The Spatial and Seasonal Variation of Aerosol Components in Taiwan

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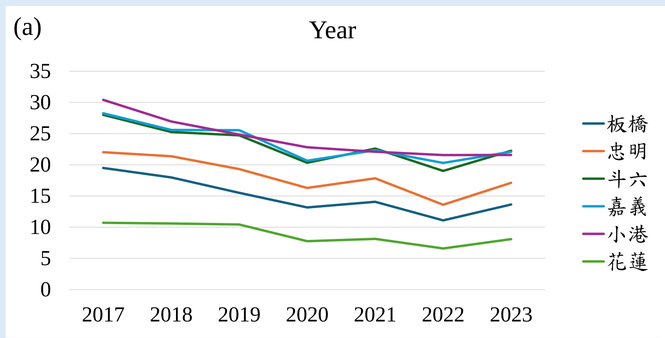
Introduction

This study analyzed the filter paper data collected from six stations (Banqiao, Zhongming, Douliu, Chiayi, Xiaogang, and Hualien) between 2017 and 2023 to explore their spatial and temporal variations. The data included $PM_{2.5}$ and its components (OC, EC, SO_4^{2-}, NO_3^-, and NH_4^+), which collectively account for 60-70% of total $PM_{2.5}$. Additionally, ozone data were obtained from the air quality monitoring network of the Ministry of the Environment over the same seven-year period (2017-2023). The daily ozone concentration was calculated as the eight-hour average value from 09:00 to 16:00. As shown in Figure 1(a), $PM_{2.5}$ concentrations at all stations displayed an annual decreasing trend, indicating that government efforts in air quality control, including limiting industrial emissions, improving traffic management, and promoting green energy, have been effective. It is important to investigate whether there is a corresponding decrease in $PM_{2.5}$ components, to identify any seasonal variation differences, and to determine the key factors influencing changes in pollution levels.

Distribution of $PM_{2.5}$ concentration and its components



Components	Banqiao	Zhongming	Douliu	Chiayi	Xiaogang	Hualien
$PM_{2.5}$	15.0	18.2	23.2	23.5	24.3	8.9
OC	3.5(23%)	3.8(21%)	4.6(20%)	4.2(18%)	4.4(18%)	1.7(20%)
EC	0.7(5%)	0.8(4%)	0.8(4%)	0.8(3%)	1.1(5%)	0.3(3%)
SO_4^{2-}	3.4(23%)	3.8(21%)	4.0(17%)	4.3(18%)	4.4(18%)	2.1(24%)
NO_3^-	1.2(8%)	2.6(14%)	4.4(19%)	4.7(20%)	4.6(19%)	0.5(6%)
NH_4^+	1.4(9%)	1.9(11%)	2.6(11%)	2.7(11%)	2.6(11%)	0.8(8%)
OTHERS	4.8(32%)	5.3(29%)	6.8(29%)	6.9(30%)	7.1(29%)	3.5(39%)

Table 1. Annual mean concentration of $PM_{2.5}$ and its components from the Ministry of the Environment stations during 2017-2023.

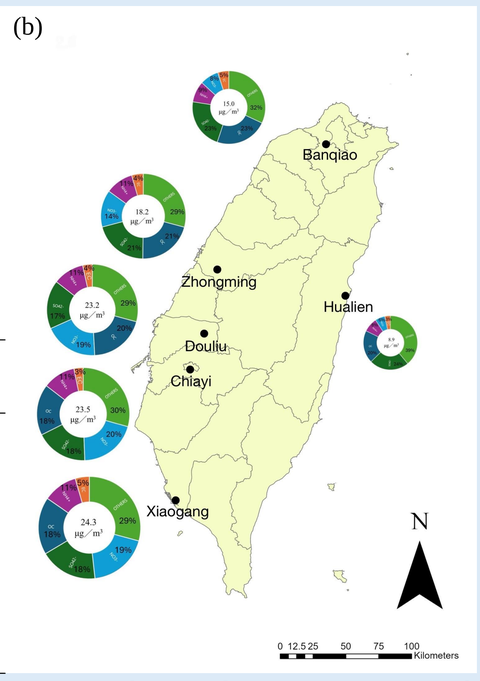


Figure 1. The annual mean concentration of $PM_{2.5}$ (a) and the distribution of its components at six stations (Banqiao, Zhongming, Douliu, Chiayi, Xiaogang, and Hualien) between 2017 and 2023.

- The $PM_{2.5}$ concentration in the Yunlin-Chiayi-Kaohsiung region is significantly higher than the others, indicating a north-to-south increasing trend in pollution levels.
- There has been a significant increase in NO_3^- levels in the western plains, particularly in the central to southern regions.

Annual variation in $PM_{2.5}$ components

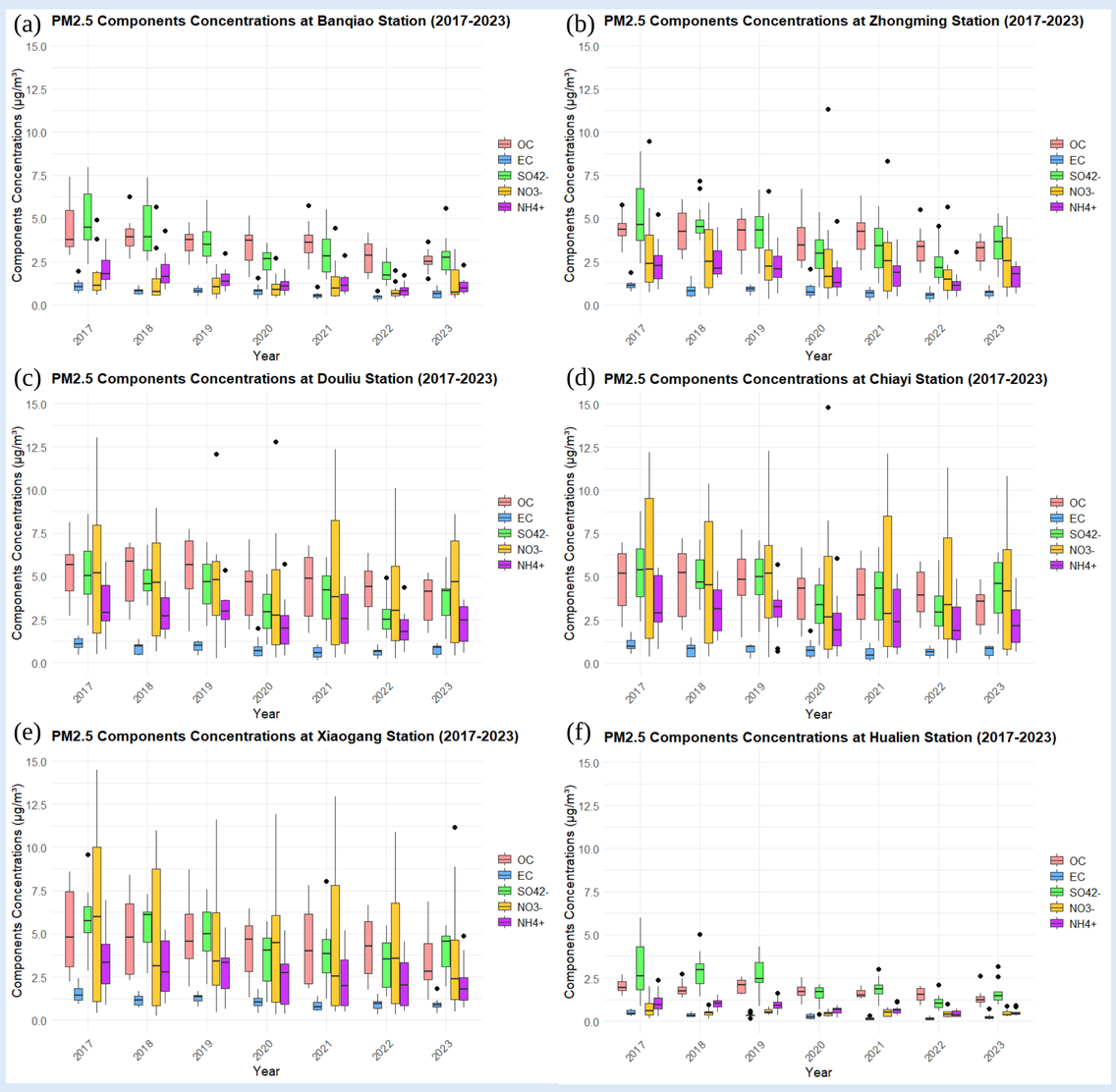


Figure 2. The box plots of the annual mean of $PM_{2.5}$ components at (a) Banqiao Station (b), Zhongming Station (c), Douliu Station (d), Chiayi Station (e), Xiaogang Station, and (f) Hualien Station

- The SO_4^{2-} and OC are the dominant species at Banqiao and Zhongming while NO_3^- becomes the significant species at the stations Douliu, Chiayi and Xiaogang. Except for 2020, there are not a clearly decreasing trend for NO_3^- at Douliu and Chiayi.
- In eastern Taiwan, Hualien has the lowest $PM_{2.5}$ concentration among these six stations. The SO_4^{2-} and OC are the dominant species at Hualien station.

Seasonal variation of $PM_{2.5}$ components and ozone concentrations

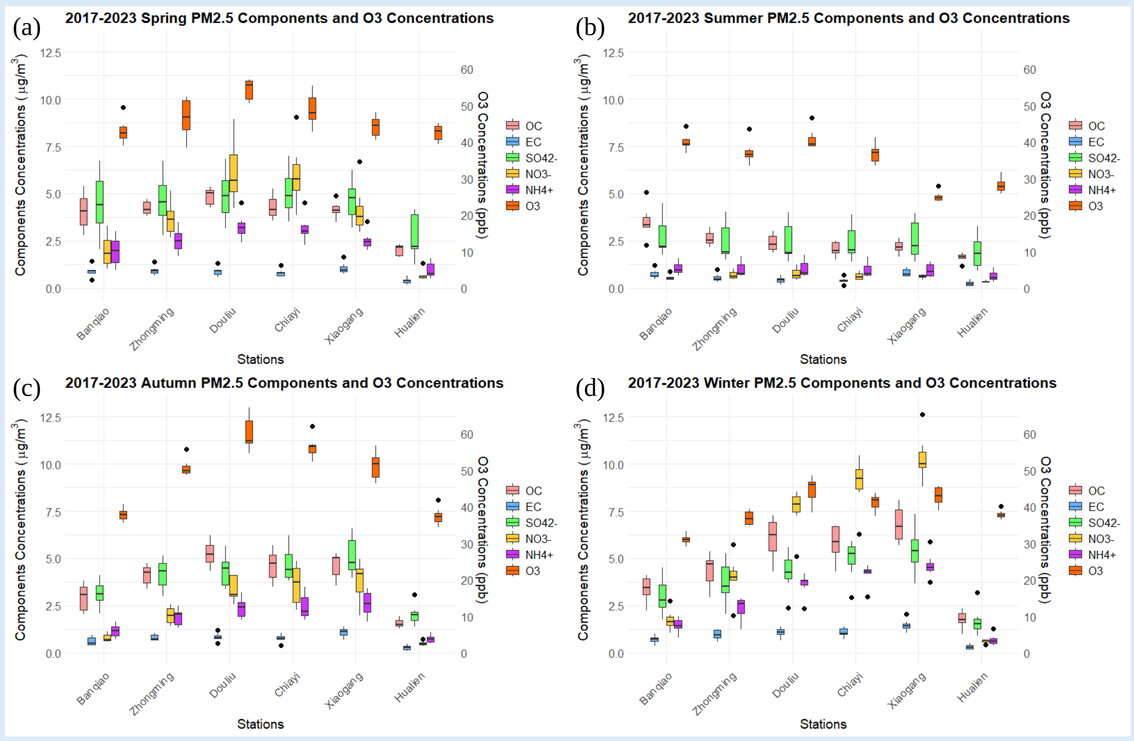


Figure 3. Seasonal variation of $PM_{2.5}$ components and daytime ozone concentrations across stations: (a) Spring (b), Summer (c), Autumn (d), Winter

- In spring, the SO_4^{2-} is major contribution species to $PM_{2.5}$ at Banqiao, Zhongming, and Xiaogang, whereas NO_3^- is the dominant component at Douliu and Chiayi stations. Douliu recorded the highest concentration of ozone and the concentrations of NO_3^-, NH_4^+, and OC as well.
- In autumn, the highest concentration of OC was found at Douliu station, while Xiaogang recorded the highest values for all the other components. The SO_4^{2-} is the dominant species at all other stations except for Douliu.
- In winter, the highest concentrations of all $PM_{2.5}$ components were observed at Xiaogang, with a particularly notable increase in NO_3^- concentration. The compositional shares of $PM_{2.5}$ in the Yunlin-Chiayi-Kaohsiung region remained consistent throughout the season. In contrast, the northern, central, and eastern regions were dominated by OC.

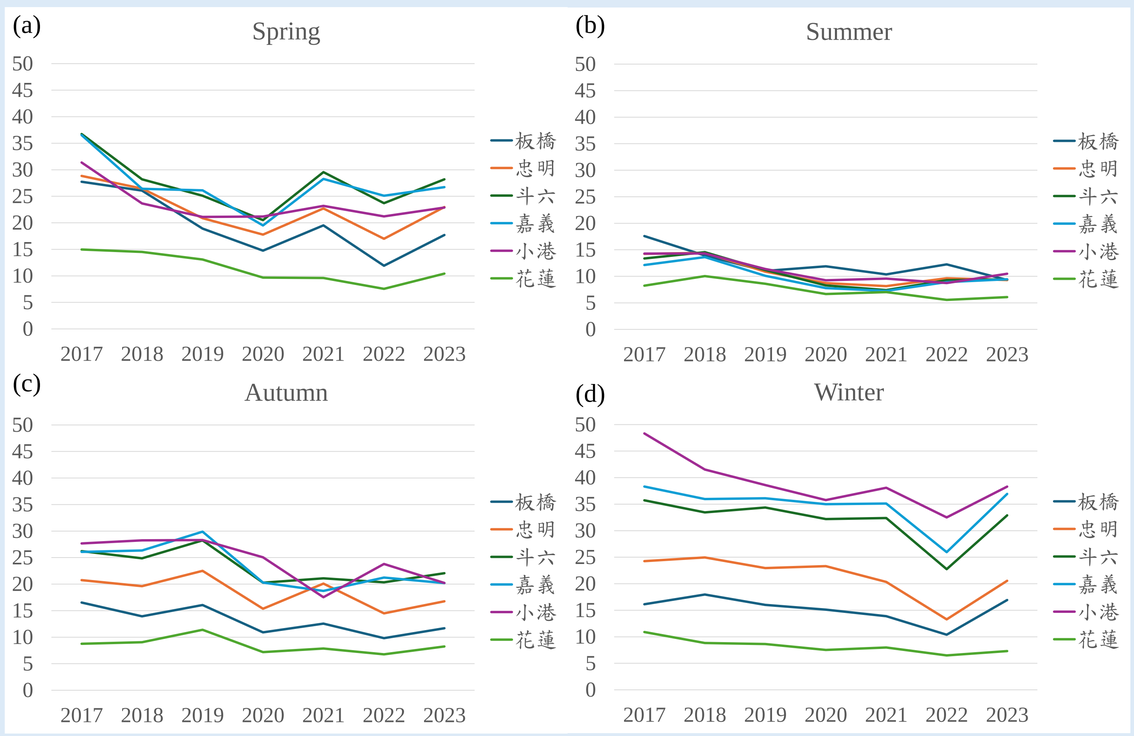


Figure 4. The seasonal and annual Variation of $PM_{2.5}$ concentration across six stations: (a) Spring ,(b) Summer , (c) Autumn, (d) Winter

- In spring, $PM_{2.5}$ levels at Douliu and Chiayi are significantly higher than other stations, indicating the most polluted area is in the Yunlin-Chiayi region.
- In autumn, the highest pollution level is in the south of Yunlin (Douliu, Chaiyi and Xiaogang) region compared to other stations.
- In winter, the Xiaogang station has the highest $PM_{2.5}$ concentration comparing to the others.
- Overall, the $PM_{2.5}$ levels are low due to high temperatures, elevated boundary layer heights, and frequent rainfall in summer.

Summary

1. **Higher $PM_{2.5}$ concentration in southern Taiwan:** There is a noticeable increase in pollution levels from the northern to southern regions, with $PM_{2.5}$ concentrations significantly higher in the south than in other areas.

2. **Composition differences in $PM_{2.5}$ and trends:** Overall, the SO_4^{2-} and OC are the dominant species at Banqiao and Zhongming while NO_3^- becomes the significant species at the stations Douliu, Chiayi and Xiaogang. Except for 2020, there are not a clear decreasing trend for NO_3^- at Douliu and Chiayi.

3. **Significant seasonal differences:** In spring, the SO_4^{2-} is major contributor to $PM_{2.5}$ at Banqiao, Zhongming, and Xiaogang, whereas NO_3^- is the dominant component at Douliu and Chiayi stations. Douliu recorded the highest concentration of ozone and the concentrations of NO_3^-, NH_4^+, and OC as well. In autumn, the highest pollution level is in the south of Yunlin (Douliu, Chaiyi and Xiaogang) region compared to other stations. In winter, Xiaogang has the highest levels of all components, particularly NO_3^-.