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Insights into civil aviation emissions in China: Analysis of an emission inventory of air pollutants and the ChinaHighAirPollutants (CHAP) dataset

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ABSTRACT

The emissions from the civil aviation sector are a significant source of CO_2 and air pollutants, which represent a serious threat to ambient air quality and public health. To gain a deeper understanding of civil aviation airport emissions, it is imperative to develop a precise and comprehensive emission inventory of China's civil aviation airports. However, there are limited studies dedicated to analyzing and verifying the accuracy and completeness of China's civil aviation emission inventory. Here, this study explored pollution characteristics from temporal trends and spatial distribution perspectives based on a previously developed 2019–2020 high-resolution air pollution and CO_2 emission inventory of the landing and take-off (LTO) cycle of civil aviation airports in China and the ChinaHighAirPollutants (CHAP) dataset. Besides, this study established an empirical model to evaluate the relationship between the air pollutant emissions of China's civil aviation sector in 2019–2020 and the pollutant concentration from the CHAP dataset. Compared to those in 2019, the total NOx, CO, PM, and SO_2 emissions during the LTO phase in China's civil aviation sector in 2020 decreased by 14.29%–24.32%, and the average concentrations of NO_2, CO, PM_{10}, and SO_2 in 2020 decreased by 6.33%–9.45%. The eastern, central, and southern regions of China are characterized by high emissions of pollutants, a phenomenon closely related to the economic prosperity and tourism development in these areas. They tend to boast higher route densities, increasing air transport activity and consequently resulting in elevated emissions. In addition, NOx had the highest correlation coefficient in the empirical model, with a correlation coefficient of 0.603 in 2019. Our findings provide new insights into civil aviation emissions in China from the analysis of the emission inventory of air pollutants and the CHAP dataset and provide a new method for verifying the accuracy and completeness of China's civil aviation emission inventory.

1. Introduction

The air quality of China has recently shown continuous improvement, benefiting from a series of initiatives and joint efforts across various sectors. These improvements have been achieved through concerted efforts across various sectors. Notably, the industrial sector, including the thermal power, steel, and cement industries, has played a significant role in reducing air pollution emissions by adhering to increasingly tightening standards. After implementing ultra-low emissions (ULE) standards, Tang et al. (2019) estimated substantial reductions in SO_2, NO_x, and PM emissions of 65%, 60%, and 72% in the thermal power industry, respectively. Similarly, Bo et al. (2021) reported decreases in PM and SO_2 emissions of 47% and 42%, respectively, despite a 14% increase in steel production in China from 2014 to 2018. Following the implementation of control policies and standards, the emissions of CO_2 and various conventional and nonconventional air pollutants from cement production have also decreased significantly (Guo et al., 2022; Wang et al., 2023b). Additionally, the livelihood sector in China has introduced clean heating policies (including "coal--to-gas" and "coal-to-electricity") (Xu and Ge. 2020; Chen et al., 2022). To further advance emission reduction efforts, the transportation sector in China has actively promoted and advocated for the electrification of vehicles (Yuan et al., 2021; Li and Taghizadeh-Hesary. 2022). Notably, China's aviation industry has experienced rapid development since the

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1980s (CAAC, 2021), ranking second globally in terms of annual passenger kilometers (Zhang et al., 2023), and is projected to sustain a 5% annual growth rate over the next two decades (IATA, 2020). However, the escalating demand for travel and goods transportation (Rupcic et al., 2023) has resulted in significant adverse environmental impacts (Yim et al., 2015; Lund et al., 2017; Nowak et al., 2020). Given the complexity and time required for implementing carbon reduction measures, it is imperative to conduct a comprehensive analysis of the impact of aircraft emissions on air quality and public health in China. Particularly during the carbon peak and carbon neutral periods, establishing accurate civil aviation emission inventories and analyzing the spatial and temporal characteristics of air pollutant emissions will lay the foundation for effective air quality management, the formulation of future emission reduction policies, and the determination of crucial emission pathways.

Given the above background, numerous researchers have been striving to accurately calculate aviation emissions using various methods and explore their impacts on air quality. The International Civil Aviation Organization (ICAO) standard emission model was used to create the majority of the previous civil aviation airports' emission inventories. ICAO divides flight activities into distinct ranges of the landing and take-off (LTO) cycle phases and the cruise, climb, and descent (CCD) cycle phases (Trozzi et al., 2016). The LTO phase of the airport cycle exhibits the highest emissions per mile and the most significant impacts near the ground; most emission inventories only consider this phase (Zhang and Tian. 2023). Drawing upon measurement data provided by ICAO, numerous researchers have developed aviation engine emission databases, both domestically and internationally, focusing on CO_2 and air pollutant emissions in the transportation industry (Pejovic et al., 2008; Xia et al., 2008; Fan et al., 2012; Stettler et al., 2011). In the pursuit of accurately estimating air pollutant emissions, researchers have proposed an enhanced approach to estimate hazardous air pollutants emitted by aircraft from 204 Chinese airports (Zhou et al., 2019). Additionally, alternative methods to improve calculation accuracy involve corrections based on the atmospheric mixing layer height or actual operating time (Li et al., 2018; Han et al., 2020). Furthermore, Zhang et al. (2022) developed the 2018 inventory of air pollutants and CO_2 emissions from domestic and international aviation in China based on real flight paths using typical flight path signals derived from automatic dependent surveillance-broadcast (ADS-B). Many researchers have used fuel consumption and fixed emission factors to calculate pollutant emissions in CCD cycle phases since fuel consumption is the dominant contributor throughout the entire flight (Cui et al., 2022; Liu et al., 2019). These studies aim to thoroughly explore the data sources, research scopes, calculation methods, and emission factors to ensure accurate quantification of pollutant emissions from civil aviation airports. However, the precision and comprehensiveness of emission inventories are frequently disregarded. Therefore, it is essential to propose an effective method for verifying the accuracy of the integrated emission inventory used by the aviation sector. This effort aims to provide more reliable and accurate data support for the environmental management of the aviation industry and promote further improvements in air quality supervision and pollution control to address the environmental challenges posed by the growing air transport sector.

The ChinaHighAirPollutants (CHAP) dataset is a comprehensive collection of remote sensing data meticulously generated through artificial intelligence techniques that incorporates multisource satellite remote sensing technology, ground-based observations, atmospheric reanalysis, emission inventories, and model simulations (Wei et al., 2023a). This dataset, characterized by its long time series, full coverage, high spatiotemporal resolution, and precision, serves as a cornerstone for air quality monitoring and environmental policymaking. Hence, the CHAP dataset exhibits potential not only for evaluating the accuracy and comprehensiveness of civil aviation pollutant emission inventories but also for comprehensively understanding the long-term impact of civil aviation activities on air quality trends. The patterns of changes in pollutant emissions can be identified, and the dynamics of alterations in pollutant discharge can be deeply studied through comparisons with historical data from civil aviation pollutant emission inventories. Furthermore, CHAP dataset facilitates the comparison of air quality monitoring data with civil aviation pollutant emission inventories, enabling a nuanced understanding of the regional impact of civil aviation activities on air quality. Based on the above background, this study proposed a method for comparing pollutant emission data in emission inventories and concentrations in the CHAP dataset to verify the accuracy of the integrated emission inventory in the civil aviation sector. These analytical insights offer a robust scientific foundation for shaping civil aviation environmental policies and contribute to strengthening air quality management, thereby ensuring public health and ecological sustainability.

Therefore, in this study, based on the previously established high-resolution air pollutant and CO_2 (HC, NOx, CO, PM, SO_2, and CO_2) emission inventory of China's civil aviation sector in 2019–2020 (You et al., 2022) combined with the CHAP dataset, an analysis was conducted on the temporal trends and spatial distribution characteristics of air pollutants and CO_2 emissions from the civil aviation sector in China during 2019–2020. Additionally, empirical models have been explored to estimate the relationships between air pollutants and CO_2 emission inventories in China's civil aviation sector from 2019 to 2020 and the CHAP dataset. This study aimed to provide insights into civil aviation emissions in China from the perspective of an air pollutant and CO_2 emission inventory of China's civil aviation sector in 2019–2020 and a CHAP dataset and to provide a reference for the analysis and verification of the accuracy and completeness of China's civil aviation emission inventory. This would contribute to assisting the government in formulating regulatory suggestions for civil aviation emissions monitoring, thereby realizing global net-zero emission goals.

2. Materials and methods

2.1. Emission inventory acquisition and methodological framework

Our previous research established a high-resolution air pollution and CO_2 emission inventory of Chinese civil aviation airports between 2017 and 2020 (You et al., 2022). Therefore, this study utilized data from the years 2019–2020 to examine air pollution and CO_2 emissions across 31 provinces and municipalities directly under the control of the central government (Hong Kong, Macao, and Taiwan are excluded from the research scope of this paper). In terms of gathering activity-level data, acquiring take-off and landing data for different types of aircraft in airports across China posed a challenge due to the intricate structure of the country's aircraft fleet, the extensive range of models available, and the lack of exact matches for all models and engines. To address this issue, this study employed the standard emission model of ICAO and adopted a method for compiling proportional emission inventories of aircraft taking off and landing flights at airports. This method has been applied in numerous projects with positive outcomes (Li et al., 2018; Wang et al., 2020). For emission factors, given the minimal changes in China's fleet configuration during the study period, it was assumed that each aircraft had an equal likelihood of take-off and landing. The weighted emission factors for the LTO (landing-takeoff) cycle stage air pollutants and the weighted consumption rate of aviation kerosene were calculated using emission factors provided by the ICAO emission factors database. The calculation methods for the emissions of air pollutants and CO_2 (HC, NOx, CO, PM, SO_2, and CO_2) have been extensively outlined in prior studies (You et al., 2022).

2.2. ChinaHighAirPollutants (CHAP) dataset and processing

The ChinaHighAirPollutants (CHAP) dataset was used to determine air pollutant surface concentrations (Wei et al., 2022, 2023b; Liu et al., 2020). The dataset used multisource satellite remote sensing and

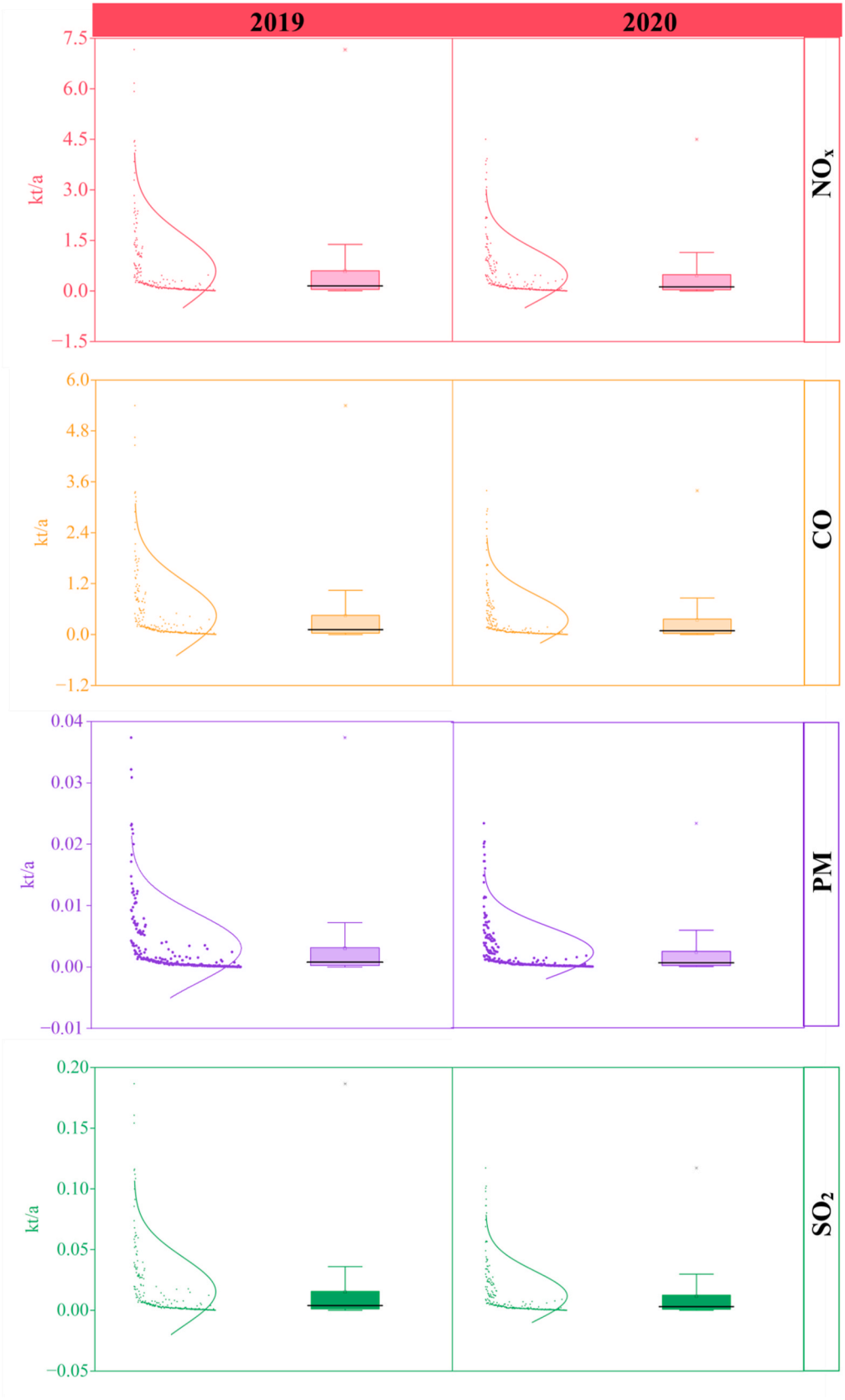


Fig. 1. Box plot of different air pollutant emissions (NOx, CO, PM, and SO_2) of the LTO cycle from China's civil aviation airports in 2019–2020.

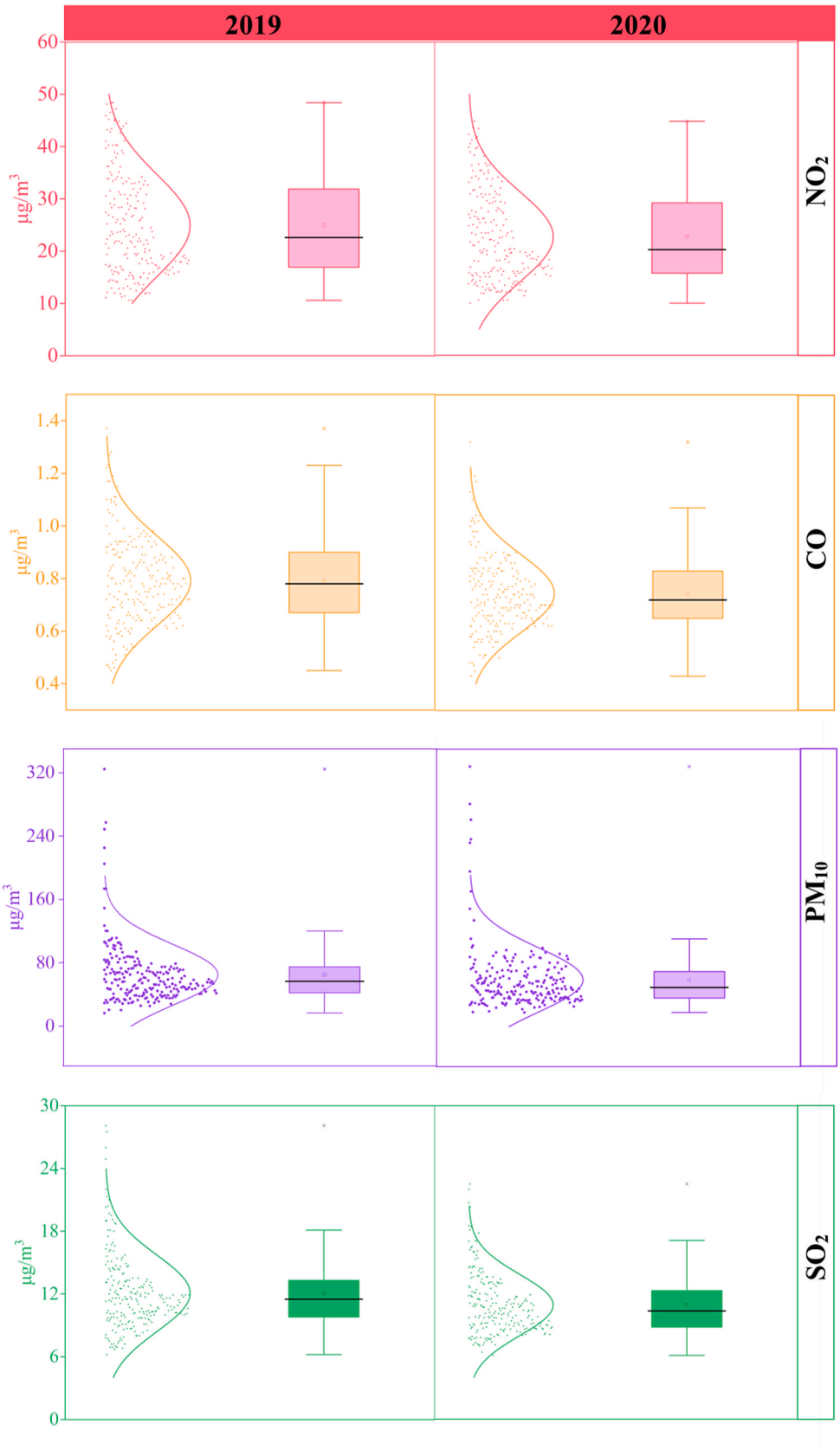


Fig. 2. Box plots of different air pollutant concentrations (NO_2, CO, PM_{10}, and SO_2) of civil aviation airports in 2019-2020 obtained from the CHAP dataset.

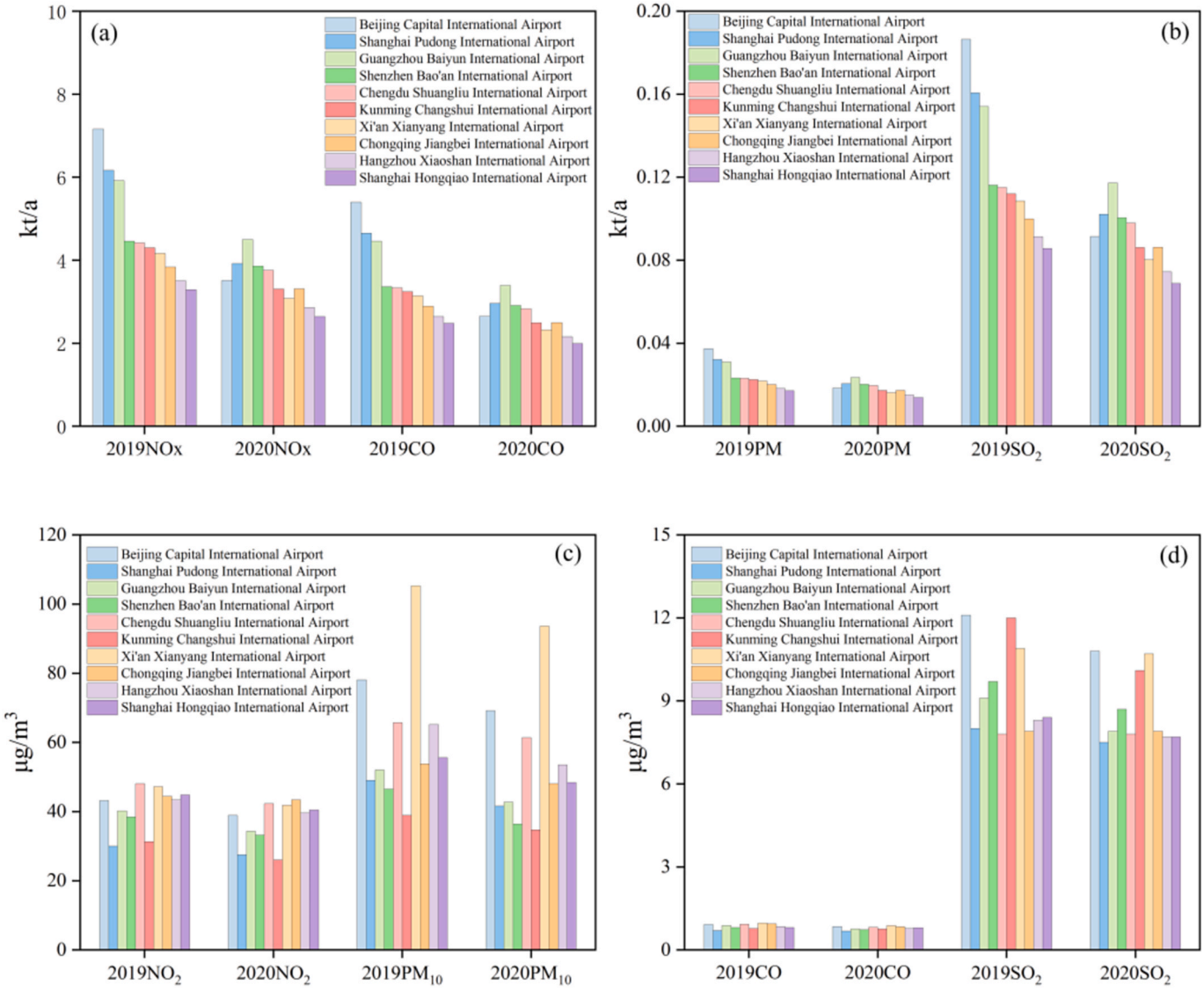


Fig. 3. Changes in pollutant emissions and corresponding pollutant concentrations of the top 10 civil aviation airports in terms of total pollutants (NOx, CO, PM, and SO_2) in 2019–2020.

artificial intelligence technology to address the spatiotemporal characteristics of air pollution, providing daily near-surface air pollutant emission values with coverage at both 1 km and 10 km resolutions across China. It integrates diverse data sources such as ground-based observations, satellite remote sensing products, atmospheric reanalysis, and emission inventories. In this study, annual concentration data of air pollutants (NO_2, CO, PM_{10}, and SO_2) at civil aviation airports (spatial resolution: 1 km × 1 km) were analyzed. This study used a geographic information system (GIS) to extract the concentrations of relevant pollutants from airports in the CHAP dataset.

2.3. Empirical models

The empirical models were conducted to examine the relationship between the air pollutant concentration data obtained from the CHAP dataset and pollutant emissions from civil aviation airports in China. The analysis revealed the relationship between emissions and pollutant concentrations, and an empirical model is depicted in Eq. (1).

$$lny = klnx + c \quad (1)$$

where x is the emission of NOx, CO, PM, and SO_2 in the emission inventory; y is the concentration of air pollutants (NO_2, CO, PM_{10}, and SO_2) extracted from the CHAP dataset; and k and c are coefficients.

3. Results and discussion

3.1. Temporal trends

During the period from 2019 to 2020, there were significant temporal changes in the emissions of air pollutants from civil aviation airports in China (Fig. 1). In 2020, the emissions of NOx, CO, PM, and SO_2 in China's civil airports in the LTO cycle ranged from 0 to 4.50 kt/a, 0~3.39 kt/a, 0~0.02 kt/a, and 0~0.12 kt/a, respectively. Compared with those in 2019, the total NOx, CO, PM, and SO_2 emissions in the LTO cycle phase from China's civil airports in 2020 decreased by 22.42%, 22.38%, 14.29%, and 24.32%, respectively. The significant reduction in emissions from China's civil airports in 2020 can be primarily attributed to the emergence of the COVID-19 pandemic. This global crisis led to a decrease in the number of flights and passenger traffic events starting in January 2020, thereby resulting in a downward trend in the emissions of air pollutants from civil aviation airports. According to statistics, domestic routes carried 574,604,300 passengers in 2019, but by 2020, this

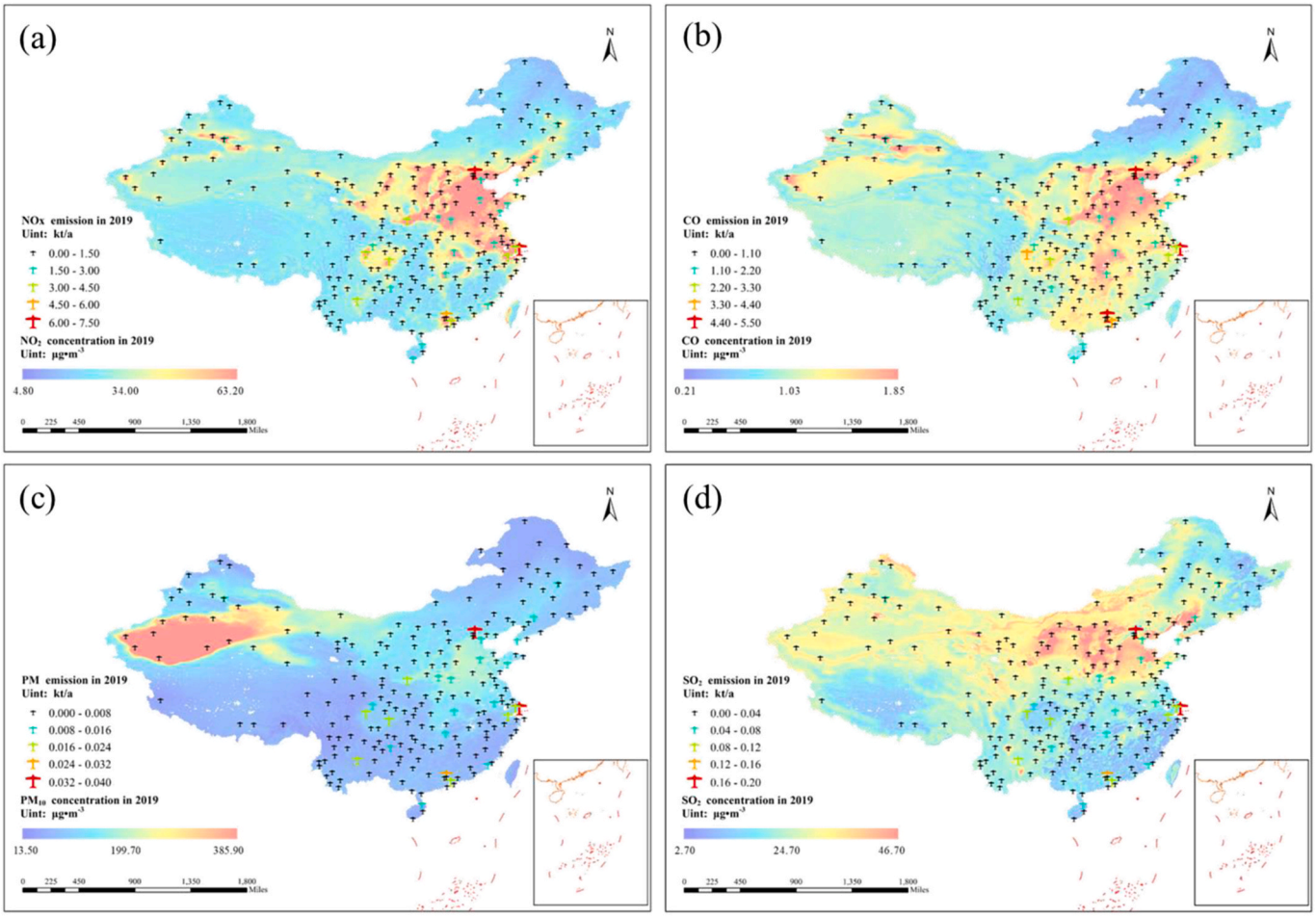


Fig. 4. Spatial distribution of air pollutant emissions in China's civil aviation airports in 2019.

figure decreased to 407,251,700 passengers (Zhang and Tian. 2023). In 2019, the top 10 airports in terms of total emissions of NOx, CO, PM and SO_2 (including Beijing Capital International Airport, Shanghai Pudong International Airport, Guangzhou Baiyun International Airport, Shenzhen Bao'an International Airport, Chengdu Shuangliu International Airport, Kunming Changshui International Airport, Xi'an Xianyang International Airport, Chongqing Jiangbei International Airport, Hangzhou Xiaoshan International Airport, and Shanghai Hongqiao International Airport) collectively accounted for approximately 33.61% of the country's total pollutant emissions. In 2020, the top 10 airports with the highest pollutant emissions remained the same as those in 2019, but there were changes in the ranking of total airport pollutant emissions. Additionally, the total emissions of NOx, CO, PM, and SO_2 from the top 10 airports in 2020 decreased by 13.46%–50.95% compared with those in 2019. Correspondingly, the concentrations of NO_2, CO, PM_{10}, and SO_2 extracted from the CHAP dataset in 2020 were 10.00–44.80 μg/m^3, 0.43–1.32 μg/m^3, 18.10–328.10 μg/m^3, and 6.10–22.50 μg/m^3, respectively (Fig. 2). Compared with those in 2019, the average concentrations of NO_2, CO, PM_{10}, and SO_2 decreased by 8.88%, 6.33%, 8.79%, and 9.45%, respectively. Additionally, this study examined the trend of pollutant concentrations corresponding to the top 10 airports in terms of total NOx, CO, PM, and SO_2 emissions. Compared with those in 2019, the concentrations of NO_2, CO, PM_{10}, and SO_2 in 2020 decreased by 2.25%–16.93%, 1.23%–13.64%, 6.54%–21.72%, and 0.00%–15.83%, respectively (Fig. 3). According to the "Statistical Bulletin on the Development of Civil Aviation Industry from 2019 to 2020", domestic passenger traffic in civil aviation has significantly decreased due to the novel COVID-19 pandemic. This decline was also reflected in the emissions of air pollutants at civil aviation airports and the concentration of air pollutants in the CHAP dataset, both indicating a downward trend.

3.2. Spatial distribution

The spatial distribution characteristics of air pollutant emission from civil airports exhibited significant regional disparities (Fig. 4-5). These emissions tended to concentrate in the eastern, central, and southern regions of China, whereas emissions in the northeast and western regions remained relatively low. This pattern was also evident in the distribution of pollutant concentrations at civil aviation airports. Areas with high emissions typically coincide with dense populations, significant economic output, well-developed air transport infrastructure, numerous airports, and frequent flight activities. Consequently, these regions bore a heavier burden of aviation emissions. Conversely, more than 70% of airports in Northeast China and Xinjiang were classified as Class 4C regional airports, characterized by fewer takeoffs and landings, resulting in reduced emissions (You et al., 2022). Moreover, An et al. also demonstrated that civil aviation has the greatest impact on the eastern and central regions of China, given the dense concentration of airports and flight routes (An et al., 2024).

Obviously, affected by the COVID-19 pandemic, civil aviation airports exhibited lower emissions and pollutant concentrations in 2020 than in 2019 (Lyu et al., 2023). Furthermore, as the consumption of aviation fuel during takeoff and landing serves as the primary source of typical pollutants such as airport carbon emissions, You et al. conducted a spatial analysis focusing on CO_2 emissions, revealing that 65.96% and 19.67% of the total airports experienced year-on-year increases in CO_2 emissions between 2019 and 2020, respectively (You et al., 2022),

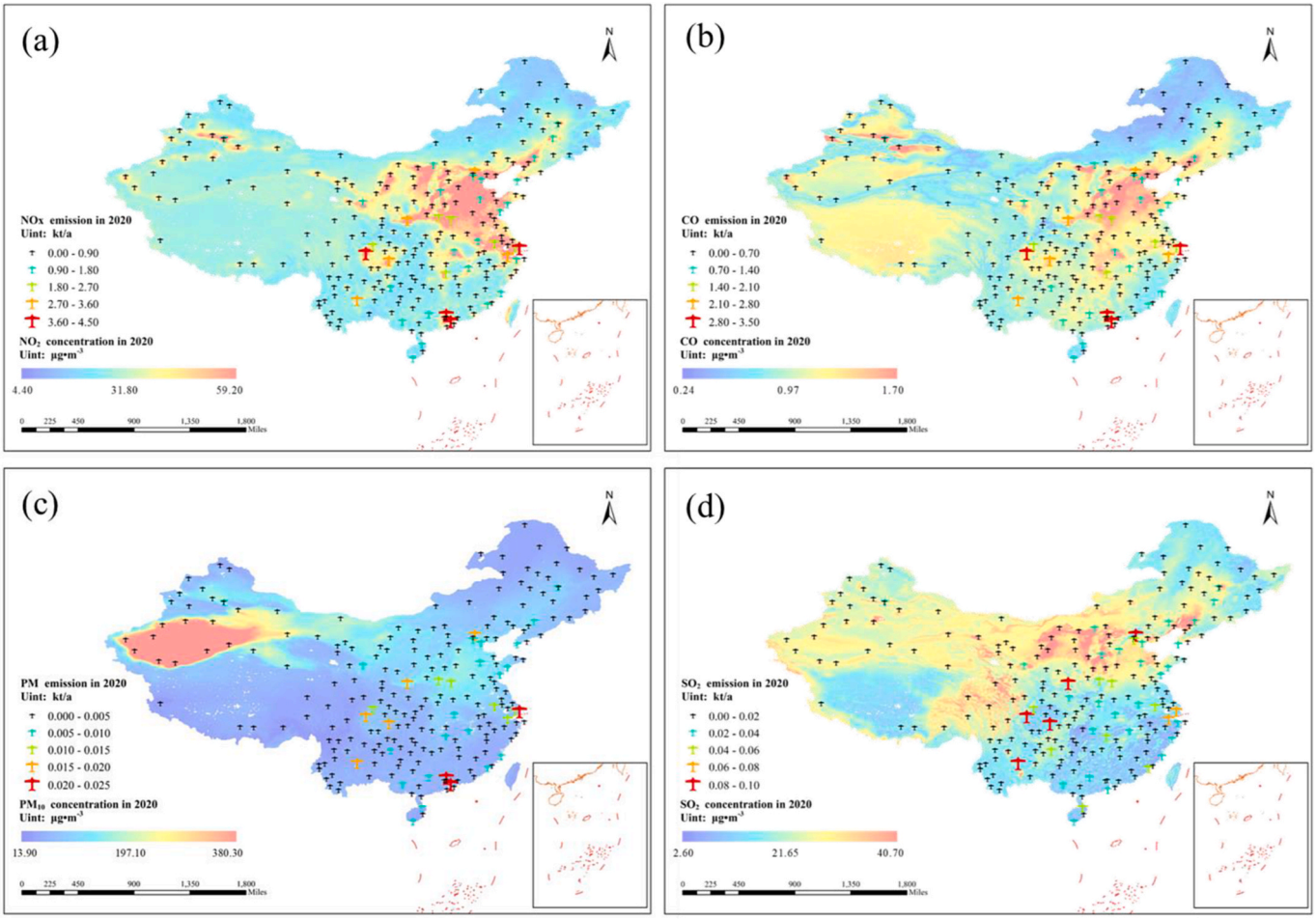


Fig. 5. Spatial distribution of air pollutant concentrations in China's civil aviation airports in 2020.

confirming the impact of the epidemic on civil aviation airports.

With the increasingly strong correlation between tourism and the air transport industry, airport pollutant emissions were closely linked to the rise and fall of the tourism industry in the region where the airport was located. During 2019–2020, Chongqing Jiangbei International Airport, Xi'an Xianyang International Airport, Guangzhou Baiyun International Airport, and Chengdu Shuangliu International Airport displayed relatively high pollutant concentrations (NO_2: 34.30–48.10 μg/m^3; CO: 0.76–0.97 μg/m^3; PM_{10}: 42.70–105.30 μg/m^3; SO_2: 7.80–10.90 μg/m^3), indicating a close relationship between air transport emissions and tourism. Despite the decrease in the number of tourists due to the COVID-19 pandemic, the concentration of pollutants at these airports remained higher than that at other airports. Furthermore, from 2019 to 2020, several airports in Xinjiang exhibited high concentrations of pollutants. On the one hand, the high air pollutant emissions at airports in Xinjiang were mainly attributed to the region's distance from eastern and central China, which made air travel more convenient than other modes of transportation (Xu et al., 2017; Liu et al., 2019). On the other hand, Xinjiang was also a tourist destination. Due to the booming tourism industry (Liu et al., 2022), aircraft flying near tourist cities have become significant sources of air pollution. In general, changes in pollutant emissions and concentrations at civil aviation airports in China reflect the real spatial distribution characteristics of pollutants.

3.3. Empirical model

In this study, an empirical model was constructed to examine the relationship between pollutant concentrations in the CHAP dataset and pollutant emissions in the air pollution emission inventory. The associations between pollutant emissions (in tonnes) calculated in the 2019–2020 emission inventory and pollutant concentrations (in μg/m^3) in the CHAP dataset were further investigated (Fig. 6). Compared with other pollutants, SO_2 emissions were relatively low. Additionally, studies have confirmed that the primary component of $PM_{2.5}$ generated by aircraft (approximately 90%) is secondary nitrate aerosols generated by nitrogen oxide emissions, indicating that particulate matter is a product of secondary conversion (Qin et al., 2021; Zhang et al., 2023). Therefore, this study primarily focused on the analysis of CO and NOx. Table 1 presents the results of the regression coefficients, with t-statistics and F-statistics providing statistical support for this relationship at the 95% confidence level.

Compared with those in 2019, the correlation coefficients in the empirical model in 2020 decreased to varying degrees, with NOx and CO decreasing by 2.82% and 13.46%, respectively. This reduction in correlation may be attributed to factors such as the decrease in annual flights, route distance, cargo volume, and passenger turnover during the epidemic period (Tanrıverdi et al., 2022; Wang et al., 2023a). The correlation coefficient of NOx (0.603) reached a level above 0.6 in 2019. A possible explanation was that NOx was the largest contributor among all air pollutants. NOx emissions from aviation airports are estimated to account for approximately 4~10% of the total anthropogenic emissions of NOx (Zhang et al., 2022). Furthermore, the NOx emission intensity from aircraft during landing and takeoff (LTO) at airports can be an order of magnitude higher than that of major highways with heavy freight truck traffic (Zhang et al., 2021). In addition, Bo et al. (2017) established an emission inventory of the Beijing Capital International

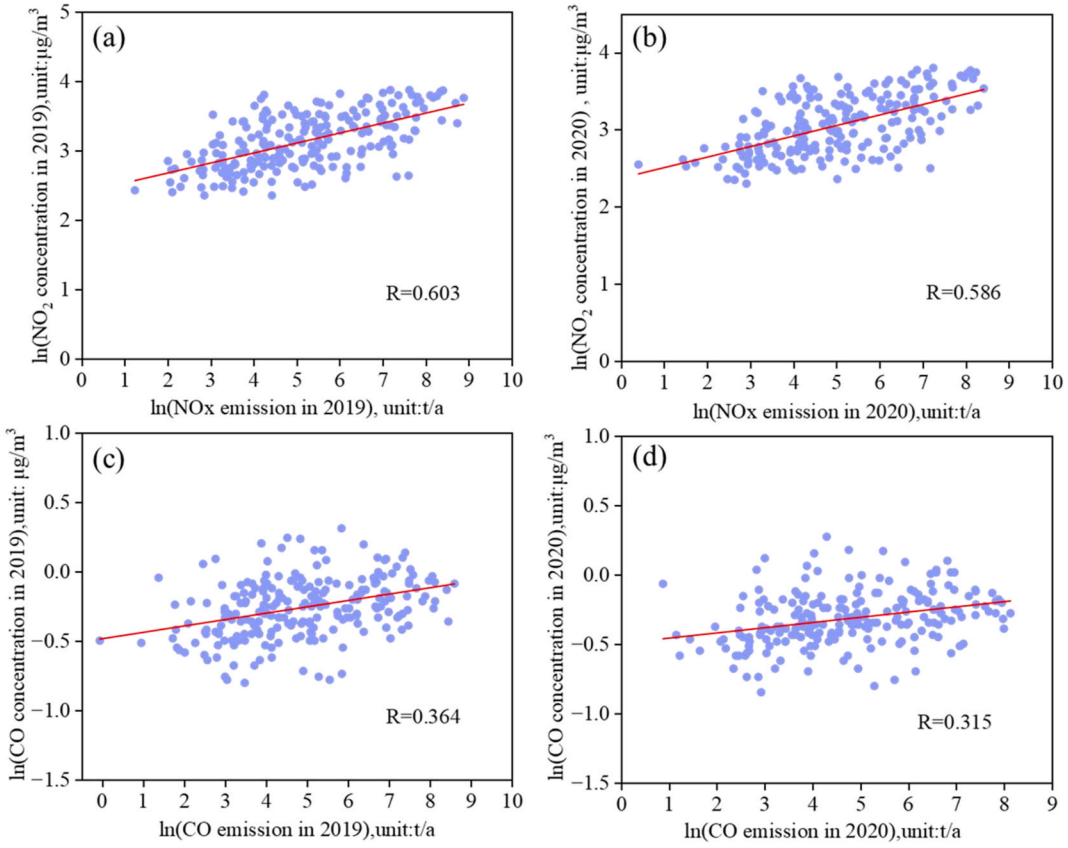


Fig. 6. Construction of empirical models between pollutant (NOx and CO) concentrations from the CHAP dataset and pollutant emissions from the air pollution emission inventory.

Table 1
The evaluation results of the relationship between pollutant emissions from civil aviation airport emission inventories in China during 2019~2020 and pollutant concentration data (NOx and CO) from the CHAP dataset.

Air pollutant	Year	Model	Correlation coefficient	t-statistic	p-value	F-statistic	Standard error
NOx	2019	$\ln y = 0.144\ln x + 2.396$	0.603	11.072	0.000	122.596	0.013
NOx	2020	$\ln y = 0.136\ln x + 2.374$	0.586	10.539	0.000	111.071	0.013
CO	2019	$\ln y = 0.046\ln x - 0.481$	0.364	5.865	0.000	34.397	0.008
CO	2020	$\ln y = 0.038\ln x - 0.491$	0.315	4.909	0.000	24.094	0.008

Airport in real-time in 2012, and the air pollution from the airport to the surrounding environment was simulated. According to a simulation of pollutant diffusion, the NOx emission from the airport had a prominent impact on the surrounding environment of the airport (Bo et al., 2017). Hence, the fluctuations in NO_2 concentrations in the CHAP dataset were strongly associated with nitrogen oxide emissions.

Furthermore, the magnitude of the decrease in the correlation coefficient of CO in the empirical model was greater than that of NOx. This may be due to the comprehensive influence of various factors, such as the chemical characteristics of CO and NOx, the impact of secondary pollutants, and other factors. Firstly, NOx and CO exhibit different chemical reaction mechanisms in the atmosphere. CO primarily reacts with hydroxyl radicals to form CO_2 via a relatively simple chemical reaction mechanism. In contrast, NOx underwent more complex photochemical reactions in the atmosphere, including reactions with hydroxyl radicals and ozone (Hu et al., 2024). Therefore, these distinct chemical reaction mechanisms influence the evolving relationship between pollutant concentrations and emissions. Secondly, NOx emissions are closely linked to the formation of secondary pollutants, such as ozone and secondary organic aerosols (Gao et al., 2022; Wu et al., 2017). This could influence the correlation between NOx emissions and concentrations. In contrast, CO emissions did not contribute to the formation of secondary pollutants. This difference may explain the observed results. Additionally, the CO concentration may be influenced by various disturbing factors, including traffic emissions, industrial emissions, and other sources of CO (Misra et al., 2013). Hence, distinguishing the contribution of civil airport emissions to NOx concentration may be relatively straightforward. This difference may also explain the observed results.

3.4. Uncertainty analysis

This study is subject to several limitations and uncertainties. Firstly, the estimation of emissions from civil aviation relied on engine emission factors recommended by the ICAO engine database. However, operational parameters influenced by engine emissions, aircraft engine types, actual operating conditions, and environmental factors may deviate from real-world scenarios, resulting in numerous uncertainties. Secondly, the engine weighting method used to determine aviation fuel consumption for various aircraft types may not accurately reflect the actual take-off and landing ratio of each aircraft, leading to uncertainties. Thirdly, the extraction of pollutant concentrations from each

airport may suffer from some inaccuracies. Finally, this paper focused on the air pollutant emissions of domestic flights, future studies could provide more detailed divisions of the air pollutant emissions from airports and aviation routes in various provinces and cities in China, as well as an overall estimate.

4. Conclusions

This study investigated the temporal trends and spatial distribution characteristics of air pollutant emissions from the civil aviation sector in China during 2019–2020 based on the previously established high-resolution air pollutant and CO_2 (HC, NOx, CO, PM, SO_2, and CO_2) emission inventory of China's civil aviation sector in 2019–2020 and the CHAP dataset. By comparing the pollutant emission data in the emission inventory and concentration in the CHAP dataset, an empirical model for examining the relationship between the air pollutant emissions of China's civil aviation sector in 2019–2020 and the pollutant concentration from the CHAP dataset was developed.

Due to the emergence of the COVID-19 pandemic, compared to those in 2019, the total NOx, CO, PM, and SO_2 emissions of the LTO cycle from China's civil airports in 2020 decreased by 22.42%, 22.38%, 14.29%, and 24.32%, respectively. Similarly, compared with those in 2019, the average concentrations of NO_2, CO, PM_{10}, and SO_2 in 2020 extracted from the CHAP dataset decreased by 8.88%, 6.33%, 8.79%, and 9.45%, respectively. Additionally, the spatial distribution characteristics of air pollutant emissions at civil airports exhibit noticeable regional disparities. Pollutant emissions were primarily concentrated in the eastern, central, and southern regions of China, while emissions in the northeast and western regions were relatively low. This trend was also reflected in the pollutant concentration distribution at civil aviation airports, which was mainly influenced by factors such as the economy, population, and tourism. Furthermore, the correlation coefficient for NOx, with a correlation coefficient of 0.603 in the empirical model, has the best correlation of all the pollutants, reaching a level above 0.6 in 2019, revealing the relationship between pollutant emissions and concentrations at civil aviation airports and providing a reference for the analysis and verification of the accuracy and completeness of China's civil aviation emission inventory.

Future studies can integrate multiple datasets, including those related to meteorological conditions, flight paths, and airport infrastructure, to enhance the accuracy and comprehensiveness of the analysis. This integration will deepen our understanding of pollutant emissions in China's civil aviation, improve emission reduction strategies, and contribute to the sustainable development of the civil aviation industry. Additionally, developing predictive models to forecast future trends in civil aviation emissions is essential for proactive decision-making and sustainable planning within the civil aviation sector.

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CRediT authorship contribution statement

Xin Xu: Writing – review & editing, Software, Methodology, Conceptualization. **Qian You:** Writing – review & editing, Conceptualization. **Zheng Zhang:** Writing – review & editing. **Zimeng Zhao:** Software, Investigation. **Zhaotong Wang:** Formal analysis, Data curation. **Bidi Zhang:** Software. **Xin Bo:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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