Environmental Research 199 (2021) 111268

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Risk analysis of different transport vehicles in India during COVID-19 pandemic

Darpan Das *, Gurumurthy Ramachandran

Johns Hopkins University, Bloomberg School of Public Health, Department of Environmental Health and Engineering, 615 N Wolfe St, Baltimore, MD, 21205, USA

ARTICLE INFO

Keywords:
Ventilation
Automobile
Auto-rickshaw
Personal exposure
Risk assessment

ABSTRACT

Due to the airborne nature of viral particles, adequate ventilation has been identified as one suitable mitigation strategy for reducing their transmission. While 'dilution of air by opening the window' has been prescribed by national and international health agencies, unintended detrimental consequences might result in many developing countries with high ambient air pollution. In the present study, $PM_{2.5}$ exposure concentration and probability of mortality due to $PM_{2.5}$ in different scenarios were assessed. A COVID airborne infection risk estimator was used to estimate the probability of infection by aerosol transmission in various commuter microenvironments: (a) air conditioned (AC) taxi (b) non-AC taxi (c) bus and (d) autorickshaw. The following were the estimated exposure concentrations in the four types of vehicles during pre-lockdown, during lockdown, and lost-lockdown: AC taxi cars (17.16 μg/m^3, 4.52 μg/m^3, and 25.09 μg/m^3); non-AC taxis: (28.74 μg/m^3, 7.56 μg/m^3, 42.01 μg/m^3); buses (21.79 μg/m^3, 5.73 μg/m^3, 31.86 μg/m^3) autorickshaws (51.30 μg/m^3, 3.50 μg/m^3, 75 μg/m^3). Post-lockdown, the probability of mortality due to $PM_{2.5}$ was highest for autorickshaws (5.67×10^{-3}), followed by non-AC taxis (2.07×10^{-3}), buses (1.39×10^{-3}), and AC taxis (1.02×10^{-3}). This order of risk is inverted for the probability of infection by SARS-COV-2, with the highest for AC taxis (6.10×10^{-2}), followed by non-AC taxis (1.71×10^{-2}), buses (1.42×10^{-2}), and the lowest risk in autorickshaws (1.99×10^{-4}). The findings of the present study suggest that vehicles with higher ventilation or air changes per hour (ACH) should be preferred over other modes of transport during COVID-19 pandemic.

1. Introduction

The World Health Organization (WHO) has declared the COVID-19 pandemic to be an airborne infectious disease (Morawska and Milton, 2020). The general consensus is that there are two main modes of transmission of the virus: (a) via larger respiratory droplets (>5 μm) that remain in the air for only a short time and travel short horizontal distances, generally a few meters, before settling out by gravity and (b) via small (<5 μm) aerosolized droplets that remain in the air for many hours or days and travel longer distances (Lu et al., 2020). While exposure to droplets can be mitigated by face masks and social distancing, exposures to smaller airborne particle need to be managed using engineering controls such as adequate ventilation. Several studies indicate that inadequate ventilation is an important mechanism for the spread of COVID virus (Lu et al., 2020; Lednicky et al., 2020; Li et al., 2020; Chen and Zhao, 2020). Ventilation as a strategy to dilute the air concentration of airborne contaminants (including virus containing particles) by exchanging air in the room with air from outside is widely accepted including for transport vehicles (URL 01). The USEPA and Centers for Disease Control (CDC) recommendations include "Improve the ventilation in the vehicle if possible (for example, open the windows or set the air ventilation/air conditioning on non-recirculation mode" and "Ask the driver to improve the ventilation in the vehicle) (URL 02, URL 03).

However, in many developing countries, diluting the indoor with ambient air increases risks to health from exposure to air pollution. $PM_{2.5}$ (particulate matter less than 2.5 μm in aerodynamic diameter) concentrations in India are an order of magnitude higher than cities in USA (Gurjar et al., 2008). Approximately 58% of districts in India recorded ambient particulate matter $PM_{2.5}$ (particulates with aerodynamic diameter ≤ 2.5 μm) pollution above the National Ambient Air Quality Standard (NAAQS) and 99% of the districts were above the WHO guidelines in 2015 (Chowdhury et al., 2019). Estimates of the burden in India show that 627,000 premature deaths and nearly 17.8 million Disability Adjusted Life Years (DALYs) to be attributable to ambient air pollution (Balakrishnan et al., 2014).

Autorickshaws and buses are other commonly used means of public

* Corresponding author.
E-mail address: ddas11@jhu.edu (D. Das).

https://doi.org/10.1016/j.envres.2021.111268
Received 27 January 2021; Received in revised form 6 April 2021; Accepted 28 April 2021
Available online 11 May 2021

transport in most of the cities in India (Choudhary and Gokhale, 2016), along with personal cars and shared cars/taxis (Mobility and Preferences, 2019). Exposure to traffic-related PM during short-term commutes has demonstrable health effects (Knibbs et al., 2011), and there is evidence that the in-cabin air can be polluted by the outdoor ambient air in India (URL 04). Piscitelli et al. (2019), in their study in Italy, estimated the health care cost due to road freight traffic related air pollution to be up to 1.2 billion EUR per year. A recent study shows that irrespective of the city and car model used, a windows-open setting showed the highest exposure, followed by fan-on and recirculation, and also that particulate matter (PM) was higher for shared cars compared to personal cars (Kumar et al., 2020; Jain, 2017).

While many cities in the developing countries like Delhi (Mahato et al., 2020; Kumari and Toshniwal, 2020) suffer from poor air quality with $PM_{2.5}$ concentrations above WHO guidelines, ambient air pollution has been shown to decrease globally during the pandemic (Venter et al., 2020). As lockdowns are removed in many parts of the word, $PM_{2.5}$ concentrations are expected to soon reach pre-lockdown levels. There is a considerable percentage of passengers in India who use autorickshaws and motorcycles who will be exposed to the ambient $PM_{2.5}$ concentrations. High $PM_{2.5}$ exposure in auto-rickshaws have been described in several studies (Pant et al., 2017; Apte et al., 2011; Gupta and Elumalai, 2019).

With the ongoing pandemic and guidelines suggested by the regulatory bodies to open window during travel, population living in low/income countries are exposed to the ambient $PM_{2.5}$ concentration. In the present study, short-term health risks (due to virus infection) and long-term or chronic risks (due to particulate matter) were assessed for several commute micro-environments. Short term or acute health risk refers to health outcomes resulting from exposures within a short period. Long term health risks are attributable to chronic exposure ($PM_{2.5}$) over a long time period that result in adverse health outcomes. The risk tradeoffs in different scenarios of pre-lockdown, lockdown and post-lockdown were assessed to estimate the risk associated with different mode of transportation.

2. Methodology

2.1. Risk due to $PM_{2.5}$ personal exposure

Using the equation developed by Fann et al. (2012), the annual number of adverse health outcomes in various scenarios were estimated (Equation 1).

$$\Delta y = y_0 \left(e^{\beta \Delta x} - 1\right) Pop \tag{1}$$

where, Δy = number of adverse health outcomes.

y_0 = baseline incidence rate.

β = effect estimate.

Δx = change in air quality.

Pop = the affected population

$$\frac{\Delta y}{Pop} = individual\ probability\ of\ death$$

In the absence of epidemiological studies in the Indian subcontinent focusing on the relationship between $PM_{2.5}$ and air pollution, effect estimates for mortality (0.02151) from ischemic heart disease were taken from Krewski et al., 2009) for $PM_{2.5}$. The baseline incidence rate of 0.00141 indicative of the total ambient and household air pollution attributable death rate for India was taken as input based on existing data (URL 05). Different case scenarios of change in air quality were evaluated: (a) background of 25 μg/m^3 based on WHO guidelines (Δx = 0); (b) pre-lockdown ambient concentration of 76.3 μg/m^3 (Kumari and Toshniwal, 2020) (Δx = 51.3); (c) during-lockdown – 38.5 μg/m^3 (Kumari and Toshniwal, 2020) (Δx = 13.5) and (d) post-lockdown – 100 μg/m^3 (Kumari and Toshniwal, 2020) (Δx = 75). Estimated in-cabin exposure in various transit micro-environments in Delhi, India were as follows: AC cars (89 ± 30 μg/m^3), non-AC cars (149 ± 13 μg/m^3), buses (113 ± 14 μg/m^3) and auto-rickshaws (266 ± 159 μg/m^3) (Maji et al., 2020). Assuming, the indoor to outdoor infiltration ratio to be 1 for autorickshaws, the average exposure concentration from Jyoti et al. (2020) was used to estimate the indoor to outdoor ratio in other transit microenvironments: 0.33 for AC-taxis, 0.56 for non AC-taxis, 0.42 for buses.

2.2. Estimation of risk due to SARS-CoV-2

A COVID airborne infection risk estimator developed by Miller et al. (2020) (Miller et al., 2020), was used to estimate the probability of infection by aerosol transmission in various commuter micro-environments: (a) air conditioned (AC)-taxi (b) non AC-taxi (c) bus and (d) autorickshaw. In these calculations, we assume that only 1 passenger is infected, the latent period of the disease is longer than the length of the model, infectious aerosols are evenly distributed throughout the vehicle interior volume, and are removed by a first-order process that includes ventilation (air changes per hour or ACH), vehicle air filtration, gravitational deposition, and viral inactivation. The probability of infection is assumed to be related to the number of quanta (airborne virus) inhaled. The average concentration of quanta in a compartment (C_{avg} in q/m^3) can be estimated as:

$$C_{avg} = \frac{E}{LV}\left[1 - \frac{1}{LD}\left(1 - e^{-LD}\right)\right] \tag{2}$$

where E is the quanta emission rate (q/hour), L is the sum of removal rates by all mechanisms (hour^{-1}), e.g., gravitational settling, and removal by ventilation and filtration systems, D is the duration of the ride, and V is the volume of the vehicle interior.

The probability of infection (P_i) is modeled as:

$$P_i = 1 - \exp(-n) \tag{3}$$

where n is the number of inhaled quanta. The assumptions given as input

Table 1
COVID airborne infection risk estimator model inputs for each scenario, including distributions and ranges used. U: Uniform distribution with (minimum, maximum) values.

S. No	Input Parameter	Units	AC Taxi	Non-AC Taxi	Bus	Auto
1	Volume (V)	m^3	19.6	19.6	93.6	5.6
2	ACH		U (0.94,15.34)	30.80	U (3.3,9.19)	10,000
3	Breathing rate	m^3/h	U (0.49,1)			
4	Passengers	people	5	5	40	5
5	Duration of trip (D)	h	0.75			
6	Decay rate of the virus	h^{-1}	0.32			
7	Deposition to surfaces	h^{-1}	0.3			
8	Additional control measures	h^{-1}	0			
11	Fraction of population infected		20.00%	20.00%	2.50%	20.00%
12	Quanta emission rate (E)	q h^{-1}	U (2,134)			
13	Mask efficiency for emission	%	U (50,60)			
14	Mask efficiency for intake	%	U (30,40)			

to the model are shown in Table 1, with many of the values relating to virus properties obtained from Miller et al. (2020). The dimensions of a typical Indian AC-taxi and non AC-taxi were taken from Adak et al. (2016); an Indian bus from Chaudhry and Elumalai, 2020) and an Indian autorickshaw from Lukic et al., 2007). Using the regression model developed by Knibbs et al. (2009), the air changes per hour (ACH) were estimated for different AC taxi speeds (0–120 km/h) representative of range of speed in Indian roads for active recirculation and fan settings, while the ACH for Non AC taxi were taken from Ott et al., 2008) for window open settings. In the absence of literature data for ACH determination of autorickshaw, a well-mixed model was assumed and estimated to be ~10,000 h^{-1}.

3. Results

3.1. Short- term and long-term risk

$PM_{2.5}$ exposure concentration and probability of mortality due to $PM_{2.5}$ in different scenarios of the lockdown are shown in Fig. 1. Exposure concentration (product of 1ndoor-Outdoor ratio and ambient concentration) in AC taxi cars were estimated to be 17.16 μg/m^3 during pre-lockdown conditions, 4.52 μg/m^3 during lockdown and 25.09 μg/m^3 after lockdown. Similarly, in non-AC taxi cars exposure concentration were estimated to be 28.74 μg/m^3 during pre-lockdown, 7.56 μg/m^3 during lockdown and 42.01 μg/m^3 during post-lockdown. Exposure concentration in buses were estimated to be 21.79 μg/m^3 lockdown, 5.73 μg/m^3 during lockdown and 31.86 μg/m^3 after lockdown. Exposure concentration in autorickshaws were estimated to be 51.30 μg/m^3 for before lockdown, 13.50 μg/m^3 during lockdown and 75 μg/m^3 after lockdown. Probability of mortality due to $PM_{2.5}$ in AC-taxis was estimated to be 6.30×10^{-4} during pre-lockdown, 1.44×10^{-4} during lockdown and 1.01×10^{-3} during post-lockdown. For non-AC taxi cars, during pre-lockdown the probability of mortality was estimated to be 1.21×10^{-3}, 2.49×10^{-4} during lockdown and 2.07×10^{-3} during post-lockdown. For buses, probability of mortality due to $PM_{2.5}$ was estimated to be 8.43×10^{-4} during pre-lockdown, 1.85×10^{-4} during lockdown and 1.39×10^{-3} during post-lockdown. For autorickshaws, the probability of mortality due to $PM_{2.5}$ was estimated to be 2.84×10^{-3} during pre-lockdown, 4.75×10^{-4} during lockdown and 5.67×10^{-3} during post-lockdown.

The probability of infection due to SARS-CoV-2 in different commute microenvironments is shown in Fig. 2. It was estimated to be 6.10×10^{-2} in AC-taxis, 1.71×10^{-2} in non-AC taxis, 1.43×10^{-2} in buses, and 1.99×10^{-4} in autorickshaws. AC taxi cars as compared to non-AC taxis have a ~250% higher probability of infection. Increasing the car driving speed from stationary to 120 km/h leads to a decrease in the probability of infection by approximately 75%. The speed of the vehicle is an important parameter which influences the air exchange rate in non-recirculation transit environments and should be considered in future exposure model predictions for transit vehicle systems. Further, based on ACH values determined by Ott et al. (2008), the probability of transmitting virus is further decreased to ~86% in window open conditions, thus indicating this as an important step towards control of transmission of the viral particles. The highest probability of infection was estimated for AC-taxi and autorickshaw were found to have the least probability of infection.

4. Discussion

Fig. 1 shows the $PM_{2.5}$ exposure concentration and probability of mortality due to $PM_{2.5}$ in calculated different scenarios. Since there are no quantitative dose-response relationships for $PM_{2.5}$ concentrations and estimates for mortality in the Indian context, we used effect estimates for mortality and baseline incidence rates for the total ambient and household air pollution attributable death rate from other sources. These estimates show that post-lockdown, the probability of mortality due to $PM_{2.5}$ was highest for autorickshaws, followed by non-AC taxis, buses, and AC taxis.

This order of risk is inverted for the probability of infection by SARS-COV-2, with the highest for AC taxis, followed by non-AC taxis, buses, and the lowest risk in autorickshaws, shown in Fig. 2. These estimates were assessed using a COVID risk estimator. Several parameters of this model are known with varying degrees of precision, and the resulting uncertainty was accounted for using distributional assumptions for those parameters. The findings of the present study suggest that vehicles with higher ventilation or air changes per hour (ACH) should be preferred over other modes of transport during COVID-19 pandemic.

The rate of mortality of this SARS-CoV-2 infection has not exceeded 3.4% globally. On the other hand, the mortality rate caused by ambient air pollution has contributed to 7.6% of all deaths in 2016 worldwide (Isaifan, 2020). India is significantly affected by this virus with ~1,80, 304 active cases and ~157.656 deaths as of 6th March 2021 (URL 06). At present there are ~10,917 deaths due to SARS-CoV-2 virus in Delhi alone. With the lockdown being lifted while the virus is still widely prevalent, there exists a combined risk of airborne and air pollution effects. High air pollution in Indian cities may lead to compromised immune systems in vulnerable individuals, which would make residents more susceptible to mortality linked to SARS-CoV-2 infection (Wu et al.,

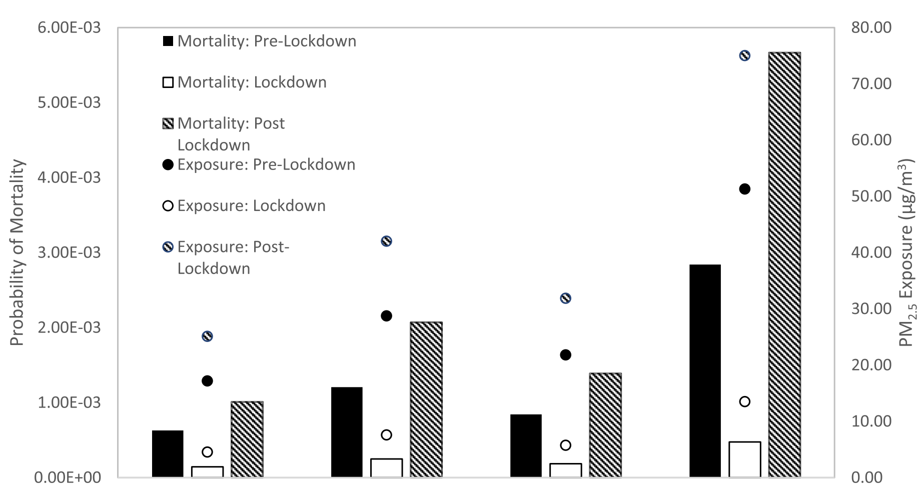

Fig. 1. Probability of mortality and $PM_{2.5}$ exposure in the different scenarios – (a) pre-lockdown, (b) lockdown and (c) post-lockdown for different micro-environments.

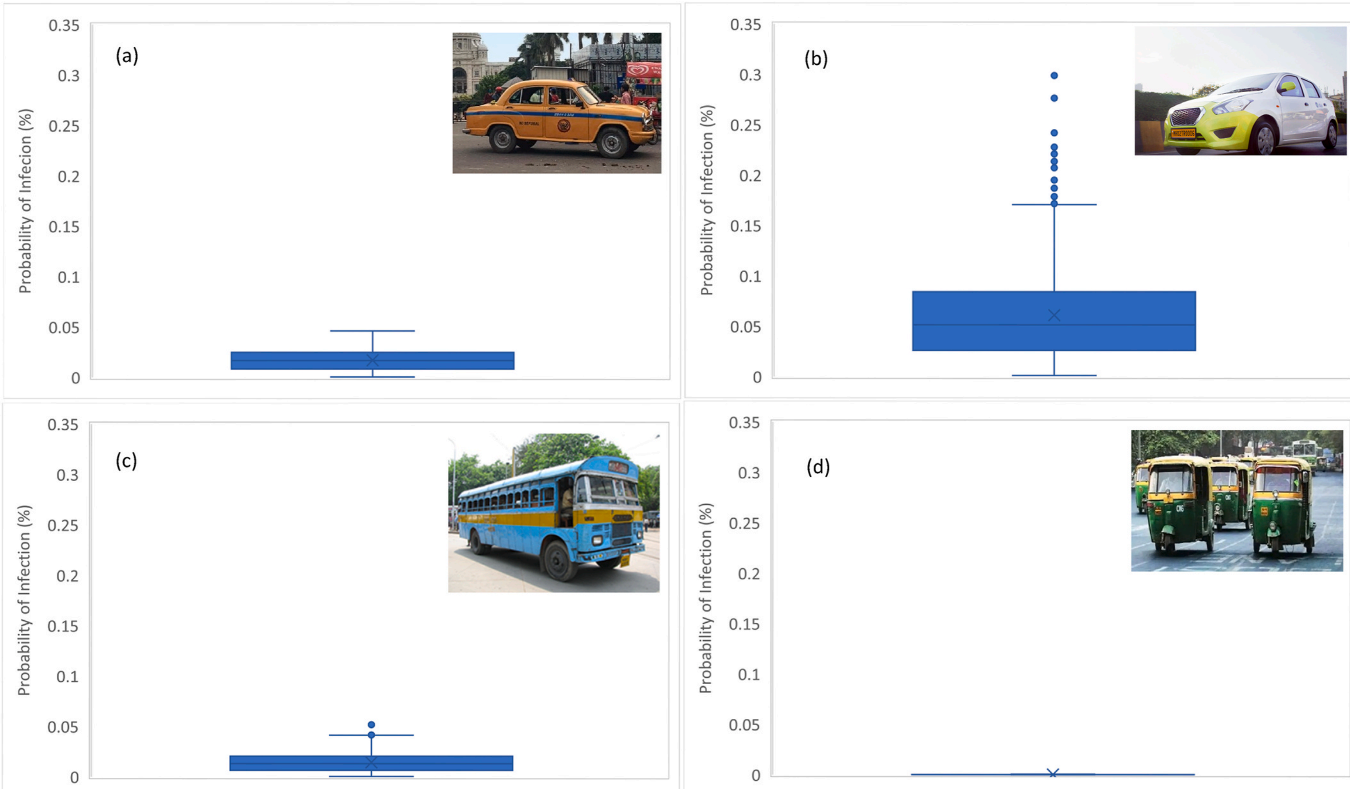

Fig. 2. Estimation of probability of infection from SARS-CoV-2 in various commute microenvironments – (a) Non-AC Taxi (b) AC Taxi (c) Bus and (d) Autorickshaw. ACH values of AC and Non-AC Taxi were taken from Knibbs et al., 2009) and Ott et al., 2008, respectively. Bus ACH values were taken from Chaudhry and Elumalai, 2020). Autorickshaws due to high ACH, have almost negligible probability of infection.

2020). Other studies have proposed a direct effect of particulate matter in boosting SARS-COV2 inter-personal transmission (Setti et al., 2020a, 2020b). The present study assesses the long-term health effects of the particulate matter. However, apart from particulate matter, traffic related pollutants include carbon monoxide, volatile organic compounds, nitrogen dioxide and poly-aromatic hydrocarbons (Han and Naeher, 2006). There is limited epidemiological evidence regarding the synergistic effects of traffic related pollutants (Mauderly and Samet, 2009). It is very likely that traffic related pollutants will increase the absolute risk values due to their synergistic effects but the risks will still be an order of magnitude lower than the short-term effects of the SARS-CoV-2 virus. Thus, synergisms between the components of the air pollution mixture, although not included in the present study, will not qualitatively alter the findings of the study.

There are two key mitigation strategies for countering virus-laden aerosols in transit vehicles: we can dilute the air by opening windows (and thus lowering the dose, which reduces the probability and the severity of infection) and/or we can remove viral particles from the air with vehicle air filters. An AC taxi typically operates its ventilation system in a recirculation mode where the air inside the car is cooled and recirculated for energy efficiency with the windows closed. While this is effective as a $PM_{2.5}$ mitigation strategy, it is not effective against infection by a fellow passenger. The risks of infection are much lower in buses and autorickshaws where the ACH's are much higher, although the passengers in these forms of transit face a much higher risk from PM2.5 exposure. The risks of infection can be reduced in AC-taxis or non-AC taxis by opening windows and running the AC in a non-recirculation mode, although this will significantly reduce the efficiency of cooling and filtration. We should also acknowledge that there are a considerable number of taxis, auto-rickshaws and cars in India that do not have built-in air-recirculation units. Maji et al. (2020), in their study found open modes of transport as the most exposed to particulate air pollution and suggest the use of masks and avoiding congestion hotspots.

Thus, the existing systems either increase chronic risk from exposure to PM2.5 or increase risk of infection to the SARS-COV-2 virus. In-cabin air purifiers (Knibbs et al., 2010; Tartakovsky et al., 2013) can be an economic solution to this dilemma. Assuming, low outdoor ventilation (ACH~1), i.e., window closed conditions, a Clean Air Deliver Rate (CADR) of 20 cfm would be enough for an effective ventilation rate of ~7 ACH. An air purifier with a filter efficiency of 90–95% can further reduce the $PM_{2.5}$ concentration in cabin environments. Energy intensive recirculation units in personal cars could also be replaced with inexpensive solar car air purifiers that are available at < $50. The usage of localized exhaust ventilation can also be an efficient strategy to remove SARS-COV-2 aerosol droplets from indoor environments (Borro et al., 2021). Another solution to the problem is the use of mass transit systems with centralized ventilation system, which may be a preferred mode of transport than personal vehicles (Fig. 3). Subway trains have 15–18 ACH which is much higher than the recommended air-exchange rates in closed spaces 6–8 ACH (URL 07). The low infection rates in public transportation systems can be maintained by including mandatory face masks; disinfecting trains and buses; and ramping and staggering businesses service work hours to reduce rush-hour crowding.

5. Conclusions

The findings of the present study indicate that the risk ranking of commute micro-environments is altered in different stages of the lockdown (Fig. 3). The risk calculations clearly indicate that while the AC-taxi option is most preferable during normal periods to mitigate air pollution (in middle- and low-income countries with poor air quality), this may not be a viable option during a pandemic. Further, autorickshaws with the highest air exchange rate show the lowest probability of

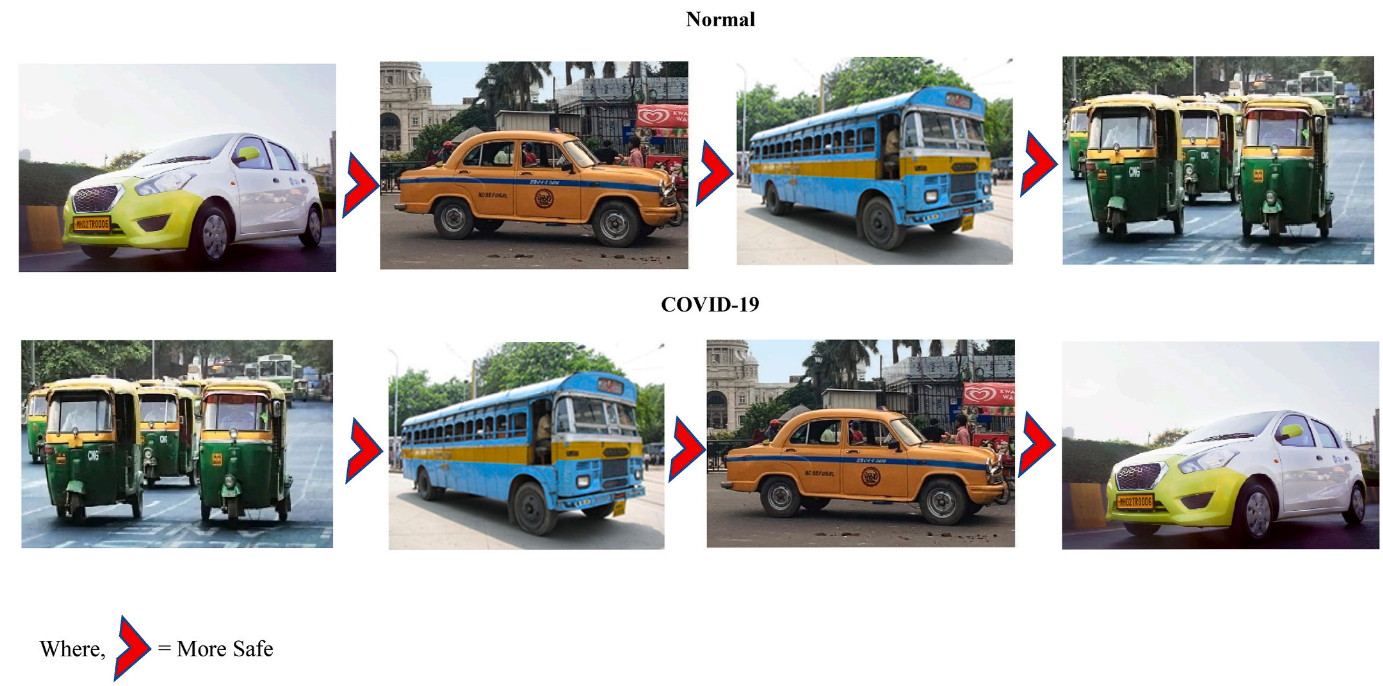

Fig. 3. Comparison of choice of preferred mode of transport during normal and COVID condition.

SARS-CoV-2 infection. Active recirculation, speed and window openings are some of the parameters which influence the ACH in a transit micro-environment and need to be considered for effective design. There are two competing risks – one increases with a set of actions while the other decreases; one is short term while the other is long term. One is a risk of infection while the other is a risk of mortality. While not directly comparable, these risk calculations can be a potential pathway for an individual to base his/her actions based on these calculations. Opening windows during the pandemic is a viable solution towards the control of transmission of virus but also expose human population to risk associated with particulate matter exposure. Autorickshaws that are a key component of mass commute systems in India and other Asian countries might prove to be a better alternative than passenger cars. Long term risks associated with particulate matter cannot be neglected and should be considered by policymakers while deciding lockdown strategies. The ongoing pandemic has presented an opportunity to reconsider and redesign ventilation systems in public transit vehicles and also the role of mass transit to not only reduce risk of infection during this time, but also reduce exposure PM2.5 and other air pollutants for the future in a sustainable manner.

Credit author statement

Darpan Das: Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Visualization, Investigation, Project administration. Gurumurthy Ramachandran: Resources, Supervision, Writing- Reviewing and Editing.

Funding

No financial assistance was received in support of the study.

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.

Acknowledgement

The authors would like to acknowledge funding support by NIEHS (Award Numbers R01ES030210-01: Flexible Bayesian Hierarchical Models for Estimating Inhalation Exposures) to Dr. Darpan Das for his postdoctoral work.

References

Adak, P., Sahu, R., Elumalai, S.P., 2016. Development of emission factors for motorcycles and shared auto-rickshaws using real-world driving cycle for a typical Indian city [Internet] Sci. Total Environ. 544, 299–308. https://doi.org/10.1016/j.scitotenv.2015.11.099. Available from:

Apte, J.S., Kirchstetter, T.W., Reich, A.H., Deshpande, S.J., Kaushik, G., Chel, A., et al., 2011. Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi, India. Atmos. Environ. 45 (26), 4470–4480.

Balakrishnan, K., Cohen, A., Smith, K.R., 2014. Addressing the burden of disease attributable to air pollution in India: the need to integrate across household and ambient air pollution exposures. Environ. Health Perspect. 122 (1), 6–7.

Borro, L., Mazzei, L., Raponi, M., Piscitelli, P., Miani, A., 2021. The role of air conditioning in the diffusion of Sars-CoV-2 in indoor environments: a first computational fluid dynamic model, based on investigations performed at the Vatican State Children's hospital. Environ. Res. (January).

Chaudhry, S.K., Elumalai, S.P., 2020. The influence of school bus ventilation scenarios over in-cabin PM number concentration and air exchange rates. Atmos Pollut Res [Internet] 11 (8), 1396–1407. https://doi.org/10.1016/j.apr.2020.05.021. Available from:

Chen, C., Zhao, B., 2020. Makeshift hospitals for COVID-19 patients: where health-care workers and patients need sufficient ventilation for more protection. Available from: J Hosp Infect [Internet 105 (1), 98–99. https://doi.org/10.1016/j.jhin.2020.03.008.

Choudhary, A., Gokhale, S., 2016. Urban real-world driving traffic emissions during interruption and congestion. Available from: Transp Res Part D Transp Environ [Internet 43, 59–70. https://doi.org/10.1016/j.trd.2015.12.006.

Chowdhury S, Chafe ZA, Pillarisetti A, Lelieveld J, Guttikunda S, Dey S. The Contribution of Household Fuels to Ambient Air Pollution in India: A Comparison of Recent Estimates. Collab Clean Air Policy Centre, New Delhi CCAPC/2019/01. 2019;(May): 16.

Fann, N., Lamson, A.D., Anenberg, S.C., Wesson, K., Risley, D., Hubbell, B.J., 2012. Estimating the national public health burden associated with exposure to ambient PM 2.5 and ozone. Risk Anal. 32 (1), 81–95.

Gupta, S.K., Elumalai, S.P., 2019. Exposure to traffic-related particulate matter and deposition dose to auto rickshaw driver in Dhanbad, India. Available from: Atmos Pollut Res [Internet] 10 (4), 1128–1139. https://doi.org/10.1016/j.apr.2019.01.018.

Gurjar, B.R., Butler, T.M., Lawrence, M.G., Lelieveld, J., 2008. Evaluation of emissions and air quality in megacities. Atmos. Environ. 42 (7), 1593–1606.

Han, X., Naeher, L.P., 2006. A Review of Traffic-Related Air Pollution Exposure Assessment Studies in the Developing World, vol. 32. Environment International. Elsevier Ltd, pp. 106–120.

Isaifan, R.J., 2020. The dramatic impact of coronavirus outbreak on air quality: has it saved as much as it has killed so far? Glob J Environ Sci Manag 6 (3), 275–288.

Jain, S., 2017. Exposure to in-vehicle respirable particulate matter in passenger vehicles under different ventilation conditions and seasons. Available from: Sustain Environ Res [Internet] 27 (2), 87–94. https://doi.org/10.1016/j.serj.2016.08.006.

Knibbs, L.D., De Dear, R.J., Atkinson, S.E., 2009. Field study of air change and flow rate in six automobiles. Indoor Air 19 (4), 303–313.

Knibbs, L.D., De Dear, R.J., Morawska, L., 2010. Effect of cabin ventilation rate on ultrafine particle exposure inside automobiles. Environ. Sci. Technol. 44 (9), 3546–3551.

Knibbs, L.D., Cole-Hunter, T., Morawska, L., 2011. A review of commuter exposure to ultrafine particles and its health effects. Available from: Atmos Environ [Internet] 45 (16), 2611–2622. https://doi.org/10.1016/j.atmosenv.2011.02.065.

Krewski, D., Jerrett, M., Burnett, R.T., Ma, R., Hughes, E., Shi, Y., et al., 2009. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality, 140. Res Rep Health Eff Inst.

Kumar, P., Hama, S., Nogueira, T., Abbass, R.A., Brand, V.S., de Fatima Andrade, M., et al., 2020. In-car particulate matter exposure across ten global cities. Aug;141395. Available from: Sci Total Environ [Internet] https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciaa939/5867798.

Kumari, P., Toshniwal, D., 2020. Impact of lockdown measures during COVID-19 on air quality– A case study of India, 00(00). Int J Environ Health Res [Internet 1–8. https://doi.org/10.1080/09603123.2020.1778646. Available from:

Lednicky, J.A., Lauzardo, M., Fan, Z.H., Jutla, A., Tilly, T.B., Gangwar, M., et al., 2020. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients, pp. 1–20, 1.

Li, Y., Qian, H., Hang, J., Chen, X., Hong, L., Liang, P., et al., 2020. Evidence for Probable Aerosol Transmission of SARS-CoV-2 in a Poorly Ventilated Restaurant, vols. 1–19.

Lu, J., Gu, J., Gu, J., Li, K., Xu, C., Su, W., et al., 2020. COVID-19 outbreak associated with air conditioning in restaurant, guangzhou, China, 2020. Emerg. Infect. Dis. 26 (7), 1628–1631.

Lukic, S.M., Mulhall, P., Choi, G., Naviwala, M., Nimmagadda, S., Emadi, A., 2007. Usage pattern development for three-wheel auto rickshaw taxis in India. VPPC 2007 - Proc 2007 IEEE Veh Power Propuls Conf, 610–6.

Mahato, S., Pal, S., Ghosh, K.G., 2020. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India, 139086. Available from: Sci Total Environ [Internet] 730 https://doi.org/10.1016/j.scitotenv.2020.139086.

Maji, K., Namdeo, A., Hoban, D., Bell, M., Goodman, P., Nagendra, M.S., et al., 2020. Analysis of Various Transport Modes to Evaluate Personal Exposure to PM 2 . 5 Pollution in Delhi (September). Available from:. Atmos Pollut Res [Internet. https://doi.org/10.1016/j.apr.2020.12.003.

Mauderly, J.L., Samet, J.M., 2009. Is there evidence for synergy among Air pollutants in causing health effects? Environ. Health Perspect. 117 (1), 1–6.

Miller, S.L., Nazaroff, W.W., Jimenez, J.L., Boerstra, A., Buonanno, G., Dancer, S.J., et al., 2020. Transmission of SARS-CoV-2 by inhalation of respiratory aerosol in the Skagit Valley Chorale superspreading event. Indoor Air (June), 2020.06.15.20132027.

Mobility, S., Preferences, C., 2019. How Urban India Moves (October).

Morawska, L., Milton, D.K.. It is time to address airborne transmission of COVID-19. Clin Infect Dis [Internet]. 2020 Jul 6;1–23. Available from: https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciaa939/5867798.

Ott, W., Klepeis, N., Switzer, P., 2008. Air change rates of motor vehicles and in-vehicle pollutant concentrations from secondhand smoke. J. Expo. Sci. Environ. Epidemiol. 18 (3), 312–325.

Pant, P., Habib, G., Marshall, J.D., Peltier, R.E., 2017. March):167–74. Available from:. PM2.5 Exposure in Highly Polluted Cities: A Case Study from New Delhi, India, vol. 156. Environ Res [Internet. https://doi.org/10.1016/j.envres.2017.03.024.

Piscitelli, P., Valenzano, B., Rizzo, E., Maggiotto, G., Rivezzi, M., Corcione, F.E., et al., 2019. Air pollution and estimated health costs related to road transportations of goods in Italy: a first healthcare burden assessment. Aug 2 Int. J. Environ. Res. Publ. Health 16 (16).

Setti, L., Passarini, F., De Gennaro, G., Barbieri, P., Perrone, M.G., Borelli, M., et al., 2020 Sep 1. SARS-Cov-2RNA found on particulate matter of Bergamo in Northern Italy: first evidence. Environ. Res. 188, 109754.

Setti, L., Passarini, F., De Gennaro, G., Barbieri, P., Licen, S., Perrone, M.G., et al., 2020b. Potential role of particulate matter in the spreading of COVID-19 in Northern Italy: first observational study based on initial epidemic diffusion. BMJ Open 10 (9), 1–9.

Tartakovsky, L., Baibikov, V., Czerwinski, J., Gutman, M., Kasper, M., Popescu, D., et al., 2013. In-vehicle particle air pollution and its mitigation. Available from: Atmos Environ [Internet 64, 320–328. https://doi.org/10.1016/j.atmosenv.2012.10.003.

Venter, Z., Aunan, K., Chowdhury, S., Lelieveld, J., 2020. COVID-19 Lockdowns Cause Global Air Pollution Declines with Implications for Public Health Risk, p. 7162.

Wu, X., Nethery, R.C., Sabath, B., Braun, D., Dominici, F., James, C., 2020. Exposure to Air Pollution and COVID-19 Mortality in the United States: A Nationwide Cross-Sectional Study [cited 2020 Oct 11]; Available from:. https://doi.org/10.1101/2020.04.05.20054502.