quad (3)$$

where  $m$  and  $k$  are the total number of cities and years, respectively;  $p_{ijt}$  denotes the proportion of indicator  $j$  for city  $i$  in year  $t$ , which can be expressed by the following equation:

Step 3. Calculate the weight of indicator  $j$  ( $w_j$ ):

$$w_j = (1 - e_j) / \sum_{j=1}^n (1 - e_j) \quad (4)$$

where  $n$  is the number of indicators.

Step 4. Calculate the weighted index of city  $i$  in year  $t$  ( $S_{ij}$ ):

$$S_{ij} = \sum_{j=1}^n u_{ijt} * w_j \quad (5)$$

After calculation by formula (4), among the five variables that represent the intensity of shipping activities, ship traffic volume has the highest weight of 33.31%, number of calls has a weight of 25.26%, weighted average turnaround time has a weight of 22.52 %, cargo throughput has a weight of 13.61%, and maximum deadweight tonnage has the lowest weight of 5.58 %. On this basis, we can calculate the comprehensive score of annual shipping intensity for each port city through formula (5).

For the remaining variables, in order to avoid the loss of their actual economic meaning and original scaling relationships, and for more intuitive data analysis and interpretation, we only changed the magnitude of their units. **Table 1** reports the symbols and data sources for each variable.

**Table 1**  
Variables introduction.

Type	Variables	Symbols	Data sources
Independent variable	Number of calls	CALL	Lloyd's List Intelligence
	Weighted average turnaround time	WAT	
	Maximum deadweight tonnage	DWT	

	Ship traffic in total	TRAFFIC	
	Cargo throughput	CARGO	China Port Yearbook
	Comprehensive score of shipping activity intensity	SCORE	Calculated
Mediating variable	Air quality index	AQI	China Meteorological Administration
Dependent variable	Average life expectancy	LIFE	Local health committees
	Traffic volume share of bulk ship	BULK	
	Traffic volume share of general cargo ship	GEN	Lloyd's List Intelligence
	Traffic volume share of liquid ship	LIQ	
	Traffic volume share of container ship	CONT	
	Transshipment/Gateway port variable	TGV	
	Industrial/Commercial port variable	ICV	China Port Yearbook
	Intermodal port variable	IMV	
Control variables	GDP per capita	PCGDP	
	Population density	POP	
	Railway freight volume	RF	China City Statistical Yearbook
	Highway freight volume	HF	
	Industrial output	INDU	
	Doctor density	DOCTOR	
	Elevation	ELEV	China Meteorological Administration
	Wind speed	WIND	

### 3.3 Nonlinear mediating effect model setting

Mediating effect models are used to examine and study the role of intermediate variables in the causal relationship between explanatory variables and explained variables, thus exploring the underlying mechanism of this relationship (He et al., 2022). Fig. 2 shows that the independent variable (X) has a comprehensive effect of  $d$  on the dependent variable (Y) and the direct influence of  $a$  from X to Y. Meanwhile, it indicates that X has indirect effects on Y by affecting the intermediate variable (M). This study used the stepwise regression method proposed by Baron and Kenny (1986). First, the independent and dependent variables were used for a regression analysis as well as to judge the sign and significance of the coefficient. Next, the independent variable and

the mediating variable were used for the regression analysis and to judge the sign and significance of the coefficients. Finally, all three kinds of variables were entered into one regression model and then used to judge the sign and significance of the coefficients. If the estimated coefficients of  $b$ ,  $c$  and  $d$  are all significant, the existence of the mediating effect can be proved. And if  $a$  is significant, then the mediating effect is a partial mediating effect, otherwise it is a full mediating effect.

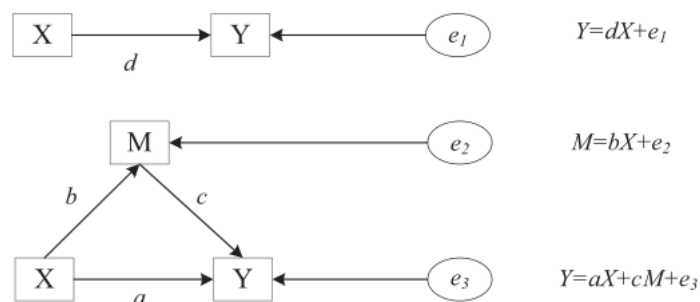


Fig. 2. The verification path of the mediating effect model.

This paper uses panel data methodology, following mediating effect model to explore the impact mechanism between shipping activities, air quality, and residents' health. Air pollution can harm residents' health and lead to a decrease in average life expectancy, which has been widely proven in previous studies (Wu et al., 2020; Hill et al., 2019). However, it is interesting to observe that the air pollution of large port cities (such as Tianjin and Shanghai) generally are more serious than that of smaller port cities (such as Beihai and Fangchenggang), but the average life expectancy of developed regions is often higher than that of underdeveloped regions, which is not entirely consistent with previous research conclusions. But there is no doubt that the health level of residents cannot be permanently improved with the continuous aggravation of pollution. It can be seen that there may be a complex nonlinear relationship between air quality and human health and lifespan, influenced by factors such as residents' living standards and medical and health conditions. Therefore, based on the traditional mediation effect model structure, we use a nonlinear mediation effect model and add the quadratic and cubic terms of the air quality index to the regression equation.

Compared to other econometric models, a panel data model considers both the cross-section and time-series of data and reflects the characteristics and changes from the two dimensions (Li et al., 2019). Before implementing this model, the multicollinearity test and the Hausman test for variables are required. Multicollinearity may jeopardize the credit of estimating results (Kov'acs et al., 2005), And the Variance Inflation Factor (VIF) is usually used to estimate the multicollinearity between explanatory variables. If the VIF value of the variables is  $>7.5$ , it suggests that the issue of multicollinearity exists in the current regression model, and thus that variable should be removed. Panel data modeling generally employs two typical estimators, i.e., random-effects estimator and fixed-effects estimator, and the Hausman test is employed to identify which one is superior in our case (Hausman, 1978).

After testing, the VIF values of each regression equation variable are all less than 7.5, indicating that there is no multicollinearity problem. The results of the Hausman test all indicate rejection of the original hypothesis, indicating that the fixed effects model should be chosen. To explore whether shipping activities have a significant effect on residents' health through the mediating factors of air quality, and the direction and magnitude of their influencing effects, several

theoretical models were constructed as follows:

$$\begin{aligned}
LIFE_{it} = & \alpha + \beta_1 SCORE_{it} + \gamma_1 BULK_{it} + \gamma_2 GEN_{it} + \gamma_3 LIQ_{it} + \gamma_4 CONT_{it} + \gamma_5 TGV_{it} \\
& + \gamma_6 ICV_{it} + \gamma_7 IMV_{it} + \gamma_8 PCGDP_{it} + \gamma_9 POP_{it} + \gamma_{10} RF_{it} + \gamma_{11} HF_{it} \\
& + \gamma_{12} INDU_{it} + \gamma_{13} DOCTOR_{it} + \gamma_{14} ELEV_{it} + \gamma_{15} WIND_{it} + \mu_t + \vartheta_i + \varepsilon_{it}
\end{aligned} \quad (6)$$

$$\begin{aligned}
AQI_{it} = & \alpha + \beta_1 SCORE_{it} + \gamma_1 BULK_{it} + \gamma_2 GEN_{it} + \gamma_3 LIQ_{it} + \gamma_4 CONT_{it} + \gamma_5 TGV_{it} \\
& + \gamma_6 ICV_{it} + \gamma_7 IMV_{it} + \gamma_8 PCGDP_{it} + \gamma_9 POP_{it} + \gamma_{10} RF_{it} + \gamma_{11} HF_{it} \\
& + \gamma_{12} INDU_{it} + \gamma_{13} DOCTOR_{it} + \gamma_{14} ELEV_{it} + \gamma_{15} WIND_{it} + \mu_t + \vartheta_i + \varepsilon_{it}
\end{aligned} \quad (7)$$

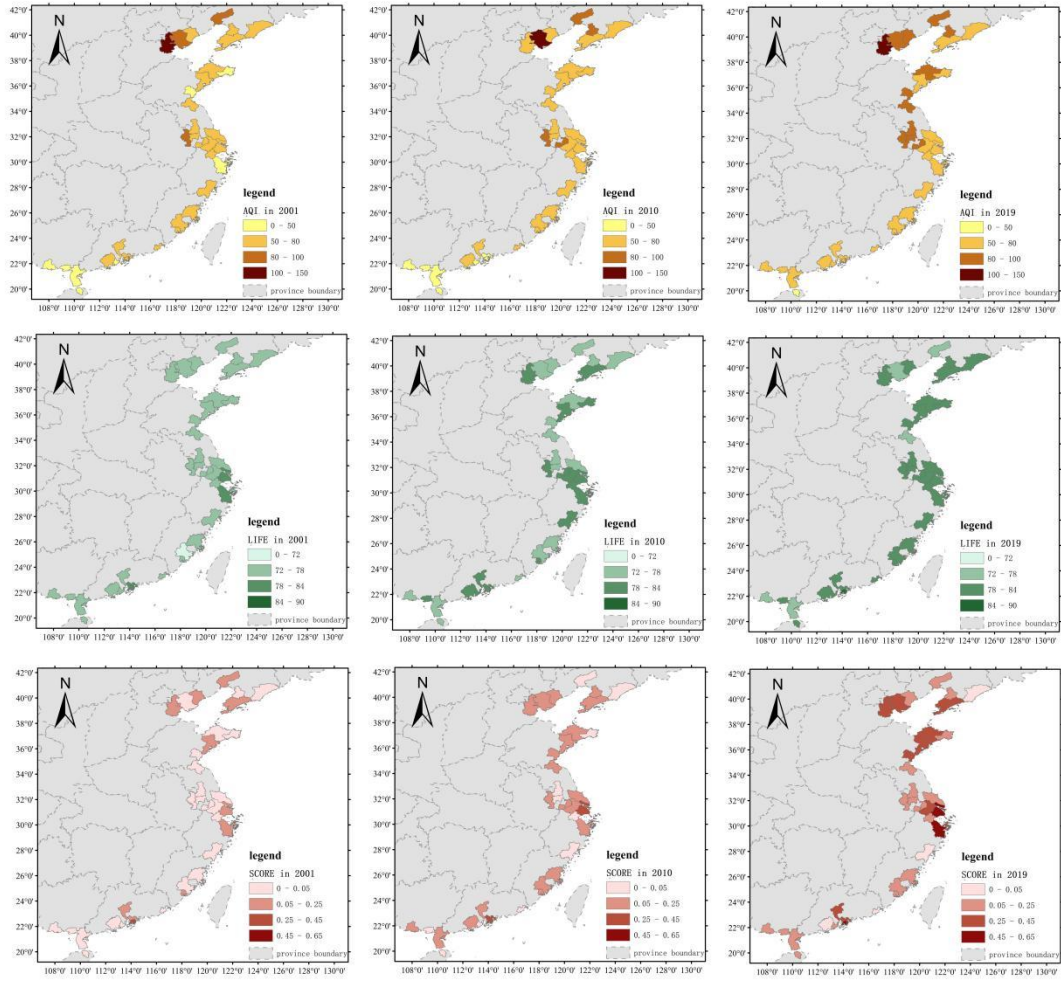
$$\begin{aligned}
LIFE_{it} = & \alpha + \beta_1 SCORE_{it} + \beta_2 AQI_{it}^3 + \beta_3 AQI_{it}^2 + \beta_4 AQI_{it} + \gamma_1 BULK_{it} + \gamma_2 GEN_{it} + \gamma_3 LIQ_{it} \\
& + \gamma_4 CONT_{it} + \gamma_5 TGV_{it} + \gamma_6 ICV_{it} + \gamma_7 IMV_{it} + \gamma_8 PCGDP_{it} + \gamma_9 POP_{it} + \gamma_{10} RF_{it} \\
& + \gamma_{11} HF_{it} + \gamma_{12} INDU_{it} + \gamma_{13} DOCTOR_{it} + \gamma_{14} ELEV_{it} + \gamma_{15} WIND_{it} + \mu_t + \vartheta_i + \varepsilon_{it}
\end{aligned} \quad (8)$$

In equations (6)-(8),  $i$  represents the year;  $j$  represents the city;  $\alpha$  denotes the constant term;  $\beta_1 \sim \beta_4$  are the estimated coefficients of the core independent variables,  $\gamma_1 \sim \gamma_{15}$  are the estimated coefficients of the control variable,  $\mu_t$  is the time fixed effect,  $\vartheta_i$  is the individual fixed effect, and  $\varepsilon_{it}$  is the random perturbation term.

## 4 Results and Discussions

### 4.1 Background statistics

**Fig. 3** shows the spatiotemporal characteristics of air pollution, death rate and cargo throughput in China's port cities during the study period. In terms of temporal trends, the air pollution, average life expectancy, and intensity of shipping activities in China's port cities are all showing an upward trend. From the spatial pattern, Northern China is the area with the most severe air pollution, especially in Tianjin, Tangshan, and Jinzhou. This is because they have developed heavy industries and are major transit areas for coal trade (Wang and Ducruet, 2014). The southern coastal areas maintain a relatively good level of environment and health. The most developed areas for shipping activities are concentrated in the central coastal areas, especially Shanghai, Ningbo, and Zhoushan. The descriptive statistics of relevant variables are presented in **Table 2**. For better understanding, the appendix provides more detailed descriptive statistical data of all variables in all 36 port cities.



**Fig. 3** The spatiotemporal changes of main variables in China's port cities from 2001 to 2019

**Table 2**

The descriptive statistics of variables.

Variable	Observations	Mean	Min	Max	Std. Dev
CALL	684	1381.39	1	15683	2022.821
WAT	684	0.801	0.042	12.969	1.122
DWT	684	113.36	6.895	237.373	59.082
TRAFFIC	684	36.784	0.02	366.397	62.49
CARGO	684	17.129	0.252	70.542	15.848
SCORE	684	0.125	0.019	0.668	0.116
AQI	684	68.061	30.233	146.214	17.332
LIFE	684	78.052	70.102	85.501	2.783
BULK	684	0.397	0.005	0.932	0.25
GEN	684	0.1	0.003	0.667	0.922
LIQ	684	0.161	0.002	0.954	0.165
CONT	684	0.23	0.002	0.964	0.269
TGV	684	0.5	0	1	0.5

ICV	684	0.361	0	1	0.481
IMV	684	0.306	0	1	0.461
PCGDP	684	6.523	0.69	46.775	5.295
POP	684	0.917	0.126	7.15	1.098
RF	684	14.146	0	121.61	20.243
HF	684	12.516	0.175	88.352	11.857
INDU	684	6.388	0.017	42.688	7.86
DOCTOR	684	25.713	6.8	88.451	13.853
ELEV	684	101.258	7.337	438.084	106.699
WIND	684	5.738	3.336	9.958	1.092

#### 4.2 Result explanation of the nonlinear mediating effect model

**Table 3** shows the regression results of nonlinear mediating effect model. According to the principle of mediating effect testing, the coefficients of SCORE in model (6) (7) and AQI3 in model (8) are both significant, indicating a mediating effect. This result indicates that the hypothesis that shipping activities affect residents' health by affecting air quality is valid. In addition, the coefficient of SCORE in model (8) is also significant at the 1% level, indicating that this influence mechanism is partially mediated.

Such results indicate that shipping activities have a significant negative impact on the health level of port cities. On the one hand, shipping activities emit a large amount of pollutants (including sulfur dioxide, nitrogen oxides, particulate matter, etc.), leading to deterioration of air quality, thereby endangering the respiratory and cardiovascular systems of coastal residents, increasing their risk of illness and death (Wu et al., 2020). On the other hand, maritime activities also influence the health levels of port cities through alternative means. This conclusion is consistent with the research of other scholars. For example, in addition to air, shipping activities can also cause water pollution and noise pollution, which have a negative impact on the health of port city residents. Water pollution can damage the water ecosystem of port cities, affect fishery resources and water source security, and threaten the dietary health and quality of life of port city residents (Endres et al., 2018; Aydin et al., 2021). Noise pollution can interfere with the sleep and rest of port city residents, trigger mental stress and mental illness, and reduce the happiness and satisfaction of port city residents (Duarte et al., 2021; Jalkanen et al., 2022). In addition, accidental deaths caused by port production activities will also reduce average life expectancy to a certain extent, directly affecting the health level of residents in port cities (Hua et al., 2021; Khan et al. 2023). Accidents such as ship collisions, oil tanker explosions, and cargo collapses can cause casualties and property damage to port city residents.

From the analysis, we have found that shipping activities have a negative impact on air quality and health, which is linear and consistent. However, the impact of air quality on health presents a complex nonlinear relationship, with a negative coefficient of the cubic term of air quality, indicating an inverted N-shaped curve. This is relatively simple to explain: initially, the deterioration of air quality can harm the respiratory and cardiovascular systems of port city residents, increasing the risk of illness and death. However, the deterioration of air quality is often accompanied by economic development and urbanization, which in turn improves residents' living conditions and medical and health standards (Wu et al., 2018; Wang et al., 2022). Therefore, the curve enters the second stage, where the decrease in air quality leads to an increase in average life expectancy. But



there is no doubt that we cannot let air quality deteriorate without restraint. When air pollutants exceed the urban load level, it will cause serious harm to the health of local residents again (Wang et al., 2022).

For different types of ships/cargo (bulk, general cargo, liquid, container), These control variables are not significant in statistical results. This is because our research aims to provide a comprehensive analysis to evaluate the overall impact of shipping activity intensity on air quality and health. The intermediate and dependent variables we selected are also comprehensive air quality index and average life expectancy, without being subdivided into specific pollutant types, disease types, or causes of death. This proves that the shipping activity intensity index we selected matches the research level, thus maintaining consistency in variable selection.

The empirical results show that different types of ports have varying impacts on air quality and residents' health. Specifically, transshipment ports have better air quality and higher average life expectancy compared to gateway ports. This may be due to the fact that transshipment ports involve less operational activities (cargo loading/unloading, storage, and logistics distribution), and the efficient circulation of cargoes reduces the accumulation of pollutants (Yu et al., 2022). At the same time, the economic benefits brought by the transshipment business also improve the living standards of residents and improve public health (Peng et al., 2023). Transshipment terminals also locate relatively far from urban areas, as seen with Yangshan, Shanghai's new port located on an island connected to mainland via a 30 kilometers bridge (Wang and Ducruet, 2012). In contrast, industrial ports significantly lower life expectancy despite having little impact on overall air quality, possibly because the handling of bulky goods (such as coal, ore, and chemicals) leads to higher localized exposure and health risks, even if these risks are not reflected in the overall air quality indicators (Vos et al., 2024). Intermodal port refers to a port that integrates multiple modes of transportation (such as highway, railway, barge, sea...) to improve transport efficiency and reduce environmental impact. However, due to the intensive logistics and operational activities, such ports may have complex impacts on the localized environment and residents' health (Hricko et al., 2014). The regression results show that intermodal ports have no significant difference in air quality compared to non-intermodal ports, but are associated with lower average life expectancy. High-intensity operation of intermodal ports may increase the cumulative effects of non-traditional pollution such as noise and traffic congestion, thereby having adverse effects on residents' health.

Among other control variables, both GDP per capita and industrial output tend to have a negative impact on air quality. This means that with economic development and the acceleration of industrialization, the emissions of exhaust gases and pollutants will also increase, resulting in a negative impact on air quality. But at the same time, economic development and urbanization will also improve the quality of life and medical level of residents, thereby increasing the average life expectancy (Li et al., 2020). The increase in population density will positively impact the environment, because the development of social progress and the increase of population density are synchronous (Xing, 2020). Higher population density often accompanies higher possibility of establishing urban infrastructure to control air pollution, such as public transportation and urban greening. Lastly, wind speed and altitude, as natural factors, also have a significant impact on air quality. When the wind speed is low, the airflow is slow, and pollutants are not easily diluted and diffused, leading to a deterioration of air quality as pollutants linger in the air for longer periods (Yan et al., 2021). Higher altitude leads to thinner air, and it is more difficult for pollutants to disperse, so the air quality is relatively worse (Yang et al., 2020). Higher doctor density indicates

more abundant local medical resources, enabling timely disease prevention, diagnosis, treatment, and rehabilitation, thus promoting improvements in health levels (Jin et al., 2015).

**Table 3**

The results of nonlinear mediating effect model

	Model (6)	Model (7)	Model (8)
SCORE	-6.364*** (-10.70)	20.630*** (3.00)	-6.4048*** (-10.75)
AQI <sup>3</sup>	—	—	-5.49e-06*** (-2.66)
AQI <sup>2</sup>	—	—	0.0015*** (2.93)
AQI	—	—	-0.1336*** (-3.12)
BULK	0.8483*** (3.14)	-0.5776 (-0.18)	0.8066*** (2.99)
GEN	0.0106 (0.02)	6.2199 (1.24)	0.1559 (0.36)
LIQ	-0.1096 (-0.33)	-8.6769** (-2.27)	-0.1751 (-0.53)
CONT	-0.1116 (-0.34)	2.0932 (0.55)	-0.0851 (-0.26)
TGV	3.8968*** (10.21)	-9.2919** (-2.10)	3.7955*** (9.93)
ICV	-3.7893*** (-9.01)	1.7751 (0.36)	-3.7682*** (-9.01)
IMV	-1.2741*** (-3.14)	4.8039 (1.02)	-1.2649*** (-3.13)
PCGDP	0.0493*** (3.50)	0.4581*** (2.81)	0.0544*** (3.84)
POP	-0.8632*** (-5.23)	-6.4714*** (-3.39)	-0.9167*** (-5.51)
RF	0.0096*** (3.33)	0.0451 (1.34)	0.0105*** (3.61)
HF	0.0146*** (2.81)	-0.1216** (-2.02)	0.0153*** (2.94)
INDU	0.0688*** (7.17)	-0.3236*** (-2.91)	0.0611*** (6.16)
DOCTOR	0.0138** (2.36)	-0.0055 (-0.08)	0.0151*** (2.60)
ELEV	0.1224*** (14.78)	0.3237*** (3.38)	0.1255*** (14.99)

WIND	0.2272*** (3.61)	-1.0795* (-1.48)	0.2042*** (3.23)
Constant term	67.4055*** (140.47)	52.056*** (9.37)	70.9836*** (58.28)
R <sup>2</sup>	0.9582	0.8557	0.9590
Root MSE	0.598	6.9211	0.5941
Var VIF < 7.5	YES	YES	YES
F test (Prob>F)	0.0000	0.0000	0.0000
Obs	684	684	684

Note: The t statistic of the corresponding explanatory variable is shown in parentheses. \*\*\*, \*\* and \* indicate significant at the significance levels of 1%, 5%, and 10% respectively.

### 4.3 Discussion

It can be seen that although shipping activities are an important economic source for port cities, they also pose threats and challenges to the environment and residents' health of port cities. Effective measures need to be taken to reduce the environmental and health costs of shipping activities and improve the sustainable development level of port cities. According to Sun et al. (2023), the inflection point of the cubic curve between the air quality index and average life expectancy can be calculated using the following equation:

$$\mu_{1,2}^* = -\frac{\beta_2 \pm \sqrt{(\beta_2^2 - 3\beta_1\beta_3)}}{3\beta_3} \quad (9)$$

where  $\beta_3$  represents the regression coefficient of the cubic power of the core explanatory variable,  $\beta_2$  represents the regression coefficient of the square power of the core explanatory variable, and  $\beta_1$  represents the regression coefficient of the core explanatory variable.  $\mu_{1,2}^*$  denote the two inflection points estimated by eq. (9).

According to the calculation results, there is an inverted U-shaped curve between air quality and average life expectancy, with two inflection points of approximately 69 and 118, respectively. Among the selected port cities in China, cities with an air quality index below 69 include Fuzhou, Quanzhou, Shantou, Zhanjiang, Zhuhai, Beihai, Fangchenggang, Haikou, Zhoushan, etc. For these cities, the current development focus should be on vigorously developing the economy and shipping industry to enhance their comprehensive strength. Specific measures such as strengthening port infrastructure construction, improving port operation efficiency, developing transshipment business, and promoting the prosperity of the shipping industry.

Most cities have an air quality index between 69 and 118, including Guangzhou, Qinhuangdao, Lianyungang, Nantong, Suzhou, Wuxi, Yangzhou, Dalian, Qingdao, Rizhao, Shanghai, Dandong, Wenzhou etc. These cities are currently in a win-win stage of economic development and health improvement. Therefore, while maintaining the development of the shipping industry and economic growth, clean energy and environmental protection technologies should be adopted to improve energy utilization efficiency, in order to minimize the impact on health. Such efforts contribute to achieving sustainable development, enabling cities to maintain economic prosperity while also

ensuring the health of their residents (Nogué-Algueró, 2020).

There are fewer cities with an air quality index close or higher than 118, mainly including Qinhuangdao, Tangshan, and Tianjin. For these cities, the growth rate of the shipping industry should be moderately slowed down to avoid the negative impact of excessive development on the environment. It is recommended to establish stricter industry environmental standards, increase efforts to rectify high pollution emissions, prevent further environmental degradation, and avoid serious harm to the health of local residents in the future, while increasing investment in air pollution control facilities, introducing advanced governance technologies, and ensuring compliance with atmospheric emissions (Wu et al., 2022). Overall, formulating corresponding development strategies for the shipping industry based on the air quality status of different cities is crucial to ensuring sustainable economic development and residents' health.

Based on our research results, we propose the following policy suggestions: For port cities that have not yet reached the first turning point of air quality index, the development of the shipping industry should be accelerated to promote economic efficiency and improve residents' living standards. For port cities located between two inflection points, efforts should be made to promote clean production technologies, improve energy efficiency, and foster smooth cargo transfers in order to minimize the negative impacts of shipping activities. This can extend the duration of this stage and enhance its positive effects. For port cities that have already exceeded the second turning point of air quality index, it is crucial to expedite the green transformation of shipping industry, so it is preferable not to excessively develop highly polluting shipping activities. Instead, stricter environmental regulation should be implemented, and pollution governance should be strengthened, in order to ensure the sustainable development of port cities. This is seen in China and elsewhere, with new ports created at distance from inner cities, such as Yangshan (Shanghai), New Priok (Jakarta), Port Qasim (Karachi), Nava Sheva (Mumbai), and Tuas (Singapore), to name but a few examples in Asia.

Regarding the current research, several limitations should be noted. Firstly, due to data availability limitations, we uniformly used air quality index to represent air pollution levels without separately considering the main pollutants emitted by maritime activities, such as PM, SO<sub>x</sub>, and NO<sub>x</sub>. Secondly, as there were no available data sources related to incidence rate and cause of death, we used only the average life expectancy as a proxy for public health, while the impact of shipping activities on health could be measured more accurately by indicators such as the incidence rate of related diseases. That is to say, the current study only considered the overall level, and has not been disaggregated. Future research could strive for larger-scale data support, select more abundant and scientifically sound variables, in order to analyze the impact mechanisms of shipping activities on air quality and public health in China and other cities of the world.

## **5 Conclusions and policy implications**

To study the impact of shipping activities on urban air quality and public health, this paper conducts correlation and regression analysis on panel data of 36 port cities in China from 2001 to 2019. We analyzed the relationship between different shipping activities and air quality and average life expectancy, and examined the impact of shipping activities on the health level of port city residents as well as the mediating effect of air quality. The main conclusions of this study are as follows.

Shipping activities have a significant impact on the health level of port cities. This impact is

influenced by the mediating variable of air quality and has a partial mediating effect. Shipping activities not only emit a large amount of exhaust gas, leading to deterioration of air quality, increasing the risk of illness and death for port city residents, but also affecting the average life expectancy of port cities through other means, such as water pollution, noise pollution, accidents, and port terminal operations as well as hinterland connectivity.

Shipping activities have a negative impact on air quality and health, which is linear and consistent. However, the impact of air quality on health presents a complex nonlinear relationship, with a negative coefficient of the cubic power of air quality, indicating an inverted N-shaped curve. The two inflection points of the curve between air quality and average expected life are about 69 and 118 respectively.

Our conclusions indicate that shipping activities have complex impacts on the air quality and public health in China's port cities, depending on the development mode and stage of shipping. Although the initial development of shipping may have negative impacts on the environment and health, it also improved the economic development level of port cities and the living and medical conditions of residents. Through appropriate policy measures and technological innovation, the negative impact of shipping activities can be alleviated or even transformed into positive impacts. However, in order to achieve sustainable development, port cities need to recognize the limitations of shipping development and take corresponding planning and management measures to ensure a balance between shipping, environment, and health.

#### **Declaration of Competing Interest**

None.

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## Appendix: Detailed Descriptive Statistics

City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	CALL	19	2231.42	638	6115	1549.69		WAT	19	0.59	0.10	1.95	0.51
Dandong		19	161.74	49	306	66.51			19	1.77	0.14	3.88	1.06
Jinzhou		19	213.26	17	597	203.70			19	0.92	0.10	3.83	0.96
Qinhuangdao		19	1124.90	179	2661	937.58			19	0.42	0.12	0.96	0.30
Qingdao		19	3140.53	903	5391	1489.91			19	0.33	0.05	0.95	0.28
Rizhao		19	1226.79	301	2561	895.60			19	0.35	0.08	0.72	0.24
Tangshan		19	1251.58	15	3904	1459.37			19	0.57	0.07	1.85	0.54
Tianjin		19	3145.26	787	6453	2160.08			19	0.51	0.09	1.39	0.42
Weihai		19	508.05	45	1025	284.47			19	0.63	0.21	3.52	0.75
Yantai		19	1757.68	257	4083	1207.75			19	0.50	0.08	1.37	0.45
Yingkou		19	724.68	148	1823	486.50			19	0.76	0.12	2.30	0.69
Jiaxing		19	345.89	11	1225	385.64			19	0.88	0.20	3.20	0.78
Lianyungang		19	1152.90	222	2206	722.67			19	0.57	0.10	1.94	0.51
Nanjing		19	366.16	88	1108	246.95			19	1.02	0.21	2.79	0.73
Nantong		19	624.84	206	1334	354.51			19	1.12	0.17	2.60	0.93
Ningbo		19	3272.26	663	8512	2193.37			19	0.18	0.04	0.53	0.15
Shanghai		19	5286.16	1848	8427	1883.32			19	0.30	0.09	0.98	0.29
Suzhou		19	1736.79	316	4303	1317.12			19	0.94	0.17	2.21	0.77
Wenzhou		19	150.21	12	400	131.98			19	1.23	0.24	4.20	1.09
Wuxi		19	485.16	166	1446	355.77			19	0.93	0.16	3.04	0.77
Yangzhou		19	273.63	16	973	305.95			19	1.17	0.21	4.45	1.11
Zhenjiang		19	197.26	1	981	262.93			19	0.74	0.05	2.17	0.66
Zhoushan		19	1185.74	28	4755	1339.12			19	0.73	0.17	2.70	0.72
Beihai		19	145.95	29	444	123.76			19	1.50	0.20	6.08	1.42
Fangchenggang		19	373.79	57	876	266.97			19	0.75	0.12	2.20	0.59
Fuzhou		19	762.42	195	1823	499.23			19	1.18	0.12	3.61	1.19
Guangzhou		19	2095.74	471	5203	1609.58			19	0.57	0.13	1.66	0.48
Haikou		19	327.37	25	1082	297.30			19	1.43	0.16	8.36	2.28
Jiangmen		19	99.26	7	329	95.22			19	2.51	0.28	12.97	3.51
Quanzhou		19	204.32	42	519	160.53			19	1.06	0.11	5.15	1.61
Xiamen		19	1662.74	701	2813	660.59			19	0.17	0.06	0.35	0.11
Shantou		19	181.74	31	456	119.83			19	1.08	0.12	7.39	1.66
Shenzhen	19	3350.47	730	7850	2008.23		19	0.14	0.04	0.41	0.12		
Hong Kong	19	8866.16	4953	15683	2199.90		19	0.11	0.07	0.21	0.03		
Zhanjiang	19	358.84	54	1112	274.75		19	0.43	0.09	1.13	0.33		
Zhuhai	19	738.16	99	2302	696.88		19	0.76	0.20	2.39	0.64		

City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	DWT	19	177.72	160.58	234.01	22.69		TRAFFIC	19	45.43	6.56	135.00	39.24
Dandong		19	75.28	19.87	164.37	39.92			19	1.72	0.18	5.55	1.50
Jinzhou		19	68.46	33.19	163.66	35.33			19	4.49	0.29	14.40	5.15
Qinhuangdao		19	151.37	91.56	200.68	28.07			19	28.75	4.42	72.88	25.66
Qingdao		19	180.57	161.31	232.62	22.10			19	109.67	15.60	236.15	75.80
Rizhao		19	138.82	81.59	201.38	37.96			19	39.78	4.28	113.89	37.58
Tangshan		19	127.37	17.06	210.69	66.16			19	46.88	0.09	146.35	56.70
Tianjin		19	151.03	75.68	232.62	50.29			19	85.55	10.45	194.45	72.50
Weihai		19	52.96	12.72	141.51	32.27			19	7.10	0.21	17.33	4.63
Yantai		19	124.05	79.76	233.03	40.59			19	34.61	3.36	100.65	30.15
Yingkou		19	132.16	39.87	170.62	40.93			19	16.57	1.31	53.75	15.45
Jiaxing		19	43.74	7.97	57.59	11.71			19	3.24	0.05	12.04	3.96
Lianyungang		19	116.77	40.67	172.50	45.93			19	25.41	2.53	62.60	20.02
Nanjing		19	47.01	30.05	88.91	12.91			19	4.21	1.04	12.72	3.35
Nantong		19	145.45	65.53	201.99	46.94			19	10.86	1.58	27.02	9.56
Ningbo		19	186.61	164.37	234.01	23.66			19	138.33	11.76	366.17	110.82
Shanghai		19	170.83	108.08	236.58	37.54			19	159.45	25.57	272.20	90.00
Suzhou		19	92.51	38.68	134.84	28.89			19	23.10	1.79	57.25	20.93
Wenzhou		19	67.10	7.32	94.92	25.32			19	2.01	0.09	5.69	2.04
Wuxi		19	84.92	43.19	237.77	43.57			19	8.08	1.71	30.94	8.35
Yangzhou	19	54.03	20.91	203.48	40.27		19	3.22	0.13	11.15	3.50		
Zhenjiang	19	50.99	23.27	152.23	29.33		19	2.75	0.02	15.34	4.14		

Zhoushan	19	177.8 1	152.0 2	217.6 7	20.19		19	37.79	0.65	131.2 2	40.33
Beihai	19	75.27	15.93	136.8 9	40.31		19	1.77	0.09	6.55	1.92
Fangchenggan g	19	102.2 1	77.14	147.7 0	17.19		19	9.64	0.83	27.15	8.51
Fuzhou	19	107.4 7	22.34	168.4 2	56.22		19	12.79	1.46	31.71	11.53
Guangzhou	19	155.0 6	68.72	217.6 1	43.32		19	45.27	5.25	100.8 3	36.46
Haikou	19	56.75	22.60	157.8 8	38.97		19	2.78	0.17	10.11	2.78
Jiangmen	19	66.04	6.90	150.6 7	37.35		19	0.86	0.02	3.02	0.78
Quanzhou	19	127.0 8	26.52	167.0 5	46.46		19	4.25	0.17	12.22	3.99
Xiamen	19	154.3 4	81.49	217.6 7	48.56		19	47.68	11.84	86.98	27.63
Shantou	19	45.93	27.99	60.14	8.60		19	1.96	0.34	4.16	1.27
Shenzhen	19	164.6 8	92.20	234.0 1	47.11		19	132.7 3	24.92	211.9 6	66.24
Hong Kong	19	175.0 7	93.50	217.6 7	29.23		19	207.8 9	104.3 1	366.4 0	47.44
Zhanjiang	19	154.1 1	85.91	172.5 0	25.10		19	11.44	2.36	38.53	10.28
Zhuhai	19	79.49	47.06	168.1 9	37.78		19	6.19	0.89	17.56	5.65



City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	CARGO	19	29.42	10.05	46.78	12.66		SCORE	19	0.184	0.105	0.343	0.078
Dandong		19	6.61	0.54	15.79	5.46			19	0.063	0.037	0.097	0.017
Jinzhou		19	6.71	1.11	15.81	4.10			19	0.050	0.031	0.082	0.015
Qinhuangdao		19	21.74	11.17	28.77	5.76			19	0.127	0.065	0.195	0.045
Qingdao		19	34.13	10.40	57.74	15.38			19	0.263	0.098	0.454	0.121
Rizhao		19	21.94	2.93	46.38	14.13			19	0.135	0.039	0.268	0.079
Tangshan		19	26.97	1.10	65.67	23.26			19	0.153	0.019	0.372	0.126
Tianjin		19	37.53	11.37	55.06	15.01			19	0.243	0.084	0.433	0.131
Weihai		19	2.57	0.67	4.47	1.41			19	0.040	0.021	0.069	0.015
Yantai		19	16.75	2.19	44.31	12.43			19	0.128	0.051	0.287	0.073
Yingkou		19	20.40	2.52	37.00	12.58			19	0.108	0.054	0.171	0.042
Jiaxing		19	4.70	1.02	10.91	3.09			19	0.040	0.020	0.064	0.012
Lianyungang		19	12.99	3.06	23.46	7.09			19	0.102	0.038	0.172	0.046
Nanjing		19	15.44	5.79	25.69	6.72			19	0.066	0.043	0.092	0.012
Nantong		19	15.73	3.51	33.62	8.30			19	0.102	0.069	0.160	0.025
Ningbo		19	38.91	12.85	58.41	14.42			19	0.299	0.093	0.637	0.163
Shanghai		19	53.22	22.10	70.54	15.15			19	0.377	0.137	0.568	0.143
Suzhou		19	31.52	3.53	60.46	20.01			19	0.146	0.054	0.254	0.071
Wenzhou		19	5.75	1.65	8.93	2.40			19	0.050	0.030	0.089	0.012
Wuxi		19	17.13	7.82	29.50	5.65			19	0.082	0.050	0.135	0.023
Yangzhou		19	7.85	1.25	14.13	4.16			19	0.053	0.027	0.101	0.021
Zhenjiang		19	10.68	2.22	32.92	6.91			19	0.048	0.029	0.116	0.022
Zhoushan		19	24.30	3.28	53.60	16.30			19	0.153	0.064	0.353	0.085
Beihai		19	1.45	0.25	3.50	1.05			19	0.048	0.024	0.107	0.020
Fangchenggang		19	6.55	1.00	11.50	4.17			19	0.062	0.041	0.084	0.014
Fuzhou		19	10.08	2.96	21.30	5.03			19	0.087	0.054	0.136	0.025
Guangzhou		19	38.34	12.82	60.62	14.93			19	0.193	0.079	0.336	0.087
Haikou		19	5.80	0.89	12.45	4.04			19	0.054	0.020	0.153	0.035
Jiangmen		19	2.42	0.39	4.48	1.60			19	0.063	0.022	0.247	0.061
Quanzhou		19	8.09	2.10	12.99	3.99			19	0.069	0.031	0.116	0.021
Xiamen	19	12.91	2.10	21.70	7.39		19	0.132	0.054	0.216	0.058		
Shantou	19	3.27	1.31	5.18	1.44		19	0.038	0.022	0.137	0.025		
Shenzhen	19	19.19	6.64	25.80	5.56		19	0.251	0.090	0.407	0.107		
Hong Kong	19	24.84	17.83	29.77	3.12		19	0.421	0.259	0.668	0.077		
Zhanjiang	19	13.61	2.21	30.19	9.31		19	0.084	0.039	0.141	0.029		
Zhuhai	19	7.12	1.98	13.84	4.30		19	0.061	0.030	0.110	0.026		

City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	AQI	19	70.41	55.79	97.36	10.35		LIFE	19	79.92	76.66	81.49	1.70
Dandong		19	68.08	56.66	76.66	5.60			19	76.49	73.34	79.16	1.97
Jinzhou		19	90.15	82.10	98.49	4.95			19	75.65	72.79	77.85	1.59
Qinhuangdao		19	73.12	54.25	129.60	17.98			19	76.62	74.38	79.50	1.47
Qingdao		19	79.06	62.18	112.40	10.31			19	79.51	76.74	80.98	1.54
Rizhao		19	67.20	43.48	96.70	19.30			19	75.63	72.74	78.94	1.92
Tangshan		19	105.90	92.44	126.60	9.06			19	74.69	72.50	77.28	1.49
Tianjin		19	94.42	72.51	146.20	19.34			19	79.89	76.71	81.84	1.87
Weihai		19	61.29	49.90	82.34	8.89			19	78.81	75.93	81.49	1.60
Yantai		19	66.49	53.61	83.93	9.13			19	77.29	74.38	80.47	1.82
Yingkou		19	81.99	71.30	96.93	6.47			19	76.54	73.48	78.52	1.62
Jiaxing		19	77.90	67.53	91.99	6.69			19	79.18	75.43	82.49	2.36
Lianyungang		19	78.18	67.81	97.00	9.40			19	75.83	73.74	78.00	1.25
Nanjing		19	87.20	73.18	122.90	12.51			19	79.51	75.38	83.59	2.68
Nantong		19	74.70	61.01	91.73	8.66			19	78.39	74.50	82.82	2.74
Ningbo		19	68.17	48.01	81.86	7.97			19	80.54	79.36	81.66	0.74
Shanghai		19	72.49	58.27	89.68	8.16			19	81.73	79.52	83.66	1.37
Suzhou		19	78.78	63.32	96.22	9.21			19	80.73	77.25	83.82	2.27
Wenzhou		19	65.68	58.52	77.12	5.15			19	78.46	75.54	81.71	1.84
Wuxi		19	86.60	78.03	101.60	5.76			19	79.41	75.64	83.00	2.76
Yangzhou		19	77.57	65.70	94.86	9.66			19	76.53	74.20	78.56	1.30
Zhenjiang		19	78.55	65.09	97.90	11.25			19	77.92	73.85	81.98	2.54
Zhoushan		19	50.64	38.66	66.16	8.01			19	78.90	77.71	80.10	0.75
Beihai		19	48.23	36.14	62.36	7.26			19	78.16	75.20	79.92	1.51
Fangchenggang		19	47.26	41.76	52.64	3.31			19	75.49	72.76	76.95	1.38
Fuzhou		19	58.32	51.51	66.60	3.94			19	77.17	74.27	80.31	1.82
Guangzhou		19	67.46	57.36	81.79	7.84			19	79.25	75.46	82.52	2.29
Haikou		19	40.11	30.23	62.50	7.23			19	76.15	73.26	78.78	1.73
Jiangmen		19	60.97	52.98	75.60	6.66			19	77.44	73.30	80.12	2.25
Quanzhou		19	57.17	49.10	63.50	3.93			19	74.22	70.10	78.10	2.60
Xiamen		19	54.57	49.88	63.10	3.43			19	78.00	73.39	80.89	2.51
Shantou		19	53.55	42.06	63.98	5.27			19	76.10	74.12	78.08	1.24
Shenzhen		19	55.33	46.74	75.57	6.18			19	81.56	80.26	82.90	0.79
Hong Kong	19	53.27	44.74	73.57	6.14		19	83.46	81.57	85.50	1.20		
Zhanjiang	19	49.08	40.87	55.58	4.72		19	75.53	74.12	77.28	0.87		
Zhuhai	19	50.26	38.45	70.86	9.36		19	79.16	76.50	83.00	2.30		

City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	BULK	19	0.172	0.101	0.299	0.060		GEN	19	0.086	0.025	0.178	0.057
Dandong		19	0.437	0.176	0.849	0.224			19	0.250	0.051	0.667	0.149
Jinzhou		19	0.432	0.227	0.587	0.098			19	0.093	0.028	0.256	0.061
Qinhuangdao		19	0.851	0.610	0.932	0.076			19	0.040	0.016	0.090	0.024
Qingdao		19	0.250	0.192	0.319	0.030			19	0.057	0.025	0.142	0.032
Rizhao		19	0.741	0.652	0.921	0.068			19	0.087	0.038	0.119	0.025
Tangshan		19	0.514	0.014	0.888	0.342			19	0.029	0.007	0.067	0.016
Tianjin		19	0.429	0.292	0.523	0.067			19	0.087	0.035	0.169	0.046
Weihai		19	0.089	0.005	0.258	0.076			19	0.084	0.038	0.409	0.082
Yantai		19	0.343	0.242	0.606	0.095			19	0.081	0.019	0.203	0.058
Yingkou		19	0.535	0.424	0.673	0.079			19	0.116	0.051	0.286	0.071
Jiaxing		19	0.332	0.009	0.652	0.230			19	0.158	0.029	0.384	0.103
Lianyungang		19	0.624	0.504	0.733	0.061			19	0.129	0.053	0.248	0.061
Nanjing		19	0.519	0.277	0.684	0.125			19	0.132	0.062	0.265	0.063
Nantong		19	0.634	0.352	0.813	0.148			19	0.122	0.054	0.277	0.064
Ningbo		19	0.183	0.067	0.338	0.071			19	0.018	0.005	0.069	0.016
Shanghai		19	0.127	0.091	0.237	0.032			19	0.063	0.030	0.125	0.033
Suzhou		19	0.495	0.284	0.675	0.144			19	0.218	0.103	0.435	0.114
Wenzhou		19	0.413	0.033	0.782	0.269			19	0.100	0.021	0.221	0.057
Wuxi		19	0.556	0.320	0.818	0.165			19	0.114	0.034	0.199	0.053
Yangzhou		19	0.585	0.415	0.897	0.132			19	0.183	0.030	0.459	0.134
Zhenjiang		19	0.535	0.042	0.882	0.276			19	0.224	0.026	0.479	0.138
Zhoushan		19	0.488	0.292	0.743	0.103			19	0.031	0.017	0.066	0.013
Beihai		19	0.610	0.279	0.740	0.118			19	0.199	0.042	0.519	0.116
Fangchenggang		19	0.800	0.581	0.879	0.076			19	0.096	0.042	0.228	0.051
Fuzhou		19	0.323	0.132	0.594	0.135			19	0.135	0.036	0.366	0.103
Guangzhou		19	0.337	0.139	0.529	0.108			19	0.077	0.024	0.195	0.054
Haikou		19	0.061	0.008	0.227	0.067			19	0.131	0.017	0.468	0.126
Jiangmen		19	0.210	0.040	0.417	0.122			19	0.099	0.005	0.205	0.063
Quanzhou		19	0.249	0.091	0.438	0.095			19	0.098	0.040	0.299	0.054
Xiamen		19	0.093	0.042	0.157	0.040			19	0.038	0.016	0.112	0.023
Shantou		19	0.322	0.110	0.616	0.121			19	0.074	0.012	0.355	0.076
Shenzhen	19	0.024	0.010	0.083	0.015		19	0.009	0.003	0.026	0.006		
Hong Kong	19	0.103	0.037	0.190	0.046		19	0.033	0.021	0.063	0.011		
Zhanjiang	19	0.558	0.260	0.692	0.115		19	0.073	0.011	0.194	0.058		
Zhuhai	19	0.314	0.127	0.467	0.126		19	0.047	0.005	0.211	0.045		

City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	LIQ	19	0.236	0.133	0.530	0.098		CONT	19	0.273	0.017	0.393	0.086
Dandong		19	0.017	0.006	0.055	0.013			19	0.029	0.002	0.082	0.020
Jinzhou		19	0.295	0.121	0.540	0.126			19	0.157	0.028	0.347	0.096
Qinhuangdao		19	0.063	0.020	0.230	0.049			19	0.018	0.003	0.045	0.014
Qingdao		19	0.117	0.075	0.178	0.024			19	0.535	0.411	0.627	0.069
Rizhao		19	0.105	0.029	0.185	0.051			19	0.031	0.004	0.088	0.023
Tangshan		19	0.421	0.045	0.954	0.349			19	0.031	0.004	0.061	0.016
Tianjin		19	0.077	0.043	0.130	0.022			19	0.305	0.137	0.436	0.073
Weihai		19	0.036	0.005	0.300	0.067			19	0.115	0.059	0.245	0.046
Yantai		19	0.073	0.007	0.161	0.038			19	0.150	0.039	0.300	0.089
Yingkou		19	0.095	0.022	0.240	0.065			19	0.159	0.003	0.346	0.135
Jiaxing		19	0.382	0.168	0.747	0.194			19	0.073	0.018	0.159	0.041
Lianyungang		19	0.028	0.012	0.068	0.015			19	0.155	0.023	0.275	0.085
Nanjing		19	0.305	0.151	0.628	0.121			19	0.016	0.002	0.045	0.010
Nantong		19	0.138	0.022	0.250	0.084			19	0.040	0.006	0.154	0.036
Ningbo		19	0.155	0.118	0.225	0.029			19	0.629	0.329	0.777	0.109
Shanghai		19	0.037	0.028	0.048	0.005			19	0.690	0.601	0.759	0.044
Suzhou		19	0.203	0.079	0.312	0.067			19	0.034	0.004	0.086	0.025
Wenzhou		19	0.124	0.016	0.378	0.104			19	0.176	0.018	0.516	0.169
Wuxi		19	0.237	0.104	0.392	0.072			19	0.038	0.002	0.135	0.036
Yangzhou		19	0.168	0.019	0.294	0.085			19	0.033	0.009	0.092	0.020
Zhenjiang		19	0.213	0.043	0.511	0.141			19	0.026	0.005	0.078	0.024
Zhoushan		19	0.349	0.177	0.644	0.131			19	0.108	0.008	0.354	0.092
Beihai		19	0.092	0.017	0.145	0.034			19	0.025	0.006	0.050	0.012
Fangchenggang		19	0.023	0.011	0.063	0.012			19	0.048	0.019	0.088	0.020
Fuzhou		19	0.021	0.008	0.069	0.015			19	0.504	0.279	0.766	0.183
Guangzhou		19	0.149	0.069	0.266	0.068			19	0.339	0.062	0.656	0.197
Haikou		19	0.054	0.012	0.192	0.055			19	0.121	0.013	0.256	0.070
Jiangmen		19	0.355	0.106	0.673	0.165			19	0.221	0.031	0.684	0.191
Quanzhou		19	0.416	0.256	0.565	0.099			19	0.164	0.014	0.400	0.135
Xiamen		19	0.016	0.007	0.030	0.006			19	0.824	0.742	0.909	0.049
Shantou		19	0.052	0.002	0.182	0.057			19	0.418	0.088	0.612	0.174
Shenzhen	19	0.011	0.003	0.027	0.006		19	0.947	0.874	0.964	0.020		
Hong Kong	19	0.046	0.026	0.062	0.009		19	0.721	0.578	0.771	0.055		
Zhanjiang	19	0.301	0.150	0.654	0.134		19	0.053	0.002	0.143	0.050		
Zhuhai	19	0.390	0.108	0.621	0.181		19	0.086	0.022	0.198	0.065		

City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	PCGDP	19	7.41	2.23	12.95	3.46		POP	19	0.459	0.436	0.474	0.013
Dandong		19	2.65	0.77	4.61	1.27			19	0.158	0.152	0.162	0.003
Jinzhou		19	2.66	0.71	4.43	1.34			19	0.303	0.292	0.314	0.007
Qinhuangdao		19	3.10	1.15	5.24	1.34			19	0.373	0.343	0.386	0.012
Qingdao		19	6.98	1.86	12.85	3.79			19	0.689	0.651	0.736	0.022
Rizhao		19	3.83	0.85	7.53	2.24			19	0.542	0.521	0.573	0.016
Tangshan		19	5.56	1.44	8.79	2.73			19	0.539	0.520	0.564	0.013
Tianjin		19	7.34	2.02	14.31	3.87			19	0.834	0.767	0.926	0.047
Weihai		19	7.60	2.54	12.88	3.28			19	0.444	0.436	0.458	0.008
Yantai		19	6.21	1.52	11.02	3.28			19	0.472	0.470	0.474	0.002
Yingkou		19	3.77	0.85	6.49	2.02			19	0.434	0.421	0.449	0.010
Jiaxing		19	5.89	1.82	11.28	2.88			19	0.863	0.834	0.893	0.016
Lianyun gang		19	2.97	0.69	6.95	2.09			19	0.662	0.617	0.701	0.031
Nanjing		19	8.10	2.10	16.57	4.64			19	0.955	0.838	1.078	0.066
Nantong		19	5.40	1.03	12.83	3.77			19	0.887	0.720	0.978	0.113
Ningbo		19	7.66	2.42	14.32	3.58			19	0.592	0.575	0.619	0.012
Shanghai		19	8.30	3.74	15.73	3.32			19	2.210	2.079	2.317	0.077
Suzhou		19	10.85	3.04	19.90	5.02			19	0.750	0.684	0.835	0.042
Wenzhou		19	3.79	1.26	7.12	1.77			19	0.660	0.627	0.687	0.022
Wuxi		19	10.46	3.13	18.00	4.76			19	0.996	0.916	1.087	0.054
Yangzhou		19	5.69	1.12	12.89	3.92			19	0.693	0.680	0.701	0.006
Zhenjiang		19	7.19	1.89	12.90	4.05			19	0.702	0.694	0.709	0.005
Zhoushan		19	6.50	1.29	11.68	3.64			19	0.671	0.665	0.681	0.004
Beihai		19	3.45	0.86	7.70	2.45			19	0.472	0.434	0.521	0.031
Fangchenggang		19	4.01	0.81	7.94	2.66			19	0.143	0.126	0.160	0.012
Fuzhou		19	5.27	1.85	12.09	3.15			19	0.518	0.487	0.579	0.028
Guangzhou		19	10.11	3.80	18.53	4.43			19	1.089	0.959	1.283	0.094
Haikou		19	3.76	1.67	7.22	1.84			19	0.906	0.604	2.707	0.610
Jiangmen		19	3.78	1.62	6.82	1.65			19	0.410	0.399	0.421	0.006
Quanzhou		19	5.07	1.67	11.41	3.00			19	0.634	0.605	0.691	0.028
Xiamen	19	7.64	3.50	15.32	3.47		19	1.148	0.859	1.534	0.191		
Shantou	19	2.46	1.01	4.77	1.21		19	2.482	2.236	2.648	0.116		
Shenzhen	19	13.50	4.64	46.77	9.46		19	1.404	0.677	2.759	0.577		
Hong Kong	19	24.25	19.85	33.36	4.18		19	6.723	6.394	7.150	0.245		
Zhanjiang	19	2.22	0.75	4.17	1.17		19	0.598	0.562	0.644	0.027		
Zhuhai	19	9.41	3.27	17.55	4.46		19	0.600	0.465	0.766	0.085		

City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	RF	19	22.04	15.05	29.83	4.27		HF	19	22.37	15.54	30.01	5.21
Dandong		19	4.15	3.08	5.58	0.80			19	5.02	2.01	7.74	2.05
Jinzhou		19	5.86	5.43	6.74	0.39			19	10.58	4.46	17.40	5.57
Qinhuangdao		19	12.07	4.39	16.80	3.79			19	4.96	3.46	6.93	1.02
Qingdao		19	42.33	5.02	62.80	19.67			19	24.80	16.30	34.17	5.68
Rizhao		19	45.01	2.31	82.32	28.49			19	6.55	1.36	12.97	3.96
Tangshan		19	32.72	23.06	44.14	6.75			19	25.77	9.55	44.15	13.78
Tianjin		19	81.53	37.27	121.61	21.87			19	26.18	19.38	36.71	6.46
Weihai		19	0.95	0.45	2.62	0.58			19	5.53	2.82	8.81	1.89
Yantai		19	13.31	5.63	23.62	5.99			19	14.96	6.98	21.39	4.14
Yingkou		19	16.08	6.77	25.81	5.62			19	10.00	2.60	16.49	5.43
Jiaxing		19	0.46	0.22	0.96	0.21			19	6.86	1.91	14.53	4.40
Lianyungang		19	27.84	9.23	45.47	13.03			19	7.30	2.91	12.30	3.16
Nanjing		19	12.93	8.17	18.20	3.28			19	13.61	9.16	22.12	4.11
Nantong		19	0.75	0.12	1.42	0.41			19	10.80	4.39	20.20	4.15
Ningbo		19	19.59	7.25	29.60	7.07			19	17.63	8.30	37.04	8.41
Shanghai		19	18.25	4.82	68.14	20.14			19	37.60	28.87	43.81	4.96
Suzhou		19	1.76	0.91	4.05	0.71			19	11.23	4.74	23.83	4.56
Wenzhou		19	3.39	0.33	7.15	2.38			19	9.59	5.08	15.18	3.02
Wuxi		19	1.48	0.72	2.16	0.54			19	10.80	5.89	17.39	3.54
Yangzhou		19	0.28	0.00	0.48	0.16			19	5.65	3.69	7.65	1.28
Zhenjiang		19	3.84	1.34	8.05	2.32			19	6.69	3.46	12.42	2.49
Zhoushan		19	0.09	0.01	0.21	0.08			19	4.44	1.27	10.37	3.01
Beihai		19	2.92	1.17	4.39	0.89			19	4.01	1.77	7.18	1.85
Fangchenggang		19	27.19	8.90	42.62	11.14			19	3.48	0.18	9.17	2.41
Fuzhou		19	3.54	2.57	4.35	0.53			19	10.23	4.85	18.02	4.95
Guangzhou		19	57.49	16.58	70.13	15.52			19	45.40	13.29	88.35	25.57
Haikou		19	6.35	0.00	11.85	3.54			19	2.62	0.32	5.33	1.37
Jiangmen		19	0.03	0.00	0.07	0.02			19	6.00	2.04	13.23	3.67
Quanzhou		19	8.61	2.43	12.10	2.91			19	9.23	4.72	20.01	4.90
Xiamen	19	6.63	2.37	10.99	2.46		19	8.90	1.33	23.16	8.03		
Shantou	19	1.00	0.60	1.36	0.22		19	3.10	1.03	6.64	1.89		
Shenzhen	19	2.77	0.67	4.80	1.42		19	16.03	4.27	25.40	8.22		
Hong Kong	19	0.22	0.10	0.48	0.13		19	29.52	17.44	40.47	7.81		
Zhanjiang	19	23.91	8.12	32.48	7.61		19	7.76	3.18	16.92	4.42		
Zhuhai	19	1.91	0.00	8.82	3.09		19	5.41	1.51	9.97	3.42		

City	Variable	Obs	Mean	Min	Max	Std. Dev		Variable	Obs	Mean	Min	Max	Std. Dev
Dalian	INDU	19	6.52	1.10	12.19	3.90		DOCTOR	19	28.35	20.89	37.86	4.49
Dandong		19	0.69	0.11	1.36	0.47			19	19.37	14.24	26.69	3.57
Jinzhou		19	1.73	0.19	3.65	1.23			19	20.62	12.14	31.99	5.83
Qinhuangdao		19	1.08	0.17	2.02	0.60			19	22.59	14.89	32.72	5.79
Qingdao		19	10.90	1.67	21.48	6.67			19	27.14	18.67	45.50	8.50
Rizhao		19	1.77	0.11	3.60	1.17			19	15.53	8.73	25.54	4.64
Tangshan		19	6.97	0.68	13.87	4.40			19	21.29	15.48	32.11	4.87
Tianjin		19	17.79	2.94	35.54	11.23			19	30.98	23.97	41.90	5.30
Weihai		19	4.78	1.06	8.52	2.35			19	24.94	14.46	38.77	7.03
Yantai		19	10.01	1.13	19.96	6.23			19	22.65	14.78	31.29	5.64
Yingkou		19	1.87	0.19	3.84	1.26			19	20.99	13.10	28.26	4.35
Jiaxing		19	4.96	0.64	9.78	3.02			19	23.40	12.81	36.87	6.74
Lianyungang		19	2.75	0.21	6.86	2.48			19	14.16	8.61	24.10	4.80
Nanjing		19	8.78	1.77	16.72	5.00			19	29.71	17.91	50.33	8.92
Nantong		19	7.90	0.78	16.85	5.65			19	18.19	11.05	27.44	5.00
Ningbo		19	9.91	1.63	18.46	5.38			19	30.35	13.47	48.63	9.20
Shanghai		19	25.65	7.00	42.69	10.99			19	34.84	26.82	52.91	8.05
Suzhou		19	21.94	2.79	41.64	12.47			19	30.30	14.50	49.16	10.94
Wenzhou		19	3.77	0.83	6.50	1.73			19	22.83	8.59	36.22	7.82
Wuxi		19	11.19	2.01	20.04	5.67			19	28.10	15.29	46.06	8.67
Yangzhou		19	5.60	0.61	11.88	3.97			19	18.16	11.06	27.48	4.45
Zhenjiang		19	4.81	0.61	10.28	3.48			19	22.72	14.31	31.37	5.59
Zhoushan		19	0.98	0.09	2.08	0.69			19	29.34	15.94	65.23	11.14
Beihai		19	0.95	0.05	2.98	1.02			19	16.87	10.13	23.45	3.31
Fangchenggang		19	0.70	0.02	1.98	0.67			19	13.94	9.33	21.85	4.87
Fuzhou		19	4.88	0.79	9.75	3.07			19	22.78	14.15	34.31	5.73
Guangzhou		19	12.95	2.83	23.26	6.83			19	43.34	30.76	61.50	9.36
Haikou		19	0.39	0.10	0.65	0.17			19	40.20	17.21	72.61	14.90
Jiangmen		19	2.94	0.94	5.05	1.41			19	18.59	12.77	27.34	4.40
Quanzhou		19	6.74	0.57	14.28	4.75			19	14.05	7.22	23.37	5.72
Xiamen		19	3.61	0.80	6.44	1.78			19	41.40	26.99	58.26	9.79
Shantou		19	1.85	0.33	3.68	1.15			19	12.80	8.60	19.20	3.50
Shenzhen	19	17.92	3.08	33.15	9.55		19	76.38	56.31	88.45	10.78		
Hong Kong	19	0.32	0.21	0.43	0.07		19	17.77	15.07	19.95	1.29		
Zhanjiang	19	1.49	0.28	2.91	0.89		19	11.03	6.80	16.10	2.79		
Zhuhai	19	2.83	0.66	5.03	1.38		19	39.94	19.65	58.20	11.95		

City	Variabl e	Ob s	Mea n	Min	Max	Std. Dev		Variabl e	Ob s	Mea n	Min	Ma x	Std. Dev
Dalian	ELEV	19	77.5	77.5	77.5	0		WIND	19	6.39	5.9 0	6.75	0.22
Dandong		19	252. 3	252. 3	252. 3	0			19	4.16	3.6 8	4.48	0.24
Jinzhou		19	76.2	76.2	76.2	0			19	5.66	5.2 4	6.05	0.23
Qinhuangdao		19	233. 4	233. 4	233. 4	0			19	4.33	3.3 4	5.04	0.56
Qingdao		19	51.1	51.1	51.1	0			19	6.09	5.5 5	7.22	0.51
Rizhao		19	130. 3	130. 3	130. 3	0			19	4.98	4.1 4	6.16	0.64
Tangshan		19	60.5	60.5	60.5	0			19	4.64	3.7 5	5.21	0.42
Tianjin		19	20.0	20.0	20.0	0			19	5.40	4.6 3	6.11	0.40
Weihai		19	59.3	59.3	59.3	0			19	8.55	7.5 6	9.96	0.74
Yantai		19	100. 5	100. 5	100. 5	0			19	6.08	5.3 2	7.42	0.61
Yingkou		19	165. 3	165. 3	165. 3	0			19	6.36	5.6 6	6.85	0.30
Jiaxing		19	7.3	7.3	7.3	0			19	5.69	5.3 1	6.03	0.23
Lianyungang		19	18.5	18.5	18.5	0			19	4.78	4.3 7	5.17	0.20
Nanjing		19	25.8	25.8	25.8	0			19	5.02	4.6 1	5.25	0.21
Nantong		19	8.4	8.4	8.4	0			19	6.19	5.7 0	6.80	0.30
Ningbo		19	121. 5	121. 5	121. 5	0			19	6.45	6.1 4	7.09	0.26
Shanghai		19	7.7	7.7	7.7	0			19	7.12	6.3 8	7.64	0.31
Suzhou	19	7.7	7.7	7.7	0		19	6.06	5.6 8	6.44	0.20		
Wenzhou	19	348. 3	348. 3	348. 3	0		19	4.26	3.6 9	4.64	0.23		
Wuxi	19	21.8	21.8	21.8	0		19	4.99	4.7 5	5.36	0.13		
Yangzhou	19	11.2	11.2	11.2	0		19	5.16	4.7 1	5.58	0.23		



Zhenjiang	19	25.9	25.9	25.9	0		19	5.01	4.7 4	5.25	0.16
Zhoushan	19	51.1	51.1	51.1	0		19	5.47	4.7 4	6.16	0.48
Beihai	19	27.6	27.6	27.6	0		19	5.47	4.8 3	6.29	0.46
Fangchenggan g	19	251. 9	251. 9	251. 9	0		19	4.31	4.0 2	4.99	0.35
Fuzhou	19	344. 2	344. 2	344. 2	0		19	6.57	5.6 3	7.48	0.56
Guangzhou	19	108. 4	108. 4	108. 4	0		19	4.99	4.5 9	5.41	0.27
Haikou	19	41.8	41.8	41.8	0		19	5.59	4.0 5	6.73	0.91
Jiangmen	19	79.5	79.5	79.5	0		19	7.11	6.7 2	7.36	0.21
Quanzhou	19	438. 1	438. 1	438. 1	0		19	7.27	6.6 8	8.16	0.35
Xiamen	19	146. 1	146. 1	146. 1	0		19	5.97	5.3 3	6.57	0.30
Shantou	19	54.8	54.8	54.8	0		19	4.81	3.9 8	5.59	0.60
Shenzhen	19	81.9	81.9	81.9	0		19	5.56	5.3 2	6.26	0.21
Hong Kong	19	122. 0	122. 0	122. 0	0		19	6.24	5.7 3	7.38	0.41
Zhanjiang	19	33.8	33.8	33.8	0		19	5.78	5.3 3	6.37	0.30
Zhuhai	19	33.9	33.9	33.9	0		19	8.06	7.6 6	8.38	0.18