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Linkages between air pollution and the health burden from COVID-19: methodological challenges and opportunities

Running head: Air pollution, health and COVID-19

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Abstract:

The COVID-19 pandemic revealed and exacerbated existing social and economic health disparities and actionable epidemiological evidence is needed to identify potential vulnerability factors to help inform targeted responses. In this commentary, methodological challenges and opportunities regarding the links between air pollution and COVID-19 are discussed with a focus on: *i*) the role of differential exposure to air pollution across populations and explain spatio-temporal variability of the epidemic spread and resultant mortality; *ii*) the indirect impacts of interventions treated as natural experiments to control COVID-19 person-to-person spread on air pollution and population health. I first discuss the potential mechanisms between exposure to air pollution and COVID-19 and the opportunity to clearly formulate causal questions of interest through the target trial framework. Then, I discuss challenges regarding the use of quasi-experimental designs that capitalize on the differential timing of COVID-19 policies including the selection of control groups and potential violations of the common shock assumption. Finally, I discuss environmental justice implications of this many-headed beast of a crisis.

Keywords: air pollution, COVID-19, natural experiments, environmental justice.

Abbreviations:

COPD: Chronic obstructive pulmonary disease

DC: District of Columbia

DID: Difference-in-Differences

HIA: Health Impact Assessment

NO2: Nitrogen dioxide

O3: Ozone

PM: Particulate Matter

SARS: Severe Acute Respiratory Syndrome

SES: Socio-Economic Status

TRAP: Traffic-Related Air Pollution

Introduction

In the last few months, the COVID-19 pandemic has disrupted our society globally. This novel coronavirus SARS-CoV-2 and the disease it causes, COVID-19, revealed and exacerbated existing social and economic compounding disparities in relation to health and health care access. Growing evidence identified strong disparities across regions and within cities at the neighborhood level as well across Socio-Economic Status (SES) or race/ethnic groups (1-3). Efforts to contain COVID-19 around the world also resulted in economic downturns creating extraordinary unemployment (4) that will likely worsen an unequal population health burden in the times to come if nothing is done to bolster social safety nets where most needed. In this context, epidemiological evidence is critically needed to understand and predict the temporal and spatial spread of the disease, evaluate the effectiveness of potential treatments and policies, understand the etiology of the disease and identify potential vulnerability factors to help inform targeted responses.

Among proposed vulnerability factors in relation to COVID-19, various environmental factors have been proposed, among which outdoor air pollution received a particular attention in the last few months. Indeed, there are many relevant epidemiological research questions regarding the links between air pollution and COVID-19. Two distinct types of epidemiological research questions were predominantly examined. First, studies of COVID-19 designed to better understand the role of differential exposure to air pollution across populations and explain spatio-temporal variability of the epidemic spread and resultant mortality. Indeed, whether individuals living in areas with poor air quality are more likely to both become infected with the virus and die from COVID-19 remains unknown. Second, studies have investigated the unintended consequences of policies implemented to control the spread of COVID-19. These studies, often analyzed as natural experiments, attempt to demonstrate how local policies may have indirectly impacted other diseases in the population through changes in specific sources of AP emissions.

In this commentary, I will describe some methodological challenges and opportunities regarding these two types of questions based on the literature (some peer reviewed, some not yet) that is available to date. I will focus on etiological questions, keeping in mind that methodological challenges regarding availability, exhaustiveness and validity of data are definitely an underlying issue (5). Finally, I will briefly discuss other related topics including environmental justice implications of this many-headed beast of a crisis.

Conceptualizing the links between exposure to air pollution and COVID-19.

Mechanisms through which acute exposure to air pollutants, such as fine particles, may impact respiratory health are well documented and include pulmonary inflammation that may reduce lung function through bronchoconstriction or an alteration of the pulmonary immune system (6, 7). In parallel, chronic exposure to fine particle pollution notably exacerbates chronic inflammation with cellular proliferation and extracellular matrix reorganization (8) and also weakens pulmonary immune response (9). Several toxicological studies have described such mechanisms (9, 10) and a vast body of epidemiological evidence confirms the role of acute and chronic exposure to various air pollutants on respiratory hospital admissions, e.g. Chronic obstructive pulmonary disease (COPD) (11) or asthma exacerbation (12). Furthermore, several papers reported that exposure to air pollution exacerbates the severity of various respiratory infections (13) such as influenza (14) and possibly another coronavirus infection the SARS (15).

A recent study found that chronic exposure to PM2.5 and ozone increases the risk of acute respiratory distress syndrome among older adults in the US (16).

Based on this background knowledge, it is conceivable to suggest that exposure to air pollution may influence the variability in the severity of COVID-19 symptoms or contribute to explaining differential spatio-temporal patterns regarding the spread of the disease. Recent studies reported that individuals with severe COVID-19 may be more likely to have had pre-existing respiratory diseases. Documenting the impact of air pollution on the severity of COVID-19 could be consequential to informing targeted responses focusing on areas with poor air quality. Yet, while some early reports (peer reviewed or not yet) aimed at investigating such relationships, there are specific methodological considerations that need to be emphasized to ensure that valid and actionable results are produced for policy and healthcare decision makers.

First, it is important to clearly conceptualize the role of air pollution in relation to COVID-19 in etiological studies with regard to the specific COVID-19 outcome of interest. Hypothesized mechanisms that are highlighted above suggest that exposure to air pollution can be conceived as an effect (measure) modifier where background air pollution levels may influence the effect amplitude of public health mitigation strategies or simply the spatial or temporal variability of the epidemic spread and symptoms severity. Yet, some preliminary studies (17-24) on this topic rather conceptualized air pollution as the main exposure of interest by regressing COVID-19 death rates on chronic air pollution levels while controlling for various time-fixed contextual factors and seasonal trends and interpreting the coefficient of a given measure of chronic exposure to air pollution as a contributor to coronavirus deaths. In this setting, the implicit causal implication of these results can be problematic and ambiguous. Indeed, such results would suggest that if, counterfactually, we were able to intervene and reduce long-term air pollution levels, we would have observed fewer COVID-19 deaths in 2020. Without even mentioning possible residual confounding (e.g. population mobility and density), documenting the potential benefits of long-term actions on air pollution levels on COVID-19 death rates is probably not the type of actionable evidence that is needed during a pandemic and does not directly address the hypotheses formulated in these papers.

In order to document whether targeted responses in areas with poor air quality would be a valuable public health strategy, alternative research questions that consider air pollution to be a modifier of a specific policy may be timely and more appropriate. For example, Lyu et al. recently evaluated the impact of State policies mandating public or community use of face masks or coverings in the US exploiting the timing of the enforcement of such policies (25). They found that 15 states (plus DC) with such mandates in place between April 8 and May 5 enjoyed a reduction in the COVID-19 daily growth rate overall, while the others did not. It would be relevant, in future studies, to assess to what extent background exposure to air pollution modifies the effectiveness of such interventions as it would align with actionable recommendations about how and where to prioritize prevention efforts. The same rationale applies to other types of treatments or policies such as testing prioritization (26). Thus, the COVID-19 intervention targeting a given screening or treatment of interest and exposure to air pollution conceptualized as an effect modifier informs about the pertinence of prioritizing the intervention of interest according to air pollution levels. Knowledge of the importance of effect modifiers would also help us to better understand the transportability of a particular intervention across regions with differing levels of air pollution. It is also important to re-emphasize that effect modification is scale dependent and that for such type of public health prioritization efforts, the additive scale has been shown to be preferable (27).

Another potential approach to better understand the air pollution link for COVID-19 symptoms severity would be to focus on alternative outcomes, such as spatio-temporal changes infection fatality rates instead of counts of COVID-19 cases or deaths. This design would better capture how exposure to air pollutants influence variability in symptoms severity or if the probability of dying from COVID-19 in a given population (with detailed information regarding COVID-19 cases and time in the denominator) is influenced by air pollution levels. Of course, getting accurate statistics and accurate numerators and denominators to estimates population attack or infection fatality rates can be an extremely challenging task (5), but hopefully such surveillance data collection will be improving with time.

In this context, the target trial framework (28, 29) can be particularly useful when designing a research question regarding the links between exposure to air pollution and COVID-19. The benefits of using the target trial framework to clarify assumptions, causal contrasts and actionable implications has been demonstrated for other topics (30-33) by clearly specifying the hypothetical manipulation that is intended in the first place. In this pandemic context with limited available data and time-sensitive actionable evidence (34), dedicating a preliminary phase to clearly identifying the intended hypothetical manipulation and how targeted actions based on background air pollution levels would maximize potential benefits, may be valuable. and the target trial framework can be a suitable tool.

Research on the consequences of mitigation efforts to control COVID-19 person-to-person spread treated as natural experiments

The current SARS-CoV-2 pandemic led to the implementation of exceptional interventions to control COVID-19 person-to-person spread. Schools and industries have been closed, gatherings banned, wearing mask in public spaces enforced and more than half the world's population lived under shelter-in-place orders for some time (35). Shelter-in-place orders impact air pollution emissions, providing the opportunity to capitalize on such a natural experiment to potentially better understand COVID-19 transmission dynamics as well as indirect beneficial health impacts associated with such stringent policies.

Such unprecedented interventions affecting both economic activity and human mobility have a substantial impact on traffic-related air pollution (TRAP) emissions, including primary pollutants such PM2.5, PM10 or NO_2. For example, some preliminary reports observed a downward trend in primary air pollutants as in the US (36), Europe, China and other locations (37). However, it has been also shown that such expected decrease in air pollutants is not systematically observed (38), especially for secondary pollutants like O3, highlighting the diversity of emission sources and the complexity of atmospheric air pollution formation processes involving transportation dynamics and interactions with meteorological conditions.

Several studies aimed at analyzing how such COVID-19 related policies impacted air pollution concentrations and, consequently, population health. Properly inferring that any changes in air pollution and health outcomes (COVID-19 related or not, such as traffic injuries or asthma exacerbation rates) are attributable to a given COVID-19 policy is critical to inform other jurisdictions about which measures to adopt during the pandemic or even to provide evidence about traffic related measures in a post-COVID-19 era. Yet, such a task requires a sound identification strategy including the choice of appropriate control group(s) as a substitute for the counterfactual trend for the outcome of interest had the policy of interest not been implemented. Emerging literature in this regard utilized various approaches to identify and select control groups, which may have substantial influence on a study's conclusions. Some studies compared observed values for air pollution measures or a given health outcome during the COVID-19 response period (e.g. March 2020) to the same period one year before as the control period. This approach is common to quantify excess mortality or morbidity associated with a natural disaster (39) or other extreme weather events (40). Yet, such a strategy is prone to several potential biases given the numerous possible determinants of year to year variability in air pollution and health outcomes. This is particularly true given the complexity of air pollution atmospheric chemistry highlighted above. Other research extended the selection of control groups to other jurisdictions or additional years. For example, Berman et al. (36) defined a COVID-19 period (March 13–April 21), and a pre-COVID-19 period (January 8th-March 12th) that they compared to historical data averaging years 2017-2019 for each county in California. In the same vein, Chen et al. (41) conducted a health impact assessment (HIA) in China and calculated differences in daily air pollution concentrations observed during the quarantine period in 2020 with concentrations in the same lunar calendar periods from 2016 to 2019. Bekbulat et al. (38) adopted a distinct approach and defined a "robust differences" metric comparing a pollutant's median concentration during a week in 2020 to a distribution of median concentrations observed in the same week over the past 10 years.

Such natural experiments can be used to employ quasi-experimental designs (42) that would capitalize on the differential timing of interventions and/or the type of implemented actions. In this regard, difference-in-differences (DID) methods and extensions can be particularly useful to estimate the changes in air pollution or health outcomes attributable to a specific COVID-19 related policy after accounting for some identification assumptions. Such assumptions, including the common trends and common shock, can be easily violated in the context of COVID-19 policies (43). For instance, it may be challenging to identify an appropriate control group that would have a parallel trend for the outcome of interest given that the timing and intensity of policies are strongly correlated with the spatio-temporal variation of the spread of the disease. Indeed, jurisdictions that may first undertake actions to control COVID-19 person-to-person spread may also suffer from earlier and higher rates which motivates such policies. Given the known timing of the disease incubation period and lagged effects (44, 45), it is likely to initially observe an increase in the counted cases after the implementation of the policy of interest. This highlights the importance of accounting for both pre-trends and lagged expected effects when designing a study to evaluate the health impact of such policies.

It has also been shown that anticipation behaviors may take place where people took social distancing precautions before any official restrictions were in place(46). Several jurisdictions also implemented various policies at the same time and local communities or institutions such as universities may have implemented additional non-official preventive measures. This could potentially lead to violations of the common shock assumption. Furthermore, some spillover effects are expected where the COVID-19 responses may lead to drastic population mobility (47) or where abatement in traffic emissions may impact other jurisdictions across administrative borders.

Given these potential challenges, it is particularly important to design an appropriate identification strategy and adopt various sensitivity analyses and falsification tests. For example, analyses at the within-state or country levels, where all areas share the same national COVID19 policies and where the specific timing of the intervention or targeted communities are targeted could be capitalized on. It is also possible to rely on several control groups by using propensity score methods or synthetic control methods for instance. Recent developments extended the focus of synthetic control methods including a Kernel approach to consider lagged outcomes (47) or generalized synthetic Control (48) methods that integrate interactive fixed effects models and consider time varying confounding. Some recent studies have already employed DID methods to study the effect of specific policies on COVID-19 infections or deaths (49-52) and such approaches, with all considerations discussed above in mind, would offer interesting opportunities to understand the various impacts associated with COVID-19 policies on air pollution and health.

The environmental Justice implications of the COVID-19 crisis

Finally, it is also important to emphasize that exposure to air pollution is not random and may intersect with other social determinants of health. Indeed, differential exposure and susceptibility where socio-economic and race/ethnic minorities bear disproportionate burden from air pollution are well documented (53-56). Such environmental justice issues are critical and may contribute to explain the reported differential impacts of COVID-19 on race/ethnic communities in the US for example (1). Documenting such disparities as well as their historical and structural determinants is critical to emphasize and provide evidence to address blatant inequalities during this COVID-19 crisis and the economic recession to come. At the same time, in the US, some environmental regulations have relaxed air quality standards justified by the need to mitigate economic impacts following COVID-19 interventions (57). Such policies may have undesirable impacts, especially among vulnerable communities, given the well documented disproportional exposures to industrial emissions highlighting environmental injustice concerns. Health impacts studies that would quantify the potential expectable calamitous implications of such de-regulations are needed to help prevent an even more unequal spread of the disease.

Conclusion

In this commentary, I aimed at discussing methodological challenges and opportunities regarding the links between air pollution and COVID-19 focusing on two types of research questions: i) the role of air pollution as an effect modifier in the spatio-temporal variability in the disease spread and the variability of symptom severity and fatality rates; ii) the indirect impacts of interventions to control COVID-19 person-to-person spread on air pollution and population health. Of course, other environmental health study questions are being explored and could also be extremely important for informing prevention efforts. Exposure science studies (58) can help elucidate the transmission of the virus through aerosols, how personal protective equipment usage influences personal exposure, the source to receptor pathways, viability of the virus on different surfaces, environments and meteorological conditions like humidity, temperature and ultraviolet radiation. Occupational health (59, 60) can also provide critical actionable evidence by identifying high-risk workers given that some workplace conditions (e.g. health care providers and caregivers; water and wastewater sector; construction workers…) may increase severity of health outcomes or interact with other risks such as extreme heat (61). At the same time, other challenges include the capability to manage compound risks regarding extreme weather events such as extreme heat (62). Considering the double jeopardy that some communities may face regarding COVID-19 and the disproportionate burden they face during extreme weather events as well as conflicts between COVID-19 preventive actions and adaptation strategies to cope with extreme heat, for example (e.g. cooling centers vs. social distancing; wearing masks vs. respiratory distress), pandemic preparedness strategies for climate adaptation are imperative. In such time-sensitive pandemic context, actionable evidence is needed to help inform targeted interventions to help mitigate the spread of diseases while minimizing socio-economic inequalities and taking into account compound risks in a changing climate, especially given the expected economic recession to come.

References

1. Millett GA, Jones AT, Benkeser D, et al. Assessing differential impacts of COVID-19 on Black communities. *Annals of Epidemiology*. 2020 (47) 37:47.
2. Bailey ZD, Moon JR. Racism and the Political Economy of COVID-19: Will We Continue to Resurrect the Past? [available online ahead of print May 28, 2020]. *Journal of Health Politics, Policy and Law* 2020. DOI: 10.1215/03616878-8641481
3. van Dorn A, Cooney RE, Sabin ML. COVID-19 exacerbating inequalities in the US. *Lancet (London, England)* 2020;395(10232):1243.
4. Gangopadhyaya A, Garrett AB. Unemployment, Health Insurance, and the COVID-19 Recession. *Health Insurance, and the COVID-19 Recession (April 1, 2020)* 2020. Available at https://www.urban.org/research/publication/unemployment-health-insurance-and-covid-19-recession. Accessed on June 6, 2020.
5. Pearce N, Vandenbroucke JP, VanderWeele TJ, et al. Accurate statistics on COVID-19 are essential for policy guidance and decisions. American Public Health Association, 2020. 110, 949_951, https://doi.org/10.2105/AJPH.2020.305708
6. Hoek G, Krishnan RM, Beelen R, et al. Long-term air pollution exposure and cardio-respiratory mortality: a review. *Environmental health* 2013;12(1):43.
7. Laumbach RJ, Kipen HM. Respiratory health effects of air pollution: update on biomass smoke and traffic pollution. *Journal of allergy and clinical immunology* 2012;129(1):3-11.
8. Berend N. Contribution of air pollution to COPD and small airway dysfunction. *Respirology* 2016;21(2):237-44.
9. Kurt OK, Zhang J, Pinkerton KE. Pulmonary health effects of air pollution. *Current opinion in pulmonary medicine* 2016;22(2):138.
10. Ciencewicki J, Jaspers I. Air pollution and respiratory viral infection. *Inhalation toxicology* 2007;19(14):1135-46.
11. Heinrich J, Schikowski T. COPD patients as vulnerable subpopulation for exposure to ambient air pollution. *Current environmental health reports* 2018;5(1):70-6.
12. Orellano P, Quaranta N, Reynoso J, et al. Effect of outdoor air pollution on asthma exacerbations in children and adults: systematic review and multilevel meta-analysis. *PloS one* 2017;12(3):e0174050.
13. Mehta S, Shin H, Burnett R, et al. Ambient particulate air pollution and acute lower respiratory infections: a systematic review and implications for estimating the global burden of disease. *Air Quality, Atmosphere & Health* 2013;6(1):69-83.

14. Liang Y, Fang L, Pan H, et al. PM 2.5 in Beijing–temporal pattern and its association with influenza. *Environmental Health* 2014;13(1):102.
15. Cui Y, Zhang Z-F, Froines J, et al. Air pollution and case fatality of SARS in the People's Republic of China: an ecologic study. *Environmental Health* 2003;2(1):1-5.
16. Rhee J, Dominici F, Zanobetti A, et al. Impact of long-term exposures to ambient PM2. 5 and ozone on ARDS risk for older adults in the United States. *Chest* 2019;156(1):71-9.
17. Ogen Y. Assessing nitrogen dioxide (NO2) levels as a contributing factor to the coronavirus (COVID-19) fatality rate. *Science of The Total Environment* 2020 726:138605. https://doi.org/10.1016/j.scitotenv.2020.138605
18. Conticini E, Frediani B, Caro D. Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy? *Environmental pollution* 2020 261:114465. https://doi.org/10.1016/j.envpol.2020.114465
19. Travaglio M, Yu Y, Popovic R, et al. Links between air pollution and COVID-19 in England. *medRxiv* 2020. doi: https://doi.org/10.1101/2020.04.16.20067405. Accessed June 11, 2020
20. Wu X, Nethery RC, Sabath BM, et al. Exposure to air pollution and COVID-19 mortality in the United States. *medRxiv* 2020. doi: https://doi.org/10.1101/2020.04.05.20054502. Accessed June 11, 2020
21. Magazzino C, Schneider N. The Relationship between Air Pollution and COVID-19-related deaths: An Application to three French Cities. Accessed at shorturl.at/jpqI3 on June 11, 2020
22. Liang D, Shi L, Zhao J, et al. Urban Air Pollution May Enhance COVID-19 Case-Fatality and Mortality Rates in the United States. *medRxiv* 2020. doi: https://doi.org/10.1101/2020.05.04.20090746. Accessed June 11, 2020.
23. Cole M, Ozgen C, Strobl E. Air Pollution Exposure and COVID-19. 2020. Accessed at shorturl.at/nwJO9 on June 9, 2020.
24. Yongjian Z, Jingu X, Fengming H, et al. Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. *Science of the total environment* 2020 727:138704. https://doi.org/10.1016/j.scitotenv.2020.138704
25. Lyu W, Wehby GL. Community Use Of Face Masks And COVID-19: Evidence From A Natural Experiment Of State Mandates In The US: Study examines impact on COVID-19 growth rates associated with state government mandates requiring face mask use in public. *Health Affairs* 2020:10.1377/hlthaff. 2020.00818.
26. Weinberg CR. Making the best use of test kits for COVID-19. *American Journal of Epidemiology* 2020;189(5):363–364. https://doi.org/10.1093/aje/kwaa080
27. Knol MJ, VanderWeele TJ. Recommendations for presenting analyses of effect modification and interaction. *International journal of epidemiology* 2012;41(2):514-20.
28. Dorn HF. Philosophy of inferences from retrospective studies. *American Journal of Public Health and the Nations Health* 1953;43(6_Pt_1):677-83.
29. Hernán MA, Robins JM. Using big data to emulate a target trial when a randomized trial is not available. *American journal of epidemiology* 2016;183(8):758-64.
30. Huitfeldt A, Hernan MA, Kalager M, et al. Comparative effectiveness research using observational data: active comparators to emulate target trials with inactive comparators. *eGEMs* 2016;4(1):1234. doi: 10.13063/2327-9214.1234
31. García-Albéniz X, Hsu J, Hernán MA. The value of explicitly emulating a target trial when using real world evidence: an application to colorectal cancer screening. *European journal of epidemiology* 2017;32(6):495-500.
32. Caniglia EC, Rebecca Z, Jacobson DL, et al. Emulating a target trial of antiretroviral therapy regimens started before conception and risk of adverse birth outcomes. *AIDS (London, England)* 2018;32(1):113.

33. Dickerman BA, García-Albéniz X, Logan RW, et al. Avoidable flaws in observational analyses: an application to statins and cancer. *Nature Medicine* 2019;25(10):1601-6.
34. Graeden E, Carlson C, Katz R. Answering the right questions for policymakers on COVID-19. *The Lancet Global Health* 2020;8(6):e768-e9.
35. Sandford A. Coronavirus: Half of humanity now on lockdown as 90 countries call for confinement. Euronews, 2020. [Accessed on June 9th 2020]
36. Berman JD, Ebisu K. Changes in US air pollution during the COVID-19 pandemic. *Science of The Total Environment* 2020 739:139864. https://doi.org/10.1016/j.scitotenv.2020.139864
37. Otmani A, Benchrif A, Tahri M, et al. Impact of Covid-19 lockdown on PM10, SO2 and NO2 concentrations in Salé City (Morocco). *Science of The Total Environment* 2020 735:139541. https://doi.org/10.1016/j.scitotenv.2020.139541
38. Bekbulat B, Apte JS, Millet DB, et al. PM2. 5 and Ozone Air Pollution Levels Have Not Dropped Consistently Across the US Following Societal Covid Response. 2020. https://doi.org/10.26434/chemrxiv.12275603.v7. Accessed on June 9, 2020.
39. Sandberg J, Santos-Burgoa C, Roess A, et al. All over the place?: differences in and consistency of excess mortality estimates in Puerto Rico after Hurricane Maria. *Epidemiology* 2019;30(4):549-52.
40. Azhar GS, Mavalankar D, Nori-Sarma A, et al. Heat-related mortality in India: Excess all-cause mortality associated with the 2010 Ahmedabad heat wave. *PLoS One* 2014;9(3):e91831.
41. Chen K, Wang M, Huang C, et al. Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. *The Lancet Planetary Health* 2020 4(6): e210–e212. doi: 10.1016/S2542-5196(20)30107-8
42. Bor J. Capitalizing on natural experiments to improve our understanding of population health. *American journal of public health* 2016;106(8):1388.
43. Goodman-Bacon A, Marcus J. Using difference-in-differences to identify causal effects of covid-19 policies. Survey Research Methods. 2020 14(2), 153-158. https://doi.org/10.18148/srm/2020.v14i2.7723
44. Liu Z, Magal P, Seydi O, et al. A COVID-19 epidemic model with latency period. *Infectious Disease Modelling* 2020. 5: 323–337. doi: 10.1016/j.idm.2020.03.003
45. Wynants L, Van Calster B, Bonten MM, et al. Prediction models for diagnosis and prognosis of covid-19 infection: systematic review and critical appraisal. *bmj* 2020;369.
46. Google. Covid-19 community mobility reports. https: // www. google. com/ covid19/ mobility/; 2020. (Accessed on June 6th 2020).
47. Pullano G, Valdano E, Scarpa N, et al. Population mobility reductions during COVID-19 epidemic in France under lockdown. *medRxiv* 2020. doi: https://doi.org/10.1101/2020.05.29.20097097. Accessed on June 9, 2020.
48. Xu Y. Generalized synthetic control method: Causal inference with interactive fixed effects models. *Political Analysis* 2017;25(1):57-76.
49. Dave DM, Friedson AI, Matsuzawa K, et al. When do shelter-in-place orders fight COVID-19 best? Policy heterogeneity across states and adoption time. National Bureau of Economic Research, 2020. Accessed at shorturl.at/guBOU on June 11, 2020.
50. Fang H, Wang L, Yang Y. Human mobility restrictions and the spread of the novel coronavirus (2019-ncov) in china. National Bureau of Economic Research, 2020. doi: https://doi.org/10.1101/2020.03.24.20042424. Accessed June 11, 2020.
51. Friedson AI, McNichols D, Sabia JJ, et al. Did california's shelter-in-place order work? early coronavirus-related public health effects. National Bureau of Economic Research, 2020. Accessed at https://www.iza.org/publications/dp/13160 on June 11, 2020.

52. Hsiang S, Allen D, Annan-Phan S, et al. The effect of large-scale anti-contagion policies on the COVID-19 pandemic. *Nature* 2020:1-9.
53. Hajat A, Hsia C, O'Neill MS. Socioeconomic Disparities and Air Pollution Exposure: a Global Review. *Current environmental health reports* 2015;2(4):440-50.
54. Brulle RJ, Pellow DN. Environmental justice: human health and environmental inequalities. *Annu Rev Public Health* 2006;27:103-24.
55. Mohai P, Pellow D, Roberts JT. Environmental justice. *Annual Review of Environment and Resources* 2009;34:405-30.
56. Mohai P, Saha R. Which came first, people or pollution? A review of theory and evidence from longitudinal environmental justice studies. *Environmental Research Letters* 2015;10(12):125011.
57. Holden E. Trump orders agencies cut environment reviews, citing 'economic emergency'. The Guardian, 2020. [Accessed on June 9th 2020]
58. Deziel NC, Allen JG, Scheepers PT, et al. The COVID-19 pandemic: a moment for exposure science. *Journal of Exposure Science & Environmental Epidemiology* 2020: Jul;30(4):591-593
59. Koh D. Occupational risks for COVID-19 infection. *Occupational medicine (Oxford, England)* 2020;70(1):3.
60. Bouziri H, Smith DR, Descatha A, et al. Working from home in the time of covid-19: how to best preserve occupational health? *Occupational and Environmental Medicine* 2020;77(7):509-10.
61. Morabito M, Messeri A, Crisci A, et al. Heat warning and public and workers' health at the time of COVID-19 pandemic. *Science of The Total Environment* 2020 738:140347. doi: 10.1016/j.scitotenv.2020.140347
62. Martinez G, Linares C, De'Donato F, et al. Protect the vulnerable from extreme heat during the COVID-19 pandemic. *Environmental Research* 2020;187:109684. doi: 10.1016/j.envres.2020.109684