Impact of Ozone Pollution on Human Health and Economic Loss Assessment

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Abstract: The problem of ozone (O₃) pollution in the air has become increasingly prominent in recent years, and the health effects of O₃ pollution on people have attracted more attention. O₃ is the primary pollutant with the highest over-limit rate in the Guangdong-Hong Kong-Macao Pearl River Delta. Based on the data of O₃ concentration, exposed pollution, baseline mortality, and hospitalization rate monitored by the Pearl River Delta Regional Air Quality Monitoring Network (PRD-RAQMN) in Shenzhen. This study evaluates the impact of O₃ pollution on human health and economic loss in Shenzhen from 2006 to 2018 by using the relative risk model, benefit conversion method, and disease cost method. The annual mean value of daily 8 h maximum concentration of O₃ in Shenzhen shows an overall significant upward trend from 2006 to 2018, with an average annual value range of 70 to 190.92 μg/m³ and an average value of 112.89 μg/m³. The number of death and hospitalization caused by O₃ pollution increases significantly, and the incidence of respiratory system diseases is higher than that of circulatory system diseases. However, the mortality caused by circulatory system diseases was higher than that caused by respiratory system diseases. The economic loss of health caused by O₃ pollution increased yearly, with an annual average economic loss of 82.46 million RMB, reached 658.31 million RMB in 2018, accounted for 0.0272% of Shenzhen’s GDP in 2018.

Keywords: Ozone, Health Effects, Economic Loss, Shenzhen

1. Introduction

With the continuous acceleration of global industrialization and urbanization, the impact of urban air pollution on human health, economy, and society is becoming more and more important, so it has been paid great attention to by all countries and relevant organizations in the world. In recent years, many studies have been carried out on the effects of air pollution and population health as a reference basis for formulating and assessing relevant environmental policies. According to the global gender and environment outlook published by the United Nations Environment Programme in 2006, air pollution was one of the main factors leading to environmental and health problems in both developed and developing countries [1]. Global burden of disease (GBD) [2] reported that the disability-adjusted life year (DALY) caused by O₃ was 4.1 million people/year in 2015 [3]. Compared with the results in 2006, the number of deaths worldwide associated with particulate pollution and ozone (O₃) pollution increased significantly and reached 4.09 million (95%CI: 3.62-4.58 million) and 0.23 million (95%CI: 0.09-0.38 million) in 2016, respectively. The mortality of residents increased by 0.26% (95%CI: 0.15%-0.37%) with every 10 μg/m³ increased in O₃.

Studies showed that O₃ has a typical biological toxic effect, which could cause inflammation of cardiovascular system and respiratory system as well as system oxidation stress response [4]. Since 2005, the results of several cohort studies suggested that long-term O₃ exposure has a potential link with mortality, and mainly affected the mortality of respiratory and cardiovascular diseases [5, 6]. There was a significant positive correlation between the increase of environmental O₃ concentration and the increase of incidence [7]. The most commonly used health terminal in this kind of research is the number of hospital admissions or emergency visits for asthma, respiratory infection and other respiratory diseases. Relevant literature found that there was a positive correlation between the change of O₃ level and the admission amount of respiratory diseases in a large number of cities [8]. Nuvolone...
et al. [9] found that the concentration of O$_3$ every increased 10 µg/m$^3$ caused the number of coronary artery deaths in hospitals to increase by 6.3% (95%CI: 1.2%–11.7%), and women, the elderly and patients hospitalized increased for cerebrovascular diseases would face high risks.

Air pollution not only affects people's health but also affects the economy. The central framework of environmental-economic accounting system (SEEA-2012) was issued by the United Nations Commission on environmental and economic accounting and has been recognized as the first international statistical standard of environmental-economic accounting [10]. The physical terminal of health loss caused by air pollution includes the total number of premature deaths of urban residents, the number of inpatients in the respiratory and circulatory system, and the number of patients with chronic bronchitis. The economic loss accounting terminal includes the economic loss caused by premature death, hospitalization, off work, and the long-term disability of chronic bronchitis patients. To assess the economic loss of air pollution to human health, the willingness to pay method (WTP) was used in western developed countries [11]. However, the disease cost method and the revised human capital method were used in developing countries with an incomplete market economy [12]. The technical specification for health risk assessment of air pollution population proposed a general model for health risk assessment. In this general model, the data of air pollution in various concentration ranges relates to epidemiological parameters, such as the relative risk of health outcomes caused by air pollution exposure of the target population, the baseline incidence of health outcomes (1/10$^3$), the proportion of population attributable risk, and the calculation of diseases incidence rate, hospitalization rate, and the mortality due to air pollution exposure. Then combined with the size of the exposed population, the number of cases or deaths attributable to air pollution exposure could be estimated. Zmirou et al. [13], Patankar & Trivedi [14], and Zhang et al. [15] used the economic burden of disease to assess the medical expenses caused by exposure to particulate air pollution in three metropolitan areas of France, Mumbai city of India, and 111 cities of China. Wei et al. used the Poisson regression model, modified human capital method and disease cost method to evaluate the acute health damage effect, early death economic loss and hospitalization, illness and outpatient economic loss of PM$_{2.5}$ exposure of Xi'an residents, respectively [16].

In recent years, the haze phenomenon characterized by a high concentration of fine particles (PM$_{2.5}$) and photochemical smog characterized by O$_3$ has been highlighted in the air pollution of urban agglomerations in China due to the rapid development of urbanization, industrialization, and the rapid increase of vehicle ownership. Air pollution has entered the era of mixed pollution and the problem of O$_3$ pollution has become increasingly prominent. The concentration of PM$_{2.5}$ in most areas showed a significant downward trend and the assessment objectives basically achieved with the release and implementation of the "ten atmospheric regulations". However, the pollution of O$_3$ was increasingly prominent at the same time. The Pearl River Delta (PRD) region is an important urban agglomeration area with rapid economic development in China. Photochemical smog is one of the main air pollution problems in the PRD of its low latitude [17]. The comparative study of O$_3$ concentration in the pilot cities in China showed that the pollution of O$_3$ in the pilot cities of the PRD was prominent and higher than that in the pilot cities in the north [18]. The concentration of O$_3$ in the pilot cities of the PRD could be nearly twice as high as that in the pilot cities of the north. According to statistics, the proportion of days of O$_3$ concentration exceeding the standard increased and the proportion of cities meeting the standard decreased in 338 cities of China from 2015 to 2017. The concentration of O$_3$ in some areas exceeded the new standard level II concentration limit (160 µg/m$^3$). The proportion of O$_3$ in the main pollutant days in Beijing, Tianjin and Hebei was second only to PM$_{2.5}$ and has a large increase. In the PRD and the Yangtze River Delta, O$_3$ replaced PM$_{2.5}$ as the primary pollutant throughout the year in 2014 and 2017, respectively [19]. O$_3$ is currently the primary air pollutant with the highest rate of excess in the PRD. In the past decade, the overall trend of the annual average concentration of O$_3$ in the air has continued to rise, and the health effects of the population caused by O$_3$ pollution have received increasing attention. However, there is a lack of long-term studies on the health effects and economic losses of O$_3$ pollution. In view of the above factors, this study uses the data of O$_3$ concentration monitored by the PRD Regional Air Quality Monitoring Network (PRD-RAQMN), exposed population, baseline mortality, and hospitalization rate from 2006 to 2018, and uses the relative risk model and other evaluation methods to evaluate the impact of O$_3$ pollution on human health and economic loss in Shenzhen in the past 13 year.

2. Research Methods

2.1. Estimation Method

The exposure effect coefficient between air pollution and health effect obtained from pollution epidemiology could be used to evaluate health risk. Based on the proportional hazard model of Poisson regression, the health effect value model formula under a certain O$_3$ concentration is obtained [20], as shown in Eq. (1).

$$ E = E_0 \times \exp[\beta \times (C - C_0)] \quad (1) $$

$$ \Delta E = E - E_0 \quad (2) $$

$$ \Delta E = E \times \{1 - 1/\exp[\beta \times (C - C_0)]\} \quad (3) $$

$$ I_i = P \times \Delta E = P \times E \times \{1 - 1/\exp[\beta \times (C - C_0)]\} \quad (4) $$

Where $E_0$ represents the health effect value at reference concentration, and $E$ is the actual health effect value at actual concentration, such as mortality and hospitalization rate. $P$ and $\beta$ are exposed population and exposure effect coefficient, respectively. $C$ and $C_0$ are the actual concentration and reference concentration, respectively. The change of health
effects due to O₃ pollution could be calculated from Eq. (1). Finally, Iᵢ caused by O₃ pollution could be calculated from Eq. (4).

The exposure effect coefficient between O₃ pollution and health terminal reflects the change of mortality and hospitalization rate of the circulatory system and respiratory system diseases for every 10 µg/m³ increase in O₃ concentration. This study retrieved epidemiological studies related to the health effects of O₃ exposure at home and abroad to obtain relevant exposure effect coefficients, as shown in Table 1.

Table 1. Exposure-response coefficient values of O₃ and various healthy terminals.

<table>
<thead>
<tr>
<th>Category</th>
<th>Health effect endpoint</th>
<th>Exposure-response coefficient (%)</th>
<th>95%CI</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>Circulatory system death</td>
<td>0.7</td>
<td>0.57~0.86</td>
<td>Liao Zhiheng et al. [17]</td>
</tr>
<tr>
<td></td>
<td>Respiratory system death</td>
<td>0.64</td>
<td>0.47~0.86</td>
<td>Liao Zhiheng et al. [17]</td>
</tr>
<tr>
<td>Hospitalization</td>
<td>Circulatory system death</td>
<td>0.13</td>
<td>0.05~0.21</td>
<td>Wang et al. [21]</td>
</tr>
<tr>
<td></td>
<td>Respiratory system death</td>
<td>0.22</td>
<td>0.15~0.29</td>
<td>Wang et al. [21]</td>
</tr>
</tbody>
</table>

Note: 95%CI represents a 95% confidence interval.

The U.S. Environmental Protection Agency (1997), the World Health Organization (2000), and the Ministry of Ecology and Environment of China revised the O₃ concentration standards, all of them used the maximum concentration of 8h per day. Therefore, the maximum concentration of 8h per day of O₃ was selected as the exposure index of O₃ concentration in this study. The selection of reference concentration reference of O₃ is very important in the evaluation of the effect of O₃ pollution on human health. The environmental background value given by the World Health Organization was mostly selected as the threshold value of O₃ pollution in the evaluation of O₃ pollution [17, 22]. According to the World Health Organization, the background concentration of O₃ in the earth’s near-surface atmosphere was 70 µg/m³ (calculated by the maximum concentration of 8 h per day, C₀=70 µg/m³) [23].

The economic loss of O₃ pollution in the atmosphere is not only related to the concentration of O₃, but also to the exposed population, economic level, and medical expense of the whole society. The health economic loss of O₃ pollution could be divided into economic loss caused by premature death and the cost of hospitalization and labor caused by circulatory and respiratory diseases. In this study, the benefit conversion method and disease cost method were used to estimate the above two types of economic losses, respectively.

(1) The economic loss of premature death estimated by benefit conversion method

The economic loss caused by the premature death of residents is estimated by the method of benefit conversion [20]. The method is as follows:

\[ W_{BJX} = W_{BJ2016} \times (I_{BJ2016} / I_{BJ2016})^e \]  \hspace{1cm} (5)

Where \( W_{BJX} \) and \( W_{BJ2016} \) are the unit economic cost of premature death in year X and 2016 in Beijing (\( W_{BJ2016} = 1197584 \) RMB) [24], respectively. \( I_{BJX} \) and \( I_{BJ2016} \) are the per capita disposable income in year X and 2016 in Beijing, respectively. The income elasticity coefficient is e and sets as 1.

\[ W = W_{BJ} \times (I/I_{BJ})^e \]  \hspace{1cm} (6)

\[ C_{death} = I_i \times W \]  \hspace{1cm} (7)

Where \( W \) and \( W_{BJ} \) are the unit economic cost of premature death in Shenzhen and Beijing, respectively. \( I \) and \( I_{BJ} \) are the per capita disposable income in Shenzhen and Beijing, respectively. \( C_{death} \) stands for the economic loss of premature death. The economic loss of premature death could be calculated from Eq. (6) and Eq. (7).

(2) The economic loss of hospitalization estimated by the disease cost method

The economic loss of hospitalization caused by O₃ pollution could be calculated by the method of disease cost, as Eq. (8).

\[ C_{hospitalization} = (C_{pi} + GDP_p \times T \times I_i) \]  \hspace{1cm} (8)

Where \( C_{hospitalization} \) and \( C_{pi} \) are defined as the economic loss of hospitalization and hospitalization cost per unit case of health terminal, respectively. \( GDP_p \) is the daily average of per capita GDP in Shenzhen, and \( T \) represents the number of days in the hospital.

2.2 Data Source and Description

The date of O₃ daily 8 h maximum concentration annual average value was from the monitoring result report of PRD-RAQMN from 2006 to 2018 [25]. The data of disease terminal mortality, hospitalization rate, unit case hospitalization cost, and hospitalization were from the summary of health statistics in Shenzhen [26]. The data of the exposed population and GDP were from the statistical yearbook of Shenzhen [27]. The annual disposable income of Shenzhen [28] and Beijing were derived from the Guangdong Statistical Yearbook and the Chinese Statistical Yearbook [29], respectively. The statistics of mortality, hospitalization rate, and resident population in Shenzhen from 2006 to 2018 were shown in Table 2.

In the monitoring results report of PRD-RAQMN from 2006 to 2018, the annual value of daily 8 h maximum concentration of O₃ was not directly given in the monitoring results report from 2006 to 2013 [30]. Through adopted the rate of daily average value, daily 8 h maximum value, and daily 1 h maximum value was 8:15:20, the annual average value of 8 h maximum concentration of O₃ was calculated according to the daily average concentration in the monitoring results. The annual average value of 8 h maximum
concentration of \( \text{O}_3 \) from 2014 to 2018 which was given in the monitoring results report was directly used in this study.

Table 2. Morality and hospitalization rate of circulatory and respiratory disease in Shenzhen from 2006 to 2018.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mortality rate (/million)</th>
<th>Hospitalization rate (/million)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Circulatory</td>
<td>Respiratory</td>
</tr>
<tr>
<td>------</td>
<td>---------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>2006</td>
<td>1.626</td>
<td>0.484</td>
</tr>
<tr>
<td>2007</td>
<td>1.759</td>
<td>0.486</td>
</tr>
<tr>
<td>2008</td>
<td>1.914</td>
<td>0.465</td>
</tr>
<tr>
<td>2009</td>
<td>1.926</td>
<td>0.411</td>
</tr>
<tr>
<td>2010</td>
<td>1.468</td>
<td>0.450</td>
</tr>
<tr>
<td>2011</td>
<td>1.694</td>
<td>0.460</td>
</tr>
<tr>
<td>2012</td>
<td>1.700</td>
<td>0.496</td>
</tr>
<tr>
<td>2013</td>
<td>2.775</td>
<td>0.345</td>
</tr>
<tr>
<td>2014</td>
<td>2.740</td>
<td>0.379</td>
</tr>
<tr>
<td>2015</td>
<td>2.662</td>
<td>0.418</td>
</tr>
<tr>
<td>2016</td>
<td>3.280</td>
<td>0.829</td>
</tr>
<tr>
<td>2017</td>
<td>3.222</td>
<td>0.812</td>
</tr>
<tr>
<td>2018</td>
<td>3.431</td>
<td>0.810</td>
</tr>
</tbody>
</table>

3. Results Analysis

3.1. Characteristic Analysis of \( \text{O}_3 \) Exposure Concentration

As shown in Figure 1, the concentration of \( \text{O}_3 \) showed an obvious upward trend from 2006 to 2018. According to the date of \( \text{O}_3 \) concentration monitored by PRD-RAQMN Shenzhen Ground Monitoring Station from 2006 to 2018, the concentration of \( \text{O}_3 \) in 2008 was in line with the benchmark value, given by the world health organization and was 70 µg/m\(^3\). However, the concentration of \( \text{O}_3 \) in other years were exceeded the standard. The annual average range of daily 8 h maximum concentration of \( \text{O}_3 \) was 70~190 µg/m\(^3\), with an average value of 112.89 µg/m\(^3\). The annual average of daily 8 h maximum of \( \text{O}_3 \) reached the maximum value of 190.92 µg/m\(^3\) in 2017 and increased 120.92 µg/m\(^3\) compared to the lowest value of 70 µg/m\(^3\) in 2008.

According to the evaluation results, 66 cases were attributed to death and hospitalization in 2006 (95%CI: 41–91), and 7150 cases were attributed to death and hospitalization in 2008 (95%CI: 4335–9943). Then the number of attributable deaths and inpatients increased yearly, and the increasing trend was basically consistent with the increasing trend of \( \text{O}_3 \) concentration. In 2008, the cases of circulatory system attributable premature death (348 cases, 95%CI: 285–424) accounted for approximately 82.26% of total attributable deaths (423 cases, 95%CI: 341–524), which indicated that \( \text{O}_3 \) pollution mainly affected human circulatory system. From 2006 to 2012, the number of deaths attributed to circulatory system and respiratory system in Shenzhen was 100 (95%CI: 81–122) and 25 (95%CI: 18–34), respectively, and then the number of deaths attributed to circulatory system and respiratory system in PRD was 1894 (95%CI: 1546–2319) and 1128 (95%CI: 830–1508), respectively. The number of deaths attributed to the circulatory system and respiratory system in Shenzhen accounted for 5.28% and 2.22% of the 13 cities in the PRD, respectively. The number of attributable deaths and inpatients calculated was 0 in 2008, due to the concentration of \( \text{O}_3 \) not reached the reference concentration.

In terms of health categories, the number of deaths...
attributed to the circulatory system and respiratory system was 1311 (95%CI: 1074~1599) and 271 (95%CI: 201~361) in 2006~2018, respectively. And the number of hospitalizations attributed to the circulatory system and respiratory system was 7506 (95%CI: 2807~12081) and 19214 (95%CI: 13141~25249), respectively. It showed that the circulatory diseases caused by O$_3$ pollution were more difficult to cure than respiratory diseases, and the hospitalization of respiratory diseases was higher than that of circulatory diseases.

3.3. Health Effects of O$_3$ Pollution in Different Age Groups

The attributed death was divided into the age group ≤1-year-old, the age group from 1 to 60 years old, and the age group ≥60 years old according to the death dates of all age groups in the summary of health statistics of Shenzhen city. The health effects of the circulatory system and respiratory system diseases were shown in Figure 4 and Figure 5, respectively. Only, the situation from 2006 to 2013 was analyzed in this study because of the limited date. The health effects of the circulatory system and respiratory system in the age group ≥60 years old accounted for 86.88% and 78.75% of the total, respectively, indicating that people aged ≥60 years old were more affected by O$_3$ pollution. In addition, the mean value of circulatory system health and respiratory system health were 458 cases and 120 cases, respectively, indicating that cardiovascular diseases mainly exist in the elderly population. Because of the aging cardiovascular for the elderly, the risk of disease increases. The age group ≤1-year-old was also greatly affected by O$_3$ pollution because of its poor resistance. The health effects of the circulatory system and respiratory system accounted for 7.42% and 17.76% of the total, respectively. And the mean health effects were 45 cases and 39 cases, respectively.

3.4. Health and Economic loss of O$_3$ Pollution

The health and economic loss of O$_3$ pollution in Shenzhen from 2006 to 2018 was calculated by Eqs. (5) - (8). As shown in Table 3, the health economic loss caused by O$_3$ pollution was very large, and the average economic loss was 82.46 million RMB/ year. The economic loss reached 658.31 million RMB (95%CI: 502.37~827.86 million RMB) and accounted for 0.0272% (95%CI: 0.0207~0.0346%) of Shenzhen’s GDP in 2018. The estimate of average economic loss was lower than the estimate of other major cities calculated by Zeng et al.[19]. This phenomenon could be attributed to that Shenzhen is a new city with a relatively young population, so the mortality rate was relatively low.

The economic losses of the circulatory system and respiratory system were 1661.23 million RMB (95%CI: 1286.61~2092.50 billion RMB) and 482.85 million RMB (95%CI: 347.87~639.22 million RMB) from 2006 to 2018, respectively. The number of inpatients was far more than the number of deaths according to the above, but the economic loss of death accounted for 77.5% of the total economic loss. Therefore, the economic loss was mainly caused by premature death. The attributable economic loss was 3.2 million RMB (95%CI: 2.47~4.09 million RMB) in 2006, while it reached 658.31 million RMB (95%CI: 502.37~837.86 million RMB) in 2018, an increase of 95.6%. Combined with Figure 1 and Figure 5, it could be seen that the attributable health economic loss increased yearly with the aggravation of O$_3$ pollution. In 2018, the economic loss of health caused by the death of the circulatory system and respiratory system increased by 454.73 million RMB and 98.37 million RMB, respectively. And the economic loss of health caused by the hospitalization of the circulatory system and respiratory system increased by 53.46 million RMB and 48.55 million RMB, respectively. It could indicate that the economic loss caused by the death of the circulatory system increased the most.
4. Discussion

4.1. Selection of Health Effect

The choice of the health effect terminal of air pollution should follow the principle of the most sensitive effect, which could sensitively and accurately reflect the adverse effects of certain air pollutants on the health of the population [31]. However, the selection of such health effect endpoints is often difficult and complicated. The influence of air pollution on human health was complex, which included acute effects and chronic effects. The toxic mechanism of $O_3$ pollution to human health was not clear. On the other hand, $O_3$ pollution may cooperate with other pollutants in the atmosphere, and the characteristics of health hazards are complex, so it is difficult to select health terminals. In this study, the death and hospitalization of the respiratory system and circulatory system diseases as health effects were selected to evaluate their economic loss. This study evaluated the risk of early death and hospitalization caused by $O_3$ pollution and did not calculate other health effects such as outpatient service. Therefore, the health effects of $O_3$ pollution may be underestimated.

4.2. Determination of Threshold

Whether there is an impact threshold for air pollutants is an important issue in health impact assessment. Some studies showed that $O_3$ has no obvious threshold value. However, relevant toxicology studies indicated that the human body has certain self-regulation and adaptability to the impact of exogenous chemicals. When the exposure pollutant reached a certain concentration and exceeded its self-regulation, pathological changes and health damage may occur. Many epidemiological studies showed that the morbidity and mortality of the relevant population would change when air pollution reached a certain concentration. The Air Quality Guideline (AQG) [23] issued by the World Health Organization (WHO) considered that there was a critical value causing health hazards, and recommended that the atmospheric environmental quality standards in the guidelines be used as threshold values for $O_3$ air pollution research. Therefore, the value of environmental background of 70 $\mu g/m^3$ (calculated as the maximum concentration of 8 h per day) given by the WHO was selected as the threshold value of $O_3$ pollution in this study.

4.3. Determination of Exposure Effect Coefficient

The impact of air pollution on human health was expressed by a dose-response function of pollutants and health hazard terminals. The health damage assessment model of air pollution first studies the correlation coefficient between a pollutant and corresponding health effect endpoint, the correlation coefficient $\beta$ between $O_3$ pollution and the health effects was calculated. Then the ratio of each unit of increase in air pollutant concentration leading to the corresponding health endpoint, such as the increase of population mortality or morbidity, which is the basis for the assessment of effect of population health. There were two methods to establish the dose-response relationship model of the health effects of air pollution. One is the method of environmental epidemiology, which is to carry out environmental epidemiology investigation and research in the areas that need to be calculated. At the same time, the corresponding air pollution monitoring data and relevant data are collected. Based on the data of various terminals of health effects and other confounding factors that endanger the health of the population, the data are statistically analyzed to obtain a statistical model and the correlation coefficient of the dose-response relationship between the two as the basis for effective evaluation. This method was divided into long-term cohort study and time-series study. Another is the basic method of health risk assessment, which is used to collect the data of relevant research literature at home and abroad. The dose-response relationship model of air pollutants and related health effect endpoints are obtained according to certain statistical methods. In this study, the exposure effect coefficient $\beta$ between $O_3$ pollution and the health terminal was used to evaluate the health effect of $O_3$ pollution in Shenzhen.

4.4. Evaluation Method of Health Economic Loss

In assessing the premature economic loss caused by

<table>
<thead>
<tr>
<th>Year</th>
<th>Mortality</th>
<th>Hospitalization</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Circulatory</td>
<td>Respiratory</td>
<td>Circulatory</td>
</tr>
<tr>
<td>2006</td>
<td>0.0225</td>
<td>0.0061</td>
<td>0.0015</td>
</tr>
<tr>
<td>2007</td>
<td>0.0429</td>
<td>0.0108</td>
<td>0.0029</td>
</tr>
<tr>
<td>2008</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>2009</td>
<td>0.0703</td>
<td>0.0137</td>
<td>0.0073</td>
</tr>
<tr>
<td>2010</td>
<td>0.2143</td>
<td>0.0601</td>
<td>0.0326</td>
</tr>
<tr>
<td>2011</td>
<td>0.3004</td>
<td>0.0746</td>
<td>0.0419</td>
</tr>
<tr>
<td>2012</td>
<td>0.1451</td>
<td>0.0388</td>
<td>0.0198</td>
</tr>
<tr>
<td>2013</td>
<td>0.3007</td>
<td>0.0342</td>
<td>0.0278</td>
</tr>
<tr>
<td>2014</td>
<td>1.0227</td>
<td>0.1295</td>
<td>0.1191</td>
</tr>
<tr>
<td>2015</td>
<td>1.6582</td>
<td>0.2386</td>
<td>0.2058</td>
</tr>
<tr>
<td>2016</td>
<td>2.5904</td>
<td>0.6002</td>
<td>0.2770</td>
</tr>
<tr>
<td>2017</td>
<td>3.9539</td>
<td>0.9143</td>
<td>0.4492</td>
</tr>
<tr>
<td>2018</td>
<td>4.5698</td>
<td>0.9898</td>
<td>0.5361</td>
</tr>
<tr>
<td>Sum</td>
<td>14.8912</td>
<td>3.1107</td>
<td>1.7210</td>
</tr>
</tbody>
</table>
pollution, China often uses per capita GDP as the value of a statistical life year’s contribution to GDP, namely the modified human capital method. It is estimated based on the loss cost of income and direct medical costs. The revised human capital method and the disease cost method is used to calculate the loss of premature death and the cost of disease, respectively. Therefore, the evaluation results obtained by the study should be the lowest value of health economic losses caused by air pollution.

5. Conclusion

Based on the analysis results, the following conclusions were drawn:
1. The annual average change of the daily 8 h maximum concentration of O₃ in Shenzhen showed an obvious upward trend from 2006 to 2018, with the average annual value ranging from 79 to 190.92 µg/m³ and the average value of 112.89 µg/m³. It reached the maximum value of 199.02 µg/m³ in 2017, and increased 120.92 µg/m³ compared to the lowest value of 70 µg/m³ in 2008, with an increase rate of 172%.
2. The number of deaths and hospitalizations due to O₃ pollution increased yearly in Shenzhen from 2006 to 2018. The incidence of respiratory system diseases caused by O₃ pollution was higher than that of circulatory system diseases. However, the mortality caused by circulatory system diseases was far higher than that of respiratory system diseases. In addition, the group whose age is beyond 60 years old is the most risk group affected by O₃ pollution.
3. The health and economic loss of O₃ pollution increased yearly in Shenzhen from 2006 to 2018, and the average economic loss was RMB 82.46 million/year. The economic loss reached RMB 658.31 million (95%CI: 502.37-827.86 million) and accounted for 0.0272% of Shenzhen’s GDP in 2018.

References


