

The Ambient Ozone and COVID-19 Transmissibility in China: A Data-Driven Ecological Study of 154 Cities

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Highlights

- We quantified the COVID-19 transmissibility by the basic reproductive number.
- The COVID-19 transmissibility could be negatively associated with ambient ozone.
- The daily 1-h maximum ozone might cover 7.6% of the transmissibility variability.
- It echoes a previous study of negative effects of ozone on the flu transmission.
- The ground-level ozone may be a “double-edged sword” to public health.

Dear Editor,

The coronavirus disease 2019 (COVID-19) has triggered a pandemic and is still spreading around the world. Exploring the environmental factors that associate with the prevalence and transmission would improve the understanding of COVID-19 and contribute to the long-term control strategies of the outbreak.^{1,2} Besides the meteorological factors³, to what extent do common air pollutants may affect the COVID-19 transmission remains unclear. To fill this knowledge gap, we examined the associations between common air pollutants and COVID-19 transmissibility in Chinese cities.

We obtained the daily count of COVID-19 cases for each Chinese city from the Chinese provincial health agencies and China National Health Commission (CNHC).⁴ We quantified the transmissibility of COVID-19 by using the basic reproduction number (R_0), a unit-free measure of infectivity that is commonly used in infectious disease epidemiology. Then, we filtered out a case series of each city from the first-case occurrence to the following 16 days for estimating the R_0 .⁵ We calculated the R_0 for each Chinese city with a Gamma distribution having mean (\pm SD) values of 5.5 (\pm 3.3) days for the serial interval averaged from previous estimations. The calculation in detail was shown in supplementary materials. As R_0 is a measurement regarding the population as a whole, the demographic heterogeneities across each city could be thus neglected.

We obtained air pollutants monitoring data in 1,642 stations from China National Environmental Center between December 10, 2019 and February 29, 2020, including ozone (O_3) with three metrics – daily average, daily 1-h maximum, and daily 8-h maximum, as well as other criteria pollutants. After calculating their average values across the time period, we computed a raster for each pollutant by the kriging interpolation. We then extracted and linked pollutants' values to each Chinese city. The spatial distribution of O_3 (1-h maximum) was shown in Fig. 1A. The corresponding meteorological factors were addressed and matched by the same method. We adopted the nonlinear (i) univariable, and (ii) multivariable, i.e., adjusted by temperature and absolute humidity, regression analyses to explore the association between R_0 and each pollutant. We carried out the fitting procedure considering two weighting schemes that are (i) equal-weighted, and (ii) weighted by the total number of cases from each city. In addition, we employed the spline regression and permutation and perturbation analysis as sensitivity analysis for validation.

A total of 154 Chinese cities were detected with the COVID-19 outbreak ($R_0 > 1$) and were included in the regression analysis. The maximal R_0 was estimated at 2.5 (95%CI: 2.4–2.6) in Wuhan (Table 1), which is largely consistent with previous estimates.^{6,7} Their spatial distribution was shown in Fig. 1B. We found that the R_0 of COVID-19 was negatively associated with the daily 1-h maximum O_3

concentration for both univariable and multivariable analyses and both weighting schemes significantly and consistently (Fig. 1C and Fig. S1). By contrast, associations with other pollutants failed to reach statistical significance. The average concentration of daily 1-h maximum O₃ across the 154 cities has a median at 73.1 µg/m³ and ranges from 51.6 µg/m³ to 106.7 µg/m³ (Table 1). The Spearman's ranked correlation coefficient between daily 1-h maximum O₃ and R₀ was -0.21 (95% CI: -0.33, -0.02) (Table S1). We estimated that the ambient O₃ could solely explain 7.6% of the variability in the R₀ of COVID-19 in terms of McFadden's pseudo-R-squared for the univariable analysis, and this term increased to 9.3% in the multivariable analysis. A similar protective association between O₃ and the transmissibility of influenza was found in a previous study.⁸ The spline regression validated the negative association (Fig. S2), and the permutation and perturbation tests represented that the observed relationship was unlikely due to chance.

To our best knowledge, this is the first study on the association of COVID-19 transmissibility with ambient ozone. Ambient ozone was associated in reducing COVID-19 transmissibility probably due to its virucidal activity and possible impact on host defense. Ozone gas is highly effective in broad-spectrum disinfection and sterilization against many repertory infections, such as SARS and influenza viruses.⁹ Ozone-primed immunity against viral infection might also play a critical role in the reduction of COVID-19 infectivity. Specifically, exposure to ambient ozone may trigger slight allergic reactions to human, which may enhance pulmonary innate immunity. Ozone-induced interleukin (IL)-33 can activate internal Th1 and CD8 T-cell reactions, which can drive protective immunity against viral infections. The IL-33 is thus utilized as an adjunct in influenza vaccines to stimulate antigen-specific immunoreactions in preclinical settings.^{10,11} However, the negative association was identified merely with the 1-h maximum ozone concentration, which implied that ambient ozone may result in the wane of COVID-19 transmissibility when its concentration reached a certain threshold. Further studies are needed to explore the dose-response relationship between ozone and COVID-19 transmissibility and to infer the threshold dose of ozone concentration.

Some limitations should be noted. First, the daily 1-h maximum ozone only covered 7.6% of the transmissibility variability since the majority of the variance would be explained by the virus-intrinsic factors. Relevant intervention would be restricted though the modest effect could still contribute to the size of a single outbreak or a local epidemic.^{8,12} Second, the imported and local cases in each city cannot be disentangled, which might introduce a constant and uniform impact on estimation of R₀ across cities. However, the proportion of the imported cases was expected to be small and had limited effect since the local government of Wuhan suspended all inbound and outbound transportations in the initiation, and most of the transmission occurred locally in each city.

Two significances of the current study were emphasized here. First, as the weather getting warmer in the Northern hemisphere, the ambient ozone concentration in many places will gradually escalate, and this could be a good sign for the COVID-19 control regionally. Second, as a highly reactive oxidant air composition, ground-level ozone is also a “double-edged sword” to public health. We advocate that more attention on the good side of ambient ozone and the trade-off of ambient ozone control to avoid over-vigilance.

Ethics approval and consent to participate

The COVID-19 cases data were collected via public domain ⁴, and thus neither ethical approval nor individual consent was applicable.

Availability of materials

All data used in this work were publicly available ⁴.

Consent for publication

Not applicable.

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Disclaimer

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Conflict of Interests

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Authors' Contributions

J. Ran and S. Zhao conceived the study and carried out the analysis. L. Han and D. Chen collected the data. J. Ran and S. Zhao drafted the first manuscript and discussed the results. All authors critically read and revised the manuscript and gave final approval for publication.

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Table 1 Descriptive statistics for the basic reproductive numbers, three ozone metrics and weather conditions across 154 Chinese cities

	Mean	SD	Min	25th	50th	75th	Max	IQR
COVID -19 transmissibility								
R_0	1.4	0.3	1.0	1.1	1.3	1.5	2.5	0.4
O₃ metrics, $\mu\text{g}/\text{m}^3$								
Daily average	43.9	7.4	27.1	38.6	43.2	48.3	71.7	9.6
1-h Maximum	75.1	10.5	51.6	69.2	73.1	79	106.7	9.7
8-h Maximum	48.3	7.7	30.1	42.4	47.8	52.9	77.1	10.5
Weather conditions								
Temperature ($^{\circ}\text{C}$)	4.3	8.3	-22.5	0.4	6.2	9.3	19.1	8.9
AH (g/m^3)	7.2	3.9	0.7	4.2	7.4	9.4	18.7	5.2

Abbreviation: R_0 , basic reproductive number; AH, absolute humidity; SD, standard deviation; Min, minimum value; Max, maximum value; IQR, interquartile range.

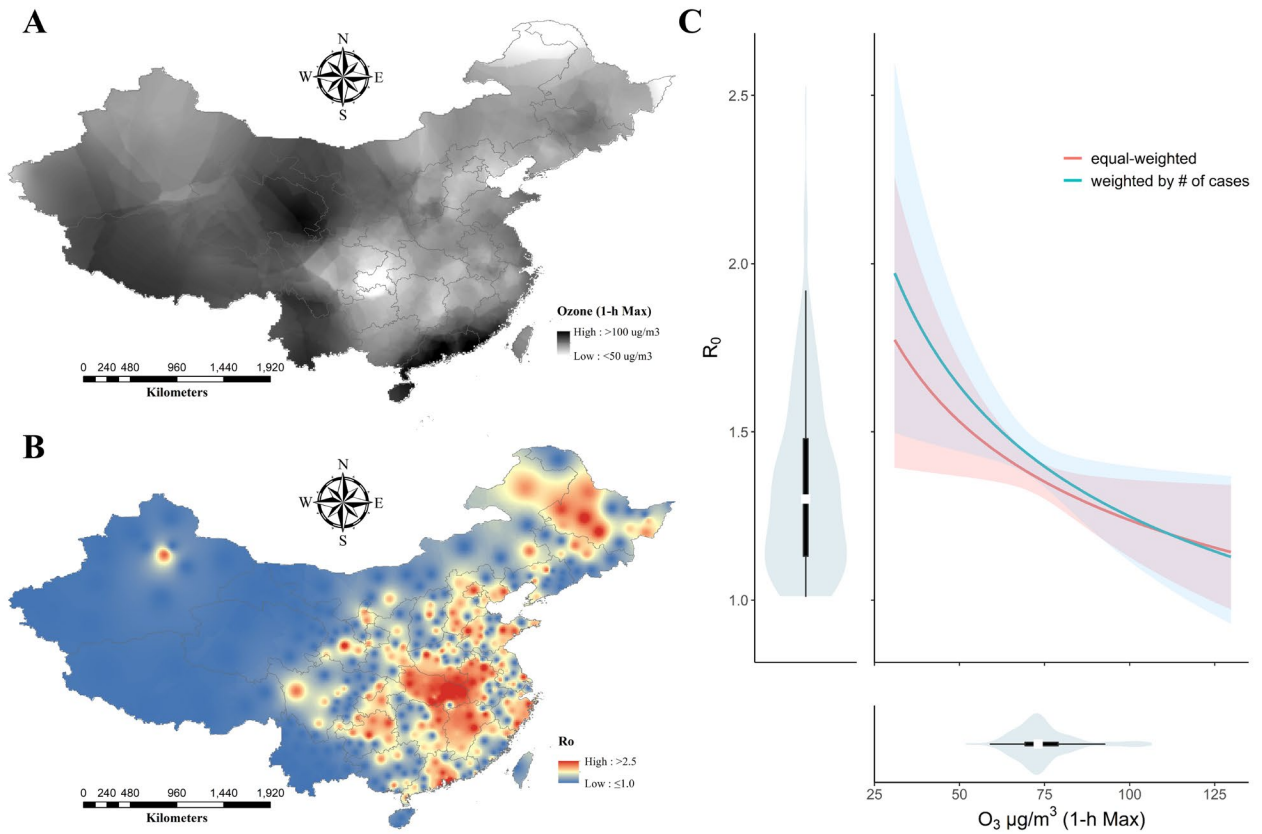


Fig.1. (A) Varying levels of mean concentrations of daily 1-h maximum ozone from December 10, 2019 to February 12, 2020 by spatial interpolation with inverse distance weighting. (B) Spatial distribution of basic reproductive number (R_0) across 154 Chinese cities. (C) Estimated nonlinear relationships and corresponding confidence intervals between the R_0 and daily 1-h maximum ozone concentrations in the multivariable regression analysis with two weighting schemes (equal-weighted and weighted by the number of cases). The violin plot on the left of the panel c indicates the distribution of R_0 and the plot in the bottom shows the distribution of ambient 1-h maximum ozone concentrations; their interquartile ranges are represented by the black rectangle, their medians are indicated by the white square, and the distribution of values was shown by the light-blue area.