Impact of China’s Recent Amendments to Air Quality Monitoring Protocol on Reported Trends

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Received: 24 September 2020; Accepted: 3 November 2020; Published: 5 November 2020

Abstract: In September 2018, China’s air quality monitoring protocol was amended from the standard conditions to actual conditions for particulate matter and to reference conditions for gaseous pollutants. Due to the amendment, the reported concentrations of the gaseous pollutants decreased by a constant rate of 8.4%, and the averages of PM$_{2.5}$ (particulate matter that has an aerodynamic diameter of 2.5 microns or smaller) reported during September 2017 and August 2018 decreased by 7.9 ± 6.1% at 99% of the monitoring stations. Comparing the periods before and after the amendment, the 12-month PM$_{2.5}$ concentrations at 17.2% of the stations actually increased despite appearing to decrease if the amendments were not considered. We reviewed 370 papers published in 2020 that utilized this air quality dataset, and 21% of these papers used the data before and after the amendment without explicitly stating whether or how conversions were conducted. It is urgent to widely broadcast the protocol amendment to ensure proper use of this extensively cited dataset.

Keywords: air quality; monitoring protocol; amendment; temporal trends; China

1. Introduction

Air pollutant concentrations in China had been reported at the standard conditions of 0 °C and 1013.25 hPa, ever since the first air quality monitoring protocol was implemented in 1982 [1,2]. However, an amendment was made to the official protocol on 1 September 2018 [3], at which time the reporting conditions for gaseous pollutants, including sulfur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), carbon monoxide (CO), and ozone (O$_3$), were changed to the reference conditions of 25 °C and 1013.25 hPa. At the same time, reporting conditions for particulate matter (PM) were changed to the actual conditions. As gas volume varies with temperature and atmospheric pressure [4], it is common to report the concentrations of gaseous pollutants at the reference conditions worldwide. As for PM, the mass concentration under actual conditions can better reflect the PM pollution status [4]. South Africa began reporting the concentration of PM under reference conditions in 2004 [5], while the United States was the first country to report PM concentrations at actual conditions beginning in 1997 [6], followed by the European Union in 2008 [7] (Figure S1).

After China’s monitoring protocol amendment, it is critical to evaluate its effects on the reported concentrations of air pollutants. Monitoring data are commonly used to compare air quality between...
countries [8,9]. However, the change in reporting conditions in China could cause inaccurate inferences if not properly understood. For example, the ambient air temperature and pressure vary widely across China [10], causing large changes to the reported PM concentrations after the protocol amendments were implemented. Monitoring data are also commonly employed to evaluate the health effects of air pollution [11–15]. Failing to notice the different conditions at which concentrations are reported can introduce deviations to dose-response evaluations. Changing the reporting conditions could also affect air quality classifications, making them seem more reasonable when compared to the World Health Organization standards [16].

This study aims to evaluate how China’s air quality monitoring protocol amendment affected the reported pollutant concentrations. We analyzed the possible deviations that would be introduced into analyses if the amendment was not considered. We also evaluated the major factors influencing the reported concentrations. In order to identify which seasons and regions were most affected by this amendment, we evaluated the impact of the amendment on the spatial patterns and temporal trends. We then conducted a literature review to assess how widely this protocol change is known in recently published studies. The results of this study are expected to alert potentially improper usage of the data from China’s national air quality monitoring stations (NAQSs).

2. Materials and Methods

2.1. Data

We downloaded hourly PM$_{2.5}$ and PM$_{10}$ measurements from China National Environmental Monitoring Centre [17] over a two-year period from 1 September 2017 to 31 August 2019, from 1517 NAQSs across Mainland China (Figure S2). We obtained the ambient air temperature and pressure data from 2167 meteorological stations maintained by China Meteorological Administration (Figure S3).

2.2. Conversion Formula

Due to the lack of onsite meteorological data for the NAQSs, co-kriging incorporating elevation was employed to interpolate the hourly temperature ($T$) and surface atmospheric pressure ($P$) to the NAQSs. The distances between the NAQSs and their own nearest meteorological stations are 24.4 ± 13.7 km (mean ± standard deviation). We conducted station-based ten-fold cross-validation to evaluate the interpolation accuracy. All the meteorological stations were randomly divided into ten groups. The temperature and atmospheric pressure for one group were interpolated based on the observations from the other nine groups. This process was repeated ten times so that every observation had a paired interpolated value, for which the coefficients of determination ($R^2$) were calculated.

Because $P$ did not change for gaseous pollutants due to the monitoring protocol amendment, which remained to be 1013.25 hPa, the conversion formula depends only on the temperature. According to the ideal gas law, the conversion formula for gaseous pollutants is as follows:

$$C_r = C_s \times \frac{T_s}{T_r},$$  \hspace{1cm} (1)

where $C_r$ is the concentration at the reference conditions of $T_r = 298$ K and $P = 1013.25$ hPa, and $C_s$ is the concentration at the standard conditions of $T_s = 273$ K and $P = 1013.25$ hPa. The conversion formula for PM is as follows:

$$C_a = C_s \times T_a \times P_a / (P \times T_a),$$  \hspace{1cm} (2)

where $P_a$ is the ambient atmospheric pressure, $T_a$ is the ambient temperature, and $C_a$ is the concentration at actual conditions. Furthermore, we used analysis of variance (ANOVA) to attribute variance of PM$_{2.5}$ differences ($\Delta C = C_a - C_r$) to seasonal and annual levels [18]. The variances of $\Delta C$ were attributed to the variances of $P_a$ and $T_a$ for evaluating the impacts of $P_a$ and $T_a$ on $\Delta C$. 
2.3. Effects on Reported Concentrations

As the conversion formulas for PM$_{2.5}$ and PM$_{10}$ are the same, and the conversion coefficient depends only on temperature and atmospheric pressure, the impact of the monitoring protocol amendment on PM$_{2.5}$ and PM$_{10}$ is similar. In addition, since PM$_{2.5}$ concentrations have greater impacts on human health [19,20], we focused on PM$_{2.5}$ in this study. The original concentrations of PM$_{2.5}$ at each monitoring site from September 2017 through August 2018 (i.e., the 12 consecutive months before the amendment) were converted to concentrations at actual conditions by using Equation (2). By comparing the original and the converted concentrations, we evaluated the effects of the amendment on the annual averages and seasonal variations. Moreover, the PM$_{2.5}$ concentrations from September 2018 through August 2019 (i.e., the 12 consecutive months after the amendment) were incorporated to evaluate possible effects on the interannual trends.

2.4. Literature Search

In order to evaluate the awareness and potential impact of the amendment on recent research, we searched Google Scholar [21] for papers that utilized monitoring data from China’s NAQSs and were published between 2018-2020. We compiled the following query phrases in double quotes from the preliminary literature review: “China (National) Environmental Monitoring Center/Centre”, “datacenter.mep.gov.cn” (former URL of the data center of China’s Ministry of Environmental Protection), “www.cnemc.cn” (URL of China’s National Environmental Monitoring Centre), “113.108 142.147” (former URL of the data server), “106.37.208.233” (current URL of the data server). Papers containing the keyword “air” and any of the phrases were retrieved.

3. Results and Discussion

3.1. Gaseous Pollutants

When reporting conditions for gaseous pollutants changed from the standard conditions to the reference conditions (25 °C and 1013.25 hPa), their concentrations decreased by a constant rate of 8.4%. Adjusting the reporting temperature from 0 to 25 °C made it closer to China’s overall average temperature (14 °C). In China, gaseous pollutants are represented by mass concentration (µg/m$^3$) while volume concentrations of parts per billion (ppb) are used in other countries like the United States and Canada. While the volume specific concentrations do not change with temperature or atmospheric pressure, the mass specific concentrations depend on actual temperature and atmospheric pressure. Thus, converting the reporting conditions to the reference conditions more appropriately reflects actual gaseous pollutant levels and ensure better comparability of data from different countries/regions [4]. As the changes to reported gaseous pollutant concentrations were subject to a constant 8.4% ratio (Equation (1)), we focused instead on the amendment’s impact on PM.

3.2. Annual PM$_{2.5}$ Averages

Due to the amendment, China’s annual average of reported PM$_{2.5}$ concentrations decreased at 99% of the monitoring stations, ranging from −0.01% to −43%, and the national annual average value decreased by 7.1% (Figure 1). The largest decrease occurred at the Naqu station on the Qinghai-Tibetan Plateau, having the lowest annual average atmospheric pressure (579 ± 5 hPa) and relatively low temperature (1.5 ± 8.1 °C). The stations where concentrations reportedly increased, ranging from +0.01 to +1.8%, were in northern and northwestern China, with high atmospheric pressure (1016 ± 15 hPa) and relatively low temperature (−6.6 ± 7.8 °C). As expected, the spatial distribution of changes to reported PM$_{2.5}$ concentrations was associated with regional topography and climate patterns. Given the wide range in elevation for monitoring stations across China (from −3 to 4516 m), the atmospheric pressure also varied considerably (from 579 to 1019 hPa). Variation in the atmospheric pressure accounted for 85% of the overall shift in reported concentrations. For areas with comparable elevation, temperature was the primary factor for variations in reported PM$_{2.5}$ concentrations ($\Delta$PM$_{2.5}$), due to
the monitoring protocol amendment. Taking the seven NAQSs at sea level as an example, temperature accounted for 99% of the variation in $\Delta PM_{2.5}$.

Figure 1. Reported shifts of annual average concentrations of PM$_{2.5}$ due to the amended monitoring protocol at Mainland China’s national air quality monitoring stations (September 2017–August 2018). Annual PM$_{2.5}$ averages decreased at 99% of air quality monitoring stations.

3.3. Seasonal PM$_{2.5}$ Averages

Seasonally, except for an increase in winter (1.4 ± 1.2 μg/m$^3$) at 24.6% of the monitoring stations, the reported PM$_{2.5}$ concentrations decreased at all stations following the monitoring protocol amendment (Figure 2). Note that the cross-validation $R^2$ values for spatially interpolating $P$ and $T$ are 0.922 and 0.972, respectively, suggesting that the estimated $P$ and $T$ on the NAQSs are generally satisfactory. Nationally, the largest decrease (−13%) occurred in summer, and the smallest (−4%) was in winter. The average temperature was 26 ± 4.8 °C in summer and 1.9 ± 9.8 °C in winter, indicating that lower temperatures made the concentrations relatively higher after the amendment. This is consistent with the results inferred directly from the conversion formula (Equation (2)).

Under the combined effects of $P$ and $T$ from the amendment, the reported shifts of the seasonal mean PM$_{2.5}$ concentrations between September 2017 and August 2018 varied from −40% to +10%, with an average of −8.8 ± 6.9% (Figure 3). The relative changes were the largest (−30% to −40%) on the Qinghai-Tibetan Plateau, where elevations exceed 4000 m, and the smallest (±10%) on the plains with elevations below 1000 m. The dashed curves indicate the relationship between temperature and pressure, which is driven by the elevation variation. The variation led to a moderate correlation between $P_a$ and $T_a$ ($r = 0.33$), which acted as a primary factor in the spatial heterogeneity of the reported concentration changes. By combining the seasonal average temperature and pressure of all stations with the conversion coefficient (Figure 3), we see that $\Delta PM_{2.5}$ is more likely to be greater than 0 under low temperature and high pressure, leading to an increasing trend of PM$_{2.5}$ concentrations at 24.6% of the stations in winter. Based on the ANOVA results of the monthly data, the variation of atmospheric pressure accounted for 69.5% of the overall shifts in the reported PM$_{2.5}$ concentrations.
The percentage change of PM$_{2.5}$ in four seasons. The percentage change of PM$_{2.5}$ concentrations at the national air quality monitoring stations in (a) spring, (b) summer, (c) fall, and (d) winter across Mainland China (September 2017–August 2018), due to the monitoring protocol change from standard conditions (298 K and 1013.25 hPa) to actual conditions (i.e., actual atmospheric pressure and temperature).

Combined effects of atmospheric temperature and pressure on the shift of reported concentrations of particulate matter (PM$_{2.5}$ or PM$_{10}$) caused by the measurement modification. The solid contour lines indicate shifted percentages of reported concentrations. Each dot represents a seasonal average data point at a monitoring site from September 2017–August 2018. Different colors denote measurements in spring (March, April, and May), summer (June, July, and August), autumn (September, October, and November), and winter (December, January, and February). Dots from regions of interests are circled with dashed ellipses.
3.4. Interannual PM$_{2.5}$ Trends

Failing to account for the significant impact that China’s air quality monitoring protocol amendment conveys could cause significant misidentification of interannual concentration trends, e.g., underestimating increasing or overestimating decreasing trends. The annual average concentrations of PM$_{2.5}$ during 2018–2019 were 39 ± 14 µg/m$^3$, but the apparent decrease from 2017–2018 would be overvalued by 7.1% (10% vs. 2.9%). In 62.7% of the stations, the magnitude of the PM$_{2.5}$ concentration decrease would be overestimated by 0.1% to 33% (Figure 4a). While in another 37.3% of the stations, the magnitude of change would be underestimated (Figure 4b). At 0.5% of the stations, the magnitude decline would be underestimated up to 0.7%. For another 36.8% stations, the magnitude of the increase would be underestimated according to two circumstances: for 19.6% of the stations, the concentrations would increase, but the magnitude of the increase would be underestimated by 2.0% to 75%; and for another 17.2% of the stations, the concentrations would appear to have declined but would have actually increased. Consequently, the apparent reduction caused by the amendment actually masks increases in pollution concentrations.

![Figure 4](https://example.com/figure4.png)

**Figure 4.** Reported (a) under- and (b) over-estimated changes (%) of the 12-month average PM$_{2.5}$ concentrations from September 2017–August 2018 (first period) and September 2018–August 2019 (second period), due to the monitoring protocol amendment effective since September 2018. Underestimation means that the actual degree of concentration increase between these two periods is larger than the reported. Overestimation means the actual degree of concentration decline is smaller than the reported.

3.5. Relevant Literature

We obtained 297, 428, and 370 published papers in the years 2018, 2019, and 2020 (through July), respectively, which all utilized monitoring data from the NAQSs. Considering the limited extent of our literature search, the number of studies is likely higher. The extensive use of this monitoring dataset highlights widespread implications of the air quality monitoring protocol amendment on current scholarship. More importantly, approximately 21% of the studies published in 2020 used data from both before and after the amendment, but none of these explicitly stated whether or how the data were converted for consistency. The literature can be found in the supporting information. It is thus urgent to raise awareness of the amendment of the monitoring protocol to avoid potential misuse of Mainland China’s NAQSs dataset.

4. Conclusions

As the 2018 amendment essentially exaggerated a decrease in the reported air pollutant concentrations, more cities nominally achieved better air quality with respect to levels of health concern. It should be noted that these nominal improvements were not totally attributable to the
pollutant emission reductions, and we should take the effect of amendment into account when investigating the interannual trends. Researchers must not only pay attention to the amendment when studying issues related to pollutant concentrations in China, but must also clearly articulate how they account for the amendment in their methods. Since our study only used two years of meteorological data, and meteorological conditions differ between years, the direct results of this study are limited in scope. Nevertheless, this study demonstrates the importance of taking China’s air pollution monitoring protocol amendment into account when seeking to evaluate pollution concentrations over time. The general patterns of our results should be consistent across any set of years chosen (before and after the amendment) for comparison. From a global perspective, as the air quality monitoring protocols differ between countries, more attention should be paid to guarantee data comparability for international investigations.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2073-4433/11/11/1199/s1, Figure S1: Evolution of pollutant measurement conditions in major countries and regions, Figure S2: National air quality monitoring stations in Mainland China, Figure S3: Meteorological stations in Mainland China.

**Author Contributions:** Conceptualization, Y.Z.; methodology, Y.Z.; software, L.J., Y.Z.; validation, L.J., Y.Z.; formal pollutant emission reductions, and we should take the effect of amendment into account when investigating the interannual trends. Researchers must not only pay attention to the amendment when studying issues related to pollutant concentrations in China, but must also clearly articulate how they account for the amendment in their methods. Since our study only used two years of meteorological data, and meteorological conditions differ between years, the direct results of this study are limited in scope. Nevertheless, this study demonstrates the importance of taking China’s air pollution monitoring protocol amendment into account when seeking to evaluate pollution concentrations over time. The general patterns of our results should be consistent across any set of years chosen (before and after the amendment) for comparison. From a global perspective, as the air quality monitoring protocols differ between countries, more attention should be paid to guarantee data comparability for international investigations.

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**Author Contributions:** Conceptualization, Y.Z.; methodology, Y.Z.; software, L.J., Y.Z.; validation, L.J., Y.Z.; formal analysis, L.J., Y.Z., G.S. and F.Y.; investigation, L.J., Y.Z.; resources, Y.Z.; data curation, L.J., Y.Z.; writing—original draft preparation, L.J.; writing—review and editing, L.J., Y.Z., G.S., F.Y., B.C.S., X.Q., X.D., X.J. and B.W.; visualization, L.J.; supervision, Y.Z.; project administration, Y.Z., B.W.; funding acquisition, Y.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study was supported by the National Natural Science Foundation of China (20276129), the Sichuan Key R&D Project (2020YFS0055), the Young Talent Team Science and Technology Innovation Project of Sichuan Province (2020JDTD0005), and the Fundamental Research Funds for the Central Universities of China (YJ201765).

**Conflicts of Interest:** The authors declare no conflict of interest.

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