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Reduction in Aviation Volume due to COVID-19 and Changes in Air Pollution near the International Airport in Taiwan

Tuan Hung Ngo[1], Wen Chi Pan[2], Alexander Waits[3,4*]

[1] Research Center for Environmental Changes, Academia Sinica, Taipei, Taiwan
[2] Institute of Environmental and Occupational Health Sciences, National Yang Ming Chiao Tung University, Taipei, Taiwan
[3] Institute of Public Health, National Yang Ming Chiao Tung University, Taipei, Taiwan
[4] Tao Yuan General Hospital, Ministry of Health and Welfare, Taoyuan, Taiwan

ABSTRACT

Measures to contain COVID-19 pandemic in Taiwan included international travel restrictions since February 2020, which resulted in a nearly 80% reduction of aviation volume at the International Taoyuan Airport (TPE), while industry and ground traffic continued to operate unaffected by the pandemic. This study attempted to assess the contribution of aviation volume to air pollution measured by a monitoring station, located 2 km southwest to the airport. We applied cluster analysis to identify TPE contribution to the major air pollutants and estimated their relationship with the number of passengers as a proxy to the flights number. From the airport containing cluster, we observed significant reduction of air pollution concentrations after the travel restrictions. The reduction percentage of SO_2 and NO_x was higher in the airport cluster (17.7% and 7.3%, respectively) compared to the total station observation (14.7% and 6.8% respectively). Spearman's coefficients indicated positive significant correlations between the number of passengers and $PM_{2.5}$ (0.06), PM_{10} (0.21), SO_2 (0.24), especially after the travel restrictions. Such low correlations were found due to the distance of 2 km between the monitoring station and the airport runway. This distance could be too far to precisely detect the contribution of aviation to air pollution, which was masked by industrial activities and ground traffic. Measuring air pollution at a closer distance to the runways is required for a better catchment of aviation impact on air quality.

Keywords: Airport, Air pollution, Aviation, COVID-19, Taiwan

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* **Corresponding Author:**
alexwaits@nycu.edu.tw

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1 INTRODUCTION

Past decades have witnessed an unprecedented growth of civic aviation, with surging emission of major air pollutants, especially in Asia (Lee *et al.*, 2021). The aviation is one of the most energy-consuming human activities, emitting multiple air pollutants, such as particular matter < 2.5 µm ($PM_{2.5}$), and < 10 µm (PM_{10}), nitrogen oxides (NO_x), carbon oxide (CO), and sulphur dioxide (SO_2), which contribute to the global warming and increased health risks (Harrison *et al.*, 2015; Yim *et al.*, 2015; Lee *et al.*, 2021). Several studies attempted to quantify NO_x emissions and other combustions products of aircraft engines near large international and small local airports (Yu *et al.*, 2004; Carslaw *et al.*, 2006; Psanis *et al.*, 2017; Zaporozhets and Synylo, 2019). Depending on the used engine, each landing-taking off cycle of an airplane could use hundreds to thousands of kilograms of fuel, which turns into tens of kilograms of NO_x, CO, and hydrocarbons (Masiol and Harrison, 2014).

Since first cases of coronavirus disease 2019 (COVID-19) were reported in Wuhan, China at the end of 2019 (WHO, 2021), the pandemic has globally disrupted multiple human activities, including the aviation. Lockdowns and slowing of economics in multiple countries revealed a side benefit

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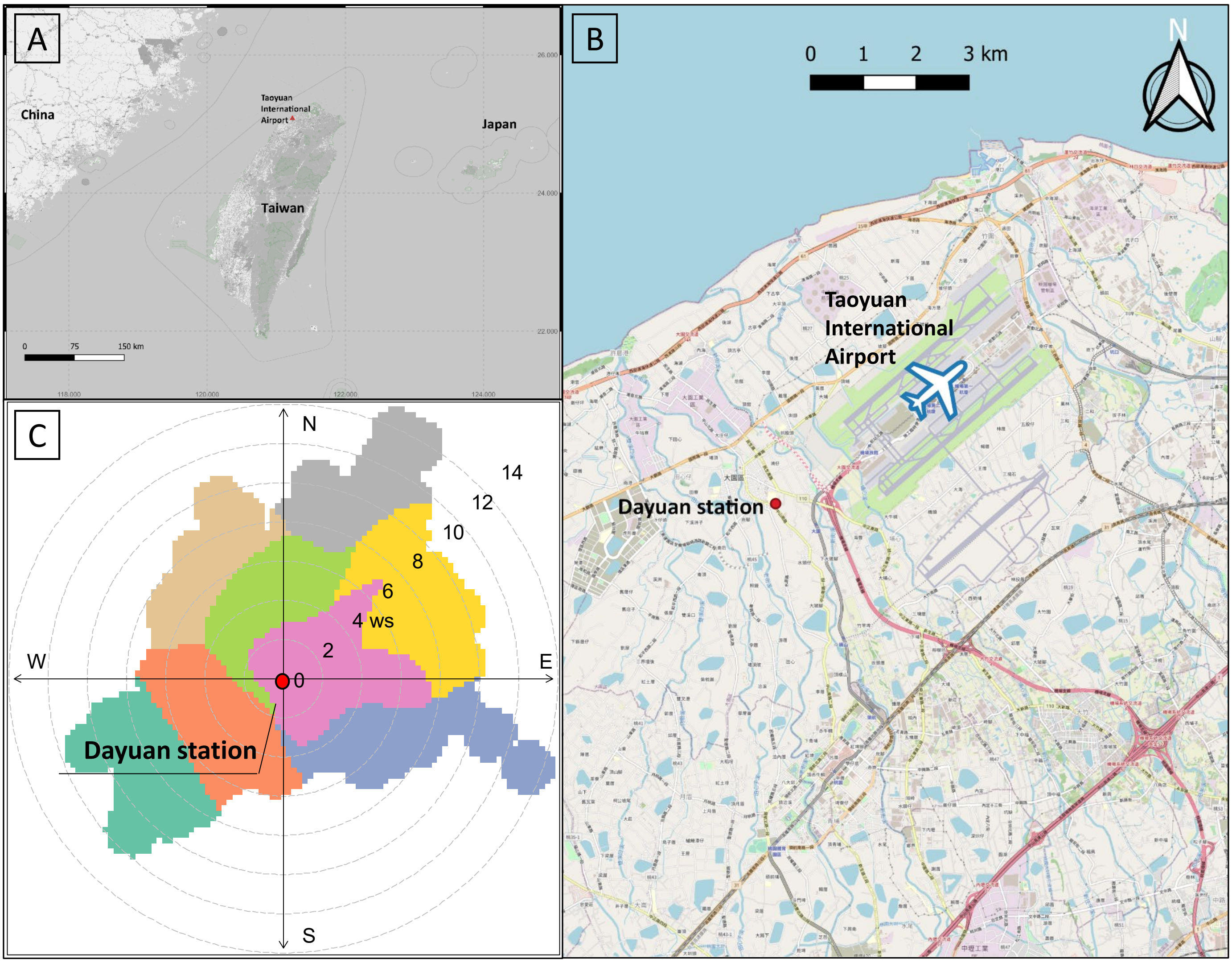

Fig. 1. Location of the monitoring station next to Taiwan Taoyuan International Airport and an example of cluster analysis. (A) Taiwan Taoyuan International Airport; (B) Dayuan monitoring station; (C) Polar plot of NO_x concentrations clusters, ws – wind speed.

of reducing the air pollution. Compared to the previous years, significant concentrations reductions of up to 70% have been observed for major air pollutants in China (Bao and Zhang, 2020; Dutheil *et al.*, 2020), India (Mahato *et al.*, 2020), Brazil (Nakada and Urban, 2020), US (Berman and Ebisu, 2020), Italy (Collivignarelli *et al.*, 2020), and South Asia (Kanniah *et al.*, 2020).

Although Taiwan is located only 180 km from China (Fig. 1(A)), the country has successfully contained the pandemic by implementing strict and timely measures. Starting from February 2020, entry for foreigners to Taiwan has been suspended (MOHW, 2021). This restriction lowered number of flights and passengers at the Taoyuan International Airport (TPE) by nearly 80% in March 2020 (Fig. 2). At the same time, no slowing down of other activities, including the ground traffic and industry, have occurred. Such a dramatic drop in aviation, while other human activities remained unchanged, provided a rare opportunity to explore contributing role of aviation at TPE airport to the air pollution.

2 METHODS

We used the data on aviation volume and air pollution from February 2019 till January 2021. The data on number of flights and passengers were obtained from the website of Taoyuan International

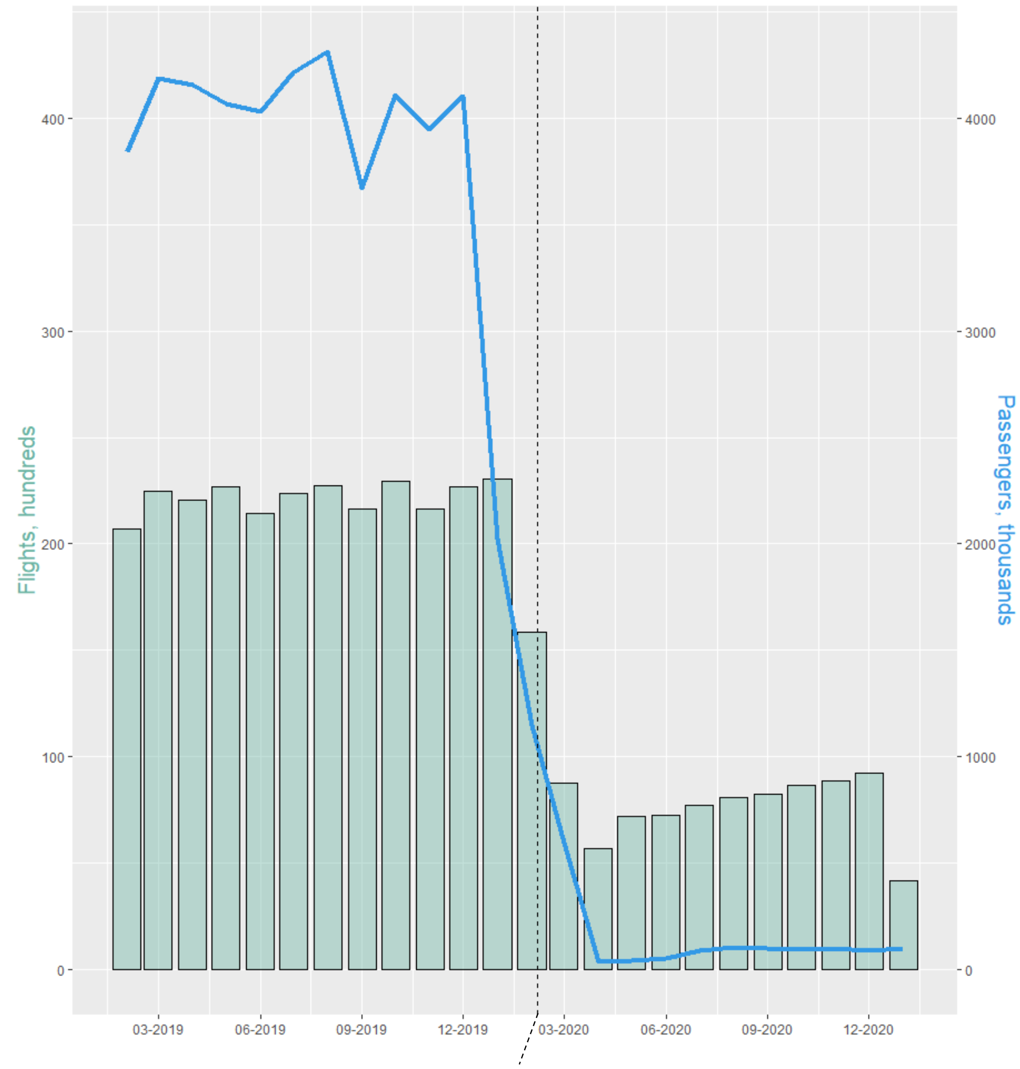

Fig. 2. Monthly numbers of all flights and passengers at Taiwan Taoyuan International Airport before and after the COVID-19 travel restrictions.

Airport Corporation Ltd. (TIAC, 2021). Since only monthly numbers of flights (including cargo) were available, we used daily number of passengers as a proxy for the daily number of flights (Fig. 2). Hourly concentrations of five air pollutants (CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2), and wind speed and direction were obtained from the database of Taiwan Environment Protection Administration, available at https://airtw.epa.gov.tw/CHT/Query/His_Data.aspx (TEPA, 2020). We used the data for the closest monitoring station (Dayuan) located 2 km south-west to the airport runway (Fig. 1(B)).

We compared the distributions of air pollutant concentrations before and after the drop in the aviation volume at TPE airport. The historical data on number of passengers and air pollutant concentrations were split by the date when entry to Taiwan has been restricted for Chinese citizens – February the 6th, 2020. The stricter measure banning the entry of all international travellers has been implemented since March the 19th, 2020 (MOHW, 2021). The sensitivity analysis using the second date did not affect our results, therefore we decided to present more conservative results using the first date of travel restrictions. Therefore, we present the analysis of the data from February 2019 to January 2020 as before travel restrictions, and the data from February 2020 to January 2021 as after the restrictions.

The correlations between daily air pollutants concentrations and number of passengers were estimated with Spearman's coefficients. Polar plots with concentrations were plotted against wind speed and direction and cluster analysis was conducted using the 'openair' package (Carslaw and Ropkins, 2012). We calculated the relative changes in the north-eastern clusters after the implementation of travel restrictions. The non-linear relationships between the daily number of passengers and air pollutants concentrations for those clusters and total concentrations at the station were plotted using penalized splines (‘mgcv’ package). All the analyses were performed using R version 4.0.5 (R Foundation for Statistical Computing, Vienna, Austria). A p-value of < 0.05 was considered statistically significant.

3 RESULTS AND DISCUSSION

3.1 Changes in Aviation Volume and Air Pollution

Before the travelling restrictions, monthly number of all type of flights at TPE airport fluctuated above 20,000, carrying about 4 million passengers. After the restrictions, monthly number of flights remarkably dropped to less than 1,000, and the numbers of passengers declined even more dramatically to about 100,000 (Fig. 2), and the numbers of flights and passengers remained strongly correlated ($r > 0.90$). Those changes in aviation volume were accompanied by the reduction in air pollutants concentrations. Overall, significant decreases in the monitored air pollution, except for CO, were observed between one year before and one year after the travelling restrictions since February 2020 (Table 1). During this time, SO_2 showed the highest percentage in mean changes of 14.7% from 3.4 ± 1.7 ppb to 2.9 ± 1.7 ppb. Both PM_{10} and $PM_{2.5}$ showed a reduction of around 12% from 30.7 ± 17.9 to 26.8 ± 16.0 µg m^{-3} and 15.4 ± 10.6 to 13.5 ± 9.25 µg m^{-3}, respectively. NO_x showed the least percentage change in mean concentrations of 6.8% from 16.2 ± 10.6 to 15.1 ± 10.1 ppb.

Totally, daily numbers of passengers were significantly correlated with SO_2 ($r = 0.24$), PM_{10} ($r = 0.21$), and $PM_{2.5}$ ($r = 0.06$) (Fig. 3). However, the direction of this correlation was very different when comparing between before and after restriction periods. Positive correlation between number of passenger and air pollution concentration was observed in the after-restriction period (Fig. S6). However, before the restriction, we found that number of passengers showed negative correlation with air pollution concentrations. This negative association occurred when the daily number of passengers reached more than 125,000, mostly during the peak tourism season in summer. However, because of meteorological reasons (rainfall and typhoon), the air pollution condition in Taiwan was lower in summer, compared to other year seasons. This phenomenon may explain the low negative associations between number of passengers and air pollution before the travel restrictions. After the restrictions, the correlations between air pollution and number of passengers were no more confounded by the tourism season.

Table 1. Hourly concentrations of air pollutants near Taiwan Taoyuan International Airport before (Feb. 2019–Jan. 2020) and after (Feb. 2020–Jan. 2021) the COVID-19 travel restrictions.

Pollutant	Overall	Before	After	Relative change in means	t-test p-value
CO (ppm), n	16,960	8,599	8,361		
Mean (SD)	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)	0.0%	0.124
Median [Min, Max]	0.3 [0.1, 1.6]	0.3 [0.1, 1.6]	0.3 [0.1, 1.3]		
NO_x (ppb), n	16,596	8,378	8,218		
Mean (SD)	15.6 (10.4)	16.2 (10.6)	15.1 (10.1)	–6.8%	< 0.001
Median [Min, Max]	13.4 [0.6, 115.0]	14.0 [0.6, 104.0]	12.7 [1.2, 115.0]		
$PM_{2.5}$ (µg m^{-3}), n	17,065	8,662	8,403		
Mean (SD)	14.5 (10.0)	15.4 (10.6)	13.5 (9.25)	–12.3%	< 0.001
Median [Min, Max]	12.0 [1.0, 129.0]	13.0 [1.0, 129.0]	11.0 [1.0, 74.0]		
PM_{10} (µg m^{-3}), n	16,953	8,532	8,421		
Mean (SD)	28.8 (17.1)	30.7 (17.9)	26.8 (16.0)	–12.7%	< 0.001
Median [Min, Max]	25.0 [0.0, 239.0]	27.0 [1.0, 239.0]	23.0 [0.0, 184.0]		
SO_2 (ppb), n	16,693	8,505	8,188		
Mean (SD)	3.1 (1.7)	3.4 (1.7)	2.9 (1.7)	–14.7%	< 0.001
Median [Min, Max]	2.8 [0, 23.7]	3.0 [0.0, 19.8]	2.6 [0.0, 23.7]		

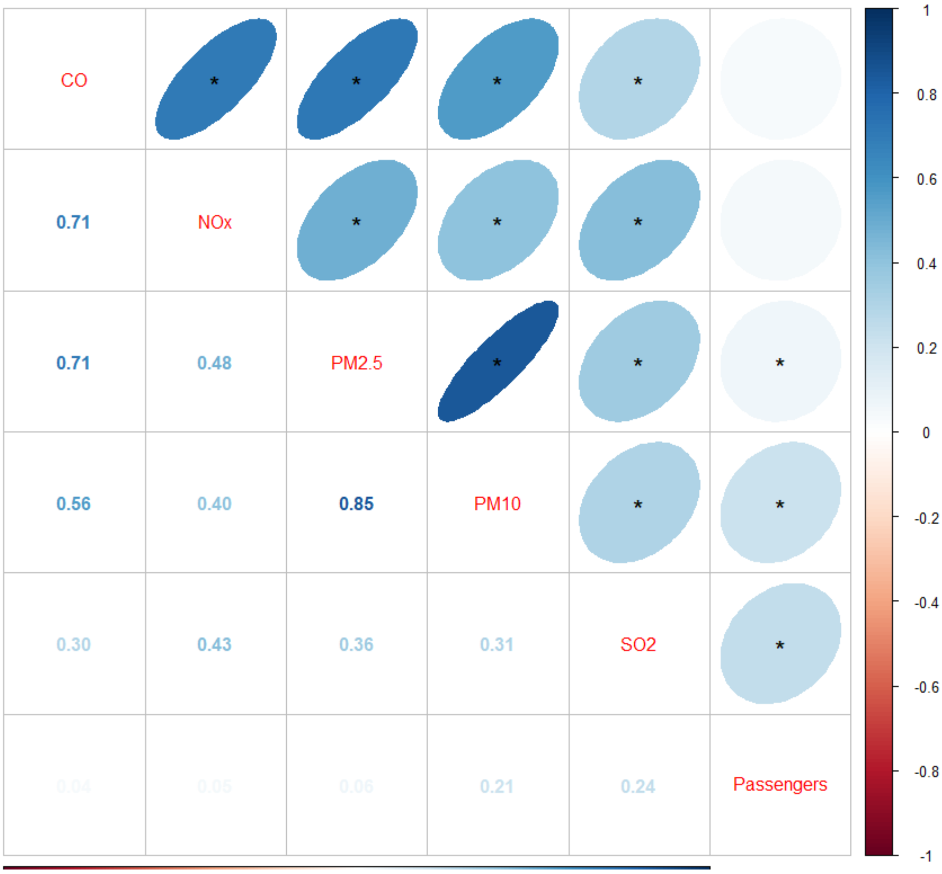

Fig. 3. Correlation matrix of daily number of passengers at Taiwan Taoyuan International Airport and concentrations of air pollutants at Dayuan monitoring station. * indicates p-value < 0.05.

3.2 Source Apportionment

Cluster analysis was conducted with the total observations at the monitoring station, including before and after the travelling restrictions. Based on TPE airport location northeast to the monitoring station at the distance of around 2 km (Fig. 1(B)), we assigned the Northeast clusters for each pollutant to represent air pollution contributed by TPE. Although this cluster assignment had similar characteristics with the long-range transport (LRT) source of air pollution in the north of Taiwan, the effect of LRT on this cluster could be ignored for the following reasons. Firstly, LRT in northern Taiwan was a series of occasional events during northeastern monsoon season in Taiwan (Wu and Huang, 2021). Since, our analysis was conducted for the whole year period, the effect of LRT on our source judgement of the cluster is not substantial. Moreover, the effect of LRT on air pollution in Taiwan did not change through the COVID lockdown (Lai and Brimblecombe, 2021), therefore, the change in air pollution concentrations in the cluster should come from local sources.

The airport clusters were cluster 5 for CO, NO_x, SO_2, cluster 4 for $PM_{2.5}$ and cluster 6 for PM_{10} (Supplementary Figs. S1, S2, S3, S4, S5). Most of these clusters included observations from north northwest (> 337.5 degrees) to east southeast (< 149.7 degrees) (Table 2). Slight exceptions were observed for $PM_{2.5}$ and SO_2 with the wind coming from other directions, which was mostly corresponded to a lower wind speed. The wind speed at the airport cluster for $PM_{2.5}$ was as low as 1.5 m s^{-1} whereas that for SO_2 was 0.7 m s^{-1}. At a lower wind speed, air pollution might have arbitrary trajectories before reaching the monitoring station. PM_{10} is a coarse particulate matter, which is much heavier than other air pollution particles, therefore a higher wind speed is required to bring PM_{10} from the airport to the monitoring station. In our cluster analysis, a wind of at least 6.2 m s^{-1} was observed to bring PM_{10} to the station, which was 2–6 times higher than the wind speed for other air pollutants.

The percentage of pollutant observations in a representative airport cluster differed for each pollutant (Table 2). Around 50% of the observations of $PM_{2.5}$ (51.0%) and SO_2 (47.7%), and

Table 2. Relative change in hourly concentrations of air pollutants detected in the Northeast clusters before (Feb. 2019–Jan. 2020) and after (Feb. 2020–Jan. 2021) the COVID-19 travel restrictions.

Pollutant	Northeast cluster wind direction range, degrees	Northeast cluster wind speed range, $m\ s^{-1}$	Northeast cluster, % of total observations	Overall Mean (SD)	Number of observations, before/after	Before, mean (SD)	After, mean (SD)	Relative change, %	t-test p-value
CO (ppm), n = 2,767	358.4–67.0	5.5–14.2	16.3	0.3 (0.1)	1,363/1,404	0.3(0.1)	0.3(0.1)	0.0	0.764
NO_x (ppb), n = 3,575	28.6–92.10	4.5–10.7	21.5	14.4 (6.8)	1,743/1,832	15.0 (6.5)	13.9 (7.01)	−7.3	< 0.001
$PM_{2.5}$ ($\mu g\ m^{-3}$), n = 8,705	337.7–149.7	1.5–11.5	51.0	13.5 (8.3)	4,597/4,208	14.1 (8.9)	12.7 (7.4)	−12.1	< 0.001
PM_{10} ($\mu g\ m^{-3}$), n = 843	34.3–77.8	6.5–11.0	5.0	37.6 (22.7)	331/512	42.0 (22.1)	37.6 (22.7)	−10.5	< 0.001
SO_2 (ppb), n = 7,968	346.8–247.0	0.7–9.6	47.7	3.1 (1.5)	4,068/3,900	3.4 (1.6)	2.8 (1.4)	−17.7	< 0.001

21.5% of NO_x were allocated in the Northeast clusters. The proportion of CO was 16.3%, and the lowest proportion of 5.0% was observed for PM_{10}. Mean concentrations of NO_x and $PM_{2.5}$ at Northeast clusters were lower, whereas the PM_{10} concentration was higher than the corresponding total concentrations at the monitoring station. Higher concentration of PM_{10} in the airport cluster implies that higher amount of PM_{10} was coming from the airport direction. Although the elevation of PM_{10} could also originated from the effect of LRT (Chen *et al.*, 2015), the fact that proportion of this cluster represented only 5% of the total PM_{10} observations (3–10 times lower than that of other pollutants) showed the effect of LRT in our analysis was minor.

Similar to the changes in total concentrations, all the pollutants in the airport clusters, except for CO, showed significant reduction after the traveling restrictions were put in place. SO_2 concentration showed the largest reduction of 17.7%, followed by $PM_{2.5}$ (12.1%), PM_{10} (10.5%), and NO_x (7.3%), which could be attributed to the reduction in the aviation volume. SO_2 and NO_x changes of the airport cluster were higher than the total mean changes of the station. Although NO_x are well-known products of aviation fuel burning (Masiol and Harrison, 2014), NO_x in the airport cluster only constituted 21.5% of the total observations. This low percentage for NO_x from the airport cluster may have been due to the presence of numerous NO_x sources in the surrounding area of the station. Moreover, we saw a lesser reduction in NO_x (7.3%) than for the other pollutants (10.5–17.7%), likely due to the short lifetime of NO_x (Delmas *et al.*, 1997), which suggests that NO_x is representative of the airport pollution while the additional reductions (on top of the 7.3%) could be from other sources beyond the airport cluster. Nevertheless, our findings suggest that aviation at TPE airport did influence NO_x pollution at the monitoring site.

We further examined the relationships between number of passengers and air pollution concentrations in both airport cluster and the total observations. All the pollutants showed non-linear relationships with the number of passengers, whereas close correlations were observed between total pollution concentrations and airport clusters (Fig. 4). As mentioned in the previous part, after stratifying the analysis to before and after restriction, we found a clear difference between the two periods (Fig. S6). Before restriction, the association between number of passengers could be confounded by factors such as tourism season. Therefore, we found the negative association between number of passengers and air pollution before the restrictions were put in place. However, after the tourism restriction were put in place, all air pollutants showed significant positive correlation with number of passengers. Although these correlation coefficients were low (0.15–0.24), the statistical significance could stem from the large sample sizes. The highest associations were found between number of passengers and NO_x (r = 0.24) and SO_2 (r = 0.23).

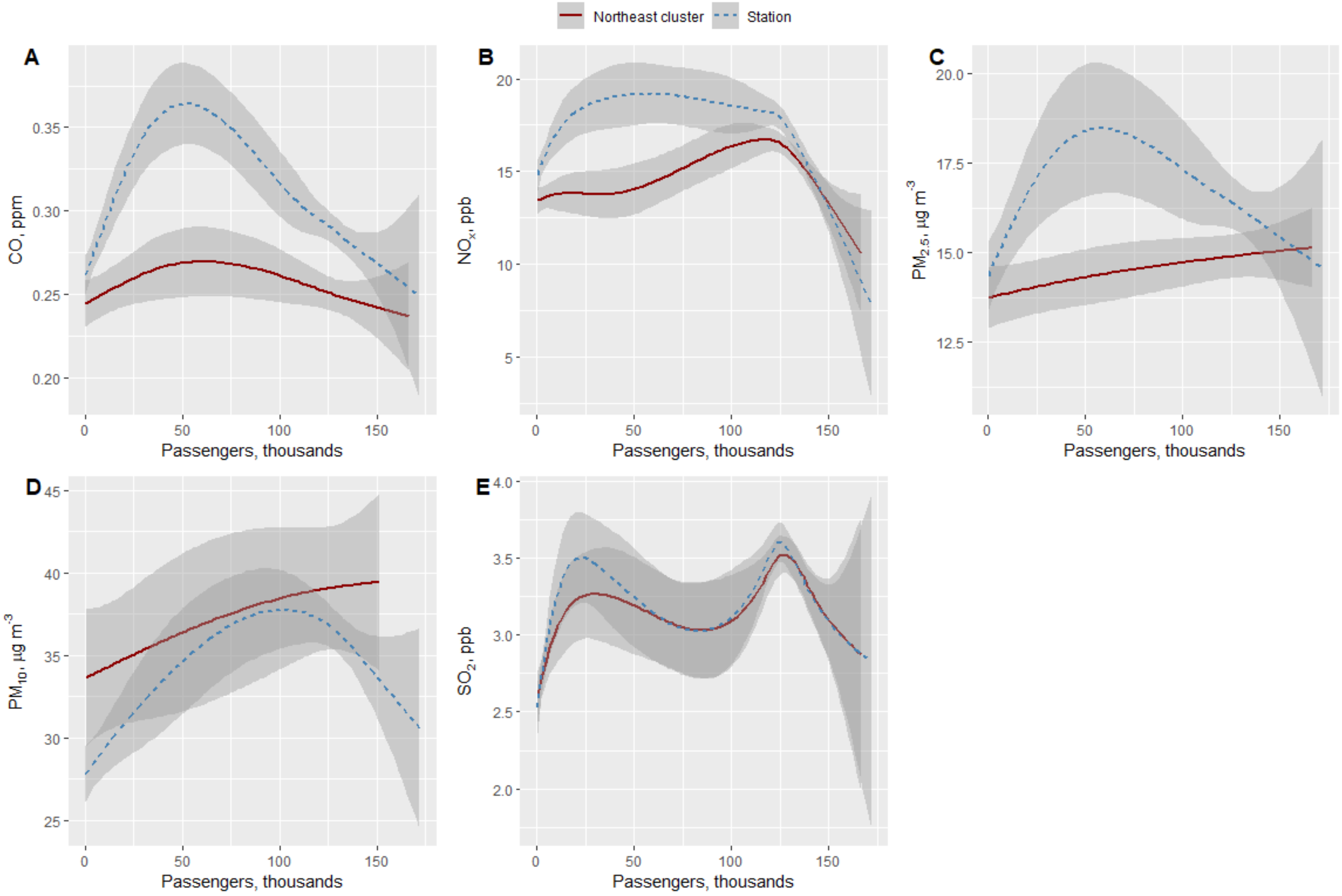

Fig. 4. Non-linear relationships between daily number of passengers at Taiwan Taoyuan International Airport and concentrations of air pollutants: (A) CO; (B) NO_x; (C) $PM_{2.5}$; (D) PM_{10}; (E) SO_2. Gray zone indicates the 95% confidence interval.

This finding strengthened the suggested effect of travel restrictions on reduction of SO_2 and NO_x discussed in the previous paragraph. Moreover, the fact that only the weak associations between aviation volume and air pollution near TPE airport were found, despite the sharp decline in numbers of flights due to the COVID-19 travel restrictions, suggests the presence of other local sources of pollution (industry or ground traffic) in the area.

To single out the airport influence on NO_x we performed a sensitivity analysis using data from Linkou station, which is located 12 km Northeast to the TPE runway and 16 km Northeast to Dayuan station, and has similar industrial and traffic activities, except the aviation. We compared the average monthly and annual concentrations. In 2019, before travel restrictions were put in place, 95% confidence intervals overlapped only in July, while other months showed significantly higher concentrations at Dayuan station (annual average 16.2 versus 14.2 ppb, t-test p-value < 0.001). In 2020, several months showed overlapping 95% confidence intervals, while monthly differences between NO_x concentration at Dayuan and Linkou were narrowed down (annual average 15.1 versus 15.0 ppb, t-test p-value = 0.596) (Fig. S7). Given the travel restrictions were the only major difference in pollution emission activities between the two stations, this analysis further supports that NO_x reduction at Dayuan could stem from the reduction in the aviation volume.

Previous study that detected significant contributions of the airport to the air pollution, especially the nitrogen oxides, used monitoring stations located as close as 180–650 m from the airport runways (Carslaw *et al.*, 2006). We based our analysis on the Dayuan monitoring station, located 2 km from the TPE airport runway, which is currently the closest Taiwan EPA monitoring station to the airport. In the future, setting a monitoring station closer to the runways would allow to observe more precise contribution of the aviation to the air pollution. Another serious limitation of this study includes only limited data provided by the airport authority. After the travel restrictions, most flights at Taoyuan station were cargo aircrafts, however, due to the lack of detailed information on aircraft types, our analysis and discussion were limited. Moreover, using hourly number of flights for take-off and landing in the future research is recommended to obtain more robust estimates of the airport contribution to the air quality.

4 CONCLUSIONS

Travelling restrictions implemented by the Taiwanese government since February 2020 to contain COVID-19 pandemic lead to the substantial reduction in aviation volume at TPE airport. The steep reduction in number of flights could have resulted in decreasing the NO_x concentration by 7.3%, and $PM_{2.5}$, PM_{10}, and SO_2 by > 10%. However, the correlations between daily numbers of passengers and air pollutants in the airport clusters were not clear, except for $PM_{2.5}$, PM_{10}, and SO_2, which displayed positive associations. Locating monitoring stations closer to the airport runway could more precisely capture the contribution of the aviation volume to the air pollution.

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DISCLAIMER

The authors have no conflicts of interest to disclose.

SUPPLEMENTARY MATERIAL

Supplementary material for this article can be found in the online version at https://doi.org/10.4209/aaqr.210297

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