Local PM$_{2.5}$ and O$_3$ Ambient Air Quality Targets Setting Study in Lishui, China

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Abstract: 2021 will be the first year of China’s 14th Five-year period, and all cities have been working on making new local environmental protection plans. To further improve air quality, reduce smog, and control ozone pollution, many cities intend to set more stringent local air quality targets than the national requirements. However, how to set a reasonable and attainable air quality targets is very important because the targets have impacts not only on the welfare of local residents, but also on the local economy. This work presents a comprehensive approach to set reasonable local air quality targets. This approach has been applied to determine PM$_{2.5}$ and O$_3$ ambient concentration targets for Lishui city in its 14th Five-year Environmental Protection Plan. In this study, five years monitoring data of PM$_{2.5}$ and O$_3$ from year 2014 to 2018 in Lishui was collected and analyzed to assess the status quo and trends of its air quality. Then the concentration distribution of PM$_{2.5}$ and O$_3$ in Lishui surrounding cities and counties in Zhejiang Province were also analyzed and the possible impacts on Lishui city were evaluated. Moreover, PM$_{2.5}$ and O$_3$ air quality standards in other developed countries were reviewed and compared with Chinese current standards to assist the setting of appropriate ambient air quality targets. Based on the analysis, three-year sliding average concentration of PM$_{2.5}$ and O$_3$ are included in Lishui’s annual air quality targets for the first time, and different air quality targets are set for both the whole city and each specific area of Lishui city.

Keywords: PM$_{2.5}$, O$_3$, Ambient Air Quality Target, Annual Average Concentration

1. Introduction

With the rapid development of China’s economy, Chinese cities have been suffering severe air pollution in the past decades. In 2013, Chinese State Council issued the “Action plan for the prevention and control of air pollution”, referred to ”Atmospheric Ten Articles”[1]. Since then, Chinese governments at all levels have taken unprecedented strong measures on air pollution control, and air quality in key areas of China has improved remarkably. China’s Ministry of Ecology and Environment announced in 2018 that all of the 45 key tasks identified in the State Council’s "Atmospheric Ten Articles" have been completed on schedule [2].

Zhejiang province is one of the most economically developed provinces in China. Located in the southwest of Zhejiang province, Lishui city is the largest prefecture city in land area, which includes one municipal district: Liantu, seven counties: Qingtian, Jinyun county, Suichang, Songyang, Yunhe, Qingyuan, Jingning, and one county-level city: Longquan city. Its land covers 17,275 km$^2$, with a resident population of 2,186,000 in 2017. In 2018, Lishui’s urban air quality ranked the first in Zhejiang province and the 5th among 169 cities in China.

To further improve air quality, reduce smog, and control ozone pollution, Lishui city intend to set more stringent local air quality targets than the national requirements in its 14th Five-year Environmental Protection Plan. However, how to set a reasonable and attainable air quality targets is very important because the targets have impacts not only on the welfare of local residents, but also on the local economy. In addition, different air quality levels in different areas of Lishui city should be considered when setting the air quality targets.
2. Analysis and Setting of Local PM$_{2.5}$ Ambient Air Quality Target

2.1. Comparison of PM$_{2.5}$ Standards in Different Countries

China’s current air quality standards were set in 2012, implemented in some areas in 2013 and made mandatory nationwide in 2016 [3]. There are two types of national air quality standards. Primary standards (Level I) set limits for Class I ambient air function area, which includes nature reserve, scenic spots and other areas in need of special protection. Secondary standards (Level II) set limits for Class II ambient air function area, which includes residential areas, commercial traffic mixed areas, cultural areas, industrial areas and rural areas. Same as China, the National Ambient Air Quality Standards (NAAQS) in U.S. also have two types of national air quality standards [4]. However, NAAQS standards are set for different protection objects, but not for different ambient air function areas. There’s no ambient function area classification in NAAQS. Primary standards set limits to protect public health, including the health of “sensitive” populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings [5].

A comparison of PM$_{2.5}$ ambient standards between China and other five developed countries and regions in the world is shown in Table 1. It can be observed in Table 1 that the national PM$_{2.5}$ secondary standards, which almost all cities in China shall obey, are much more lenient than those in the listed five developed countries and regions. In addition, different from China’s one-year average standard, both the U.S. and E.U. are using 3-year sliding average concentration index [6]. The three-year "sliding average concentration index" of PM$_{2.5}$ refers to the arithmetic average of the average PM$_{2.5}$ concentration in three consecutive natural years. Considering that the change of meteorological conditions has a certain influence on the air quality, this index can weaken the influence of inter-annual fluctuation of meteorological conditions to some extent.

| Country               | Standards (µg/m$^3$) | Averaging time | Criteria for compliance            |
|-----------------------|----------------------|----------------|------------------------------------|
| China [3]             | 15 (Level I)         | Annual         | Annual Average                     |
|                       | 35 (Level II)        | 24-hour        | 95th percentile in a year          |
|                       | 75 (Level II)        | Annual         | 3-year average                     |
| United States [4]     | 12 (Level I)         | Annual         | 3-year average                     |
|                       | 15 (Level II)        | 24-hour        | 98th percentile in 3 years         |
| European Union [6]    | 25                   | Annual         | No exceedance allowed              |
|                       | 20                   | 3-year average |                                    |
| Australia [7]         | 8                    | Annual         | No exceedance allowed              |
|                       | 25                   | 24-hour        | No exceedance allowed              |
|                       | 7                    | Annual         | Year 2025 target                   |
|                       | 20                   | 24-hour        | Year 2025 target                   |
| Japan [8]             | 15                   | Annual         | Annual Average                     |
|                       | 35                   | 24-hour        | the 98th percentile in 1 years      |
| Singapore [9]         | 12                   | Annual         | Year 2020 target                   |
|                       | 37                   | 24-hour        | Year 2020 target                   |

2.2. Status Quo and Interannual Variation of PM$_{2.5}$ Concentration in Lishui City

It is essential to understand the status quo and the change trend of Lishui’s PM$_{2.5}$ ambient air quality before setting a new PM$_{2.5}$ ambient air quality targets. As Table 2 shows, PM$_{2.5}$ ambient concentration in all of the nine counties (cities and districts) of Lishui in year 2018 are lower than the corresponding national standards. The average annual concentration in Lishui city is 25µg/m$^3$, which is 28.6% lower than the Level II national standard (i.e., 35µg/m$^3$).

| City     | Annual average concentration (µg/m$^3$) | Daily concentration (95th percentile) | Exceed limits or not |
|----------|----------------------------------------|--------------------------------------|----------------------|
| Liandu   | 28                                     | 61                                   | No                   |
| Qingtian | 26                                     | 55                                   | No                   |
| Jinyun   | 25                                     | 52                                   | No                   |
| Suichang | 25                                     | 51                                   | No                   |
| Songyang | 28                                     | 56                                   | No                   |
| Yunhe    | 23                                     | 48                                   | No                   |
| Qingyuan | 26                                     | 54                                   | No                   |
| Jingning | 23                                     | 51                                   | No                   |
| Longquan | 21                                     | 44                                   | No                   |
| Average  | 25                                     | 52                                   | No                   |

In this study, Spearman rank relational coefficient method was adopted to assess the air quality variation trends in the
nine counties (cities and districts). The Spearman rank relational coefficient was calculated by using Equation 1.

\[ r_s = 1 - \frac{6}{n(n^2-1)} \sum_{i=1}^{n} (X_i - Y_i)^2 \]  

(1)

According to China’s “Technical regulation for ambient air quality assessment (HJ663-2013)” [10], to evaluate the change trend, at least five years monitoring data from national network points shall be used. In addition, for 5 years evaluation period, only if the absolute Spearman rank coefficient \( r_s \) is greater than 0.9000 (the critical value), the change trend is statistically significant. The positive value of \( r_s \) indicates an upward trend, while the negative value indicates a downward trend. If the absolute value of the rank correlation coefficient is less than or equal to the critical value, it indicates that there’s no obvious change.

In this study, five years monitoring data from nine secondary monitoring stations in Lishui were collected and analyzed. The variation and spacial distribution of annual average concentration of PM\(_{2.5}\) in nine areas of Lishui city over the past five years (2014-2018) is shown in Table 3 and Figure 1. From Table 3, we can see that PM\(_{2.5}\) annual average concentration in five of nine areas of Lishui city and the citywide average value in year 2014 exceeded the national secondary standard, while from year 2016 to 2018, no exceedance of PM\(_{2.5}\) annual average concentration was observed in any of the nine areas.

According to the analysis of rank relational coefficients, the citywide \( r_s \) during the past five years is -1.000 with a decline rate of 35.9%, which indicates an obvious downward trend of PM\(_{2.5}\) annual average concentration in the whole city. In terms of each individual area, the \( r_s \) for six of nine counties (cities and districts) during the past five years are negative and their absolute value are greater than the critical value (0.9000). The \( r_s \) for Songyang county and Jingning county are equal to -0.9000. Although the \( r_s \) for Qingyuan county is only -0.667, lower than the critical value, there’s no exceedance from 2014 to 2018, and the average PM\(_{2.5}\) concentration in the past five years is the second lowest. The downward trend of PM\(_{2.5}\) annual average concentration in each area and the whole city can also be shown clearly in Figure 1.

### Table 3. PM\(_{2.5}\) annual average concentration in all counties (cities and districts) of Lishui city from year 2014-2018 (Unit: \( \mu g/m^3 \)).

| Area     | Year 2014 | Year 2015 | Year 2016 | Year 2017 | Year 2018 | Variation (%) | Correlation |
|----------|-----------|-----------|-----------|-----------|-----------|---------------|-------------|
| Liandu   | 44        | 38        | 33        | 33        | 28        | -36.3         | -0.975      |
| Long-quan| 32        | 25        | 24        | 23        | 21        | -34.3         | -1.000      |
| Suichang | 42        | 35        | 34        | 29        | 25        | -40.5         | -1.000      |
| Qingtian | 40        | 35        | 31        | 30        | 26        | -35.0         | -0.975      |
| Yunhe    | 35        | 29        | 27        | 27        | 23        | -34.2         | -1.000      |
| Qingyuan | 33        | 27        | 24        | 26        | 26        | -21.2         | -0.667      |
| Jinyun   | 43        | 39        | 35        | 31        | 25        | -41.9         | -1.000      |
| Song-yang| 46        | 36        | 33        | 34        | 28        | -39.1         | -0.900      |
| Jingning | 38        | 31        | 29        | 30        | 23        | -39.5         | -0.900      |
| Average  | 39        | 33        | 30        | 29        | 25        | -35.9         | -1.000      |

In terms of regional distribution, the relatively high PM\(_{2.5}\) concentration in 2014 was mainly distributed in the northwest, central and northeast of Lishui, including Liandu district, Songyang county, Jinyun county and Suichang county, with the highest concentration of 46µg/m\(^3\) in Songyang county. By 2018, relatively high PM\(_{2.5}\) concentrations were mainly distributed in the central part of Lishui, with the highest concentrations of 28µg/m\(^3\) in Liandu district and Jinyun county.

### 2.3. PM\(_{2.5}\) Regional Impacts from Outside Lishui

It is well known that ambient PM\(_{2.5}\) concentration are not only influenced by local emission sources, but also by long distance transport. Therefore, regional impacts on Lishui’s PM\(_{2.5}\) air quality should not be ignored when attempting to

![Figure 1. PM\(_{2.5}\) concentration interannual variation in all counties (cities and districts) of Lishui city from year 2014-2018.](image-url)
set a new target.

In this study, the monitoring data from 69 monitoring stations in Zhejiang province in 2018 were collected and analyzed. The spatial distribution of annual average PM$_{2.5}$ concentration in Zhejiang province in year 2018 is shown in Figure 2. In 2018, the annual average concentration range of PM$_{2.5}$ in 69 cities above the county level were between 21 $\sim$ 42 µg/m$^3$, with the annual average concentration of 31 µg/m$^3$.

According to Figure 2, the relatively high concentration of PM$_{2.5}$ is in the central and northern areas of Zhejiang and the Jinqiu basin, while the relatively low concentration is mainly in the mountainous areas in Southern Zhejiang, East Zhejiang and islands in southeast Zhejiang. Located in southwest in Zhejiang, annual average PM$_{2.5}$ concentration in Lishui city in 2018 is apparently lower than that in most of Lishui’s surrounding areas.

Figure 2. Annual average PM$_{2.5}$ concentration distribution in Zhejiang province.

In addition, PM$_{2.5}$ air quality conditions in ten counties and cities around Lishui city in 2018 were also analyzed. In the surrounding counties and cities, only PM$_{2.5}$ annual average concentration in Taishun county and Kaihua county were lower than Lishui’s average value, which is 25µg/m$^3$. The average annual concentration of PM$_{2.5}$ in Wenzhou, Yongjia and Xianju is around 30µg/m$^3$; that of PM$_{2.5}$ in Jinhua and Quzhou is higher than 30 µg/m$^3$ but lower than the national secondary standard (35 µg/m$^3$); and Wuyi, Longyou and Jiangshan’s PM$_{2.5}$ concentration even exceeded 35 µg/m$^3$. The details are shown in Table 4.

Table 4. PM$_{2.5}$ ambient air quality in cities at the county level or above surrounding Lishui in 2018.

| City   | Annual average concentration | Daily concentration (95$^{th}$ percentile) | Exceeds limits or not |
|--------|------------------------------|---------------------------------------------|------------------------|
| Wenzhou| 30                           | 60                                         | No                     |
| Yongjia| 28                           | 54                                         | No                     |
| Taishun| 21                           | 40                                         | No                     |

Obviously higher PM$_{2.5}$ concentrations in most of the surrounding areas of Lishui city will put pressure on the further improvement of Lishui’s PM$_{2.5}$ air quality. However, according to the 2018 annual report of Zhejiang province's air quality [11], the annual average PM$_{2.5}$ concentration in the province decreased significantly year by year from 2013 to 2018, and this trend is expected to continue if strict controls on emissions continue. Therefore, it can be expected that the impacts of long-distance transport of PM$_{2.5}$ from the surrounding areas on Lishui city will also decrease in the future.
2.4. Setting PM\textsubscript{2.5} Ambient Air Quality Target During the 14th “Five-year” Period in Lishui City

According to the analysis above, PM\textsubscript{2.5} annual average concentration in the whole city in 2018 was 25\(\mu\text{g/m}^3\), which is 28.6\% lower than the national secondary standard, and over the past five years, the concentration of PM\textsubscript{2.5} has steadily declined year by year. In aspect of spatial distribution, almost 45\% of the areas in Lishui city (i.e., four of nine counties) had an annual PM\textsubscript{2.5} concentration higher than 25\(\mu\text{g/m}^3\), with the highest of 28\(\mu\text{g/m}^3\) in Liandu district (the downtown area), and Songyang county. In addition, since PM\textsubscript{2.5} concentrations in most surrounding areas (i.e., eight of the ten counties) were higher than that in Lishui, the negative impacts caused by long distance transport of PM\textsubscript{2.5} on Lishui city should also be considered when setting a new PM\textsubscript{2.5} targets for the whole area. On the other hand, compared with the international air quality standards of developed countries and regions, the current annual PM\textsubscript{2.5} concentration in the E.U. is 25\(\mu\text{g/m}^3\), which indicates that the use of 25\(\mu\text{g/m}^3\) as the new target of PM\textsubscript{2.5} in Lishui is advanced. Therefore, setting PM\textsubscript{2.5} annual average concentration of 25\(\mu\text{g/m}^3\) as the new target in the 14\textsuperscript{th} Five-year Plan of Lishui is reasonable and attainable.

For specific counties (cities and districts) in Lishui city, 5 out of 9 districts and counties in Lishui in 2018 had the annual PM\textsubscript{2.5} concentration of less than or equal to 25\(\mu\text{g/m}^3\). In order to further improve their local air quality, stricter air quality standards should be introduced to these areas. From the point of view of air quality standards development and progress history, it took the U.S. 15 years to reduce its three-year sliding average concentration of PM\textsubscript{2.5} from 15 \(\mu\text{g/m}^3\) to 12 \(\mu\text{g/m}^3\) (20\% reduction) [12]. The E.U. requires its member states to reduce the three-year sliding average concentration of PM\textsubscript{2.5} by 20\% (from 25\(\mu\text{g/m}^3\) to 20 \(\mu\text{g/m}^3\)) over a 10-year period [13]. Therefore, a target of 23 \(\mu\text{g/m}^3\) (i.e., 8\% reduction) for these areas over the next 5 years (from 2021 to 2025) is reasonable.

In addition, as mentioned above, the “three-year sliding average concentration index” of PM\textsubscript{2.5} adopted by the U.S. and E.U. can weaken the influence of inter-annual fluctuation of meteorological conditions to a certain extent. Although three-year sliding average concentration is more lenient than one-year average value, it can better reflect the environmental benefits brought by pollution control, and better meet the demand of current air quality evaluation. In China, according to the “2019 Action Plan for the prevention and control of pollution in Beijing” [14], Beijing has also included the “three-year sliding average concentration” of PM\textsubscript{2.5} to evaluate air quality in its 2019 annual air quality control target. Therefore, this study suggests that the three-year sliding average concentration of PM\textsubscript{2.5} should be included and used for setting the PM\textsubscript{2.5} control targets of specific counties in Lishui’s during its 14\textsuperscript{th} Five-year Environmental Plan. The PM\textsubscript{2.5} target of three-year sliding average concentration for Longquan county, Jingning county, Yunhe county, Suichang county and Qingtian are recommended to be 23 \(\mu\text{g/m}^3\) and below, and the same index for Liandu district, Qingtian county, Qingyuan county and Songyang county are recommended to be 25\(\mu\text{g/m}^3\) and below.

3. Analysis and Setting of Local O\textsubscript{3} Air Quality Target

3.1. Comparison of O\textsubscript{3} Standards in Different Countries

The current ozone air quality standards in China include daily maximum 8-hour mean and 1-hour average. A comparison of O\textsubscript{3} ambient standards between China and other five developed countries and regions in the world is shown in Table 5. The primary standard of daily maximum 8-hour average is 100 \(\mu\text{g/m}^3\), which is the same as Singapore’s 2020 standard and more stringent than the current standard in the United States and the European Union. The secondary standard of the daily maximum 8-hour mean value is 160 \(\mu\text{g/m}^3\), which is more lenient than the 8-hour ozone standard of the United States and the European Union. However, the annual evaluation criteria for O\textsubscript{3} compliance are different between China and other countries, such as the U.S. and E.U. In China, 90\textsuperscript{th} percentile of the daily maximum 8-hour sliding mean in each year is adopted, while 3-year average 4\textsuperscript{th} highest daily maximum 8-hour rolling average is used in the U.S. and in E.U., no more than 25 days each year averaged over 3 years are allowed.

| Country       | Standards (\(\mu\text{g/m}^3\)) | Averaging time | Criteria for compliance                                                                 |
|---------------|----------------------------------|----------------|----------------------------------------------------------------------------------------|
| China         | 100 (Level I)                    | daily maximum 8-hour | 90\textsuperscript{th} percentile of daily maximum 8-hour sliding average in a year |
|               | 160 (Level II)                   | 1-hour          | /                                                                                 |
|               | 160 (Level I)                    | daily maximum 8-hour | 3-year average 4\textsuperscript{th} highest daily maximum 8-hour rolling average |
|               | 200 (Level II)                   | 1-hour          | Exceed no more than 25 days per year averaged over 3 years                          |
| United States | 140                              | daily maximum 8-hour | Alert threshold                                                                     |
| European Union| 120                              | daily maximum 8-hour | Year 2025 target                                                                   |
|               | 180                              | 1-hour          | No more than 1 day per year                                                         |
|               | 240                              | 1-hour          | No more than 1 day per year                                                         |
| Australia     | 130                              | 8-hour          | Maximum 1-hour concentration of photochemical oxidants                              |
|               | 160                              | 4-hour          | Year 2025 target                                                                   |
| Japan         | 200                              | 1-hour          | /                                                                                  |
| Singapore     | 0.06 ppm                         | 1-hour          | Maximum 1-hour concentration of photochemical oxidants                              |
|               | 100                              | 8-hour          | Year 2025 target                                                                   |
3.2. Status Quo and Interannual Variation of $O_3$ Concentration in Lishui City

It is essential to understand the status quo and the change trend of Lishui’s $O_3$ ambient air quality before setting a new $O_3$ ambient air quality targets. As Table 6 shows, 90th percentile of the daily maximum 8-hour sliding mean of $O_3$ (hereinafter referred to as $O_3$ concentration) in all of the nine counties (cities and districts) of Lishui in year 2018 are lower than the secondary national standards. The average annual concentration in Lishui city is 118µg/m$^3$, which is 26.3% lower than the secondary national standard (i.e., 160µg/m$^3$). The variation and spacial distribution of $O_3$ concentration in nine areas of Lishui city over the past five years (2014-2018) is shown in Table 7 and Figure 3. From Table 3, we can see that from year 2014 to 2018, $O_3$ concentration in all of the nine areas in Lishui city were lower than the primary national standard, which is 100µg/m$^3$. However, in 2018, compared with the previous four years, the $O_3$ concentration of all districts and counties in the city increased significantly, with an average rise rate of 57.3%. Among the nine counties and urban areas, Jingning county experienced the largest increase of 104%, with 52 µg/m$^3$ higher than that in 2014, while Yunhe county had the lowest increase of 31.8%, 27 µg/m$^3$ higher than that in 2014. According to the analysis of rank relational coefficients, both citywide and county specific $r$ during the past five years is positive and their absolute values are lower than the critical value (i.e., 0.9000), which indicates there's no obvious upward trend of $O_3$ ambient air concentration from 2014 to 2018. Only Yunhe county is an exception. Its $r$ is 1.000 and higher than the critical value, which means the upward trend of $O_3$ ambient air concentration in this county is obvious.

In terms of regional distribution, the relatively high $O_3$ concentration in 2014 was mainly distributed in the northwest and central region of Lishui, including Liandu district, Suichang county and Yunhe county, with the highest concentration of 98µg/m$^3$ in Liandu (Lishui’s downtown area). By 2018, relatively high $O_3$ concentrations were mainly distributed in the north of Lishui, with the highest concentrations of 135µg/m$^3$ in Liandu district.

### Table 6. $O_3$ Ambient concentration in Lishui in 2018.

| City    | Daily maximum 8-hour average concentration (90th percentile) | Exceed limits or not |
|---------|-------------------------------------------------------------|----------------------|
| Liandu  | 135                                                         | No                   |
| Qingtian| 125                                                         | No                   |
| Jinyun  | 112                                                         | No                   |
| Suichang| 118                                                         | No                   |
| Songyang| 119                                                         | No                   |
| Yunhe   | 112                                                         | No                   |
| Qingyuan| 114                                                         | No                   |
| Jingning| 102                                                         | No                   |
| Longquan| 121                                                         | No                   |
| Average | 118                                                         | No                   |

### Table 7. 90th percentile of the daily maximum 8-hour mean of $O_3$ in all counties (cities and districts) of Lishui city from year 2014-2018 (Unit: µg/m$^3$).

| Area     | Year 2014 | Year 2015 | Year 2016 | Year 2017 | Year 2018 | Variation (%) | Correlation |
|----------|-----------|-----------|-----------|-----------|-----------|---------------|-------------|
| Liandu   | 98        | 84        | 81        | 92        | 135       | 37.8          | 0.300       |
| Long-quan| 80        | 74        | 75        | 83        | 121       | 51.2          | 0.700       |
| Suichang | 86        | 62        | 76        | 100       | 118       | 37.2          | 0.700       |
| Qingtian | 66        | 61        | 62        | 71        | 125       | 89.4          | 0.700       |
| Yunhe    | 85        | 86        | 78        | 75        | 112       | 31.8          | 1.000       |
| Qingyuan | 65        | 46        | 42        | 60        | 114       | 75.4          | 0.300       |
| Jinyun   | 62        | 62        | 60        | 67        | 112       | 80.6          | 0.667       |
| Song-yang| 80        | 67        | 68        | 71        | 119       | 48.8          | 0.400       |
| Jingning | 50        | 39        | 35        | 57        | 102       | 104           | 0.600       |
| Average  | 75        | 65        | 64        | 75        | 118       | 57.3          | 0.462       |
3.3. \(O_3\) Regional Impacts from Outside Lishui

Same as PM\(_{2.5}\), considering pollutants’ long distance transport, \(O_3\) concentration is also influenced by emission sources outside of Lishui. The spacial distribution of \(O_3\) concentration in Zhejiang province in year 2018 is shown in Figure 4. In 2018, the 90\(^{th}\) percentile of the maximum 8-hour average ambient air concentration of \(O_3\) in 69 cities above the county level were between 96 ~ 189 \(\mu g/m^3\), with the average of 142 \(\mu g/m^3\). Among them, \(O_3\) concentration in 55 cities are lower than or equal to the national secondary standard, accounting for 79.7% of the total. According to Figure 4, the relatively high concentration of \(O_3\) is in the central and northern areas of Zhejiang, while the relatively low concentration is mainly in the mountainous areas in southwestern Zhejiang. Located in southwest of Zhejiang, \(O_3\) concentration in Lishui city in 2018 is apparently lower than that in most of Lishui’s surrounding areas.

In addition, \(O_3\) air quality conditions in ten counties and cities around Lishui city in 2018 were also analyzed. In the surrounding counties and cities, only \(O_3\) concentration in Taishun county and Kaihua county were lower than Lishui’s average value (i.e., 118\(\mu g/m^3\)). And two of the ten cities’ \(O_3\) concentrations even exceeded the secondary national standards. The details are shown in Table 8.

According to the 2018 annual report of Zhejiang province’s air quality, from 2013 to 2018, while the concentration of other pollutants decreased year by year in all districts and counties of Zhejiang province, the concentration of \(O_3\) was rising. The number of pollution days with \(O_3\) as the primary pollutant was the largest, accounting for 59.1% of the total pollution days. It has surpassed PM\(_{2.5}\) as the primary pollutant in heavy pollution weather. The \(O_3\) concentration in the ambient air of various cities fluctuated and rised, and the

\[ \text{Table 8. } O_3 \text{ ambient air quality in cities at the county level or above surrounding Lishui in 2018.} \]

| City      | Daily maximum 8-hour average concentration (90\(^{th}\) percentile) | Exceed limits or not |
|-----------|---------------------------------------------------------------|---------------------|
| Wenzhou   | 141                                                          | No                  |
| Yongjia   | 132                                                          | No                  |
| Taishun   | 96                                                           | No                  |
| Jinhua    | 165                                                          | Yes                 |
| Wuyi      | 162                                                          | Yes                 |
| Quzhou    | 152                                                          | No                  |
| Kaihua    | 115                                                          | No                  |
| Longyou   | 128                                                          | No                  |
| Jiangshan | 130                                                          | No                  |
| Xianju    | 132                                                          | No                  |
frequency that \(O_3\) concentration exceeded the standard is higher than that of other pollutants. Obviously higher \(O_3\) ambient concentrations in most of the surrounding areas of Lishui city will put pressure on the further improvement of Lishui’s \(O_3\) concentration, and the increase of regional \(O_3\) concentration in the whole province in 2018 is also an important reason for affecting the increase of \(O_3\) concentration in Lishui.

3.4. Setting \(O_3\) Ambient Air Quality Target During the 14th “Five-year” Period in Lishui City

According to the analysis above, \(O_3\) concentration in the whole area of Lishui city did not show an obvious trend of increase during the five-year period, except that \(O_3\) concentration in 2018 in each area increased obviously than that before. The reasons for the increase of \(O_3\) concentration in 2018 are complicated. Different from particulate pollution, \(O_3\) is not directly discharged from the sources, but is a product of secondary transformation. VOCs and \(NO_x\) are the main precursors of \(O_3\) [15]. Therefore, to control \(O_3\) concentration, VOCs and \(NO_x\) emission control must be coordinated. \(NO_x\) mainly comes from fossil fuel combustion and vehicle exhaust emissions, etc. VOCs comes from a wider range of sources, including industrial emissions, vehicle exhausts, domestic pollution sources and natural sources. In recent years, the \(NO_x\) emissions in Lishui is decreasing year by year (from 11,358 tons in 2014 to 4,206 tons in 2017), and the concentration of \(NO_x\) in the air is also decreasing. However, it is difficult to reduce VOCs pollution due to its complex sources and large amount of fugitive emissions. Meanwhile there is a complex relationship between the concentration of VOCs and \(NO_x\) (i.e., the precursors) and \(O_3\) (i.e., the photochemical product). The ozone concentration increases with the increase of VOCs, while the decrease of \(NO_x\) concentration may lead to the increase of \(O_3\) concentration without effective control of VOCs concentration. In addition, due to the continuous decrease of particle concentration in recent years, the light radiation enhances, which is conducive to the generation of \(O_3\) by photochemical reaction. Meanwhile, the formation of \(O_3\) needs a certain period of time. Considering pollutants’ long distance transport and dispersion in atmosphere, \(O_3\) concentration in Lishui is also affected by external sources.

Due to the complicated formation mechanism of ozone, and the difficulty of controlling the emission of ozone precursors, the prevention and control of ozone pollution in Lishui city are facing a severe situation. Although the ambient air quality in Lishui is the best in Zhejiang province, it is not appropriate to set a more stringent \(O_3\) target than its current level. In this study, it is recommended to set the 90th percentile of the maximum 8-hour daily \(O_3\) concentration in the whole area during the "14th Five-year" period to be 140 \(\mu g/m^2\), which is the same as the current U.S. zone standard.

For specific counties (cities and districts) in Lishui city, 6 out of 9 districts and counties in Lishui in 2018 had the \(O_3\) concentration of less than 120\(\mu g/m^3\). In order to further improve their local air quality, this study suggests that the 3-year average daily maximum 8-hour rolling average concentration of \(O_3\) to be included and used for setting \(O_3\) control targets for specific counties in Lishui’s during its 14th Five-year Environmental Protection Plan. The \(O_3\) target of three-year sliding average concentration for Jinyun county, Songyang county, Qingyuan county, Jingning county, Suichang county and Yunhe county are recommended to be 120 \(\mu g/m^3\) and below, and the same index for Liandu district, Longquan city and Qingtian county are recommended to be 140\(\mu g/m^3\) and below.

4. Conclusion

This work presents a comprehensive approach to set reasonable local air quality targets. Firstly, we assessed the status quo and trends of Lishui’s air quality by analyzing its five-year monitoring data of \(PM_{2.5}\) and \(O_3\) from year 2014 to 2018. Then the possible impacts on Lishui from its surrounding cities and counties in Zhejiang Province were evaluated. Moreover, \(PM_{2.5}\) and \(O_3\) air quality standards in other developed countries were reviewed and compared with Chinese current standards to assist the setting of appropriate ambient air quality targets. Based on the analysis, three-year sliding average concentration of \(PM_{2.5}\) and \(O_3\) are introduced into Lishui’s annual air quality targets for the first time, and different air quality targets are set for specific areas of Lishui city.

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