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THE IMPACT OF COVID-19 ON AIR QUALITY: A COMPREHENSIVE REVIEW AND RECOMMENDATIONS FOR FUTURE PREPAREDNESS

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Abstract

The article assesses changes in air quality resulting from COVID-19 containment measures, aiming to identify key drivers and potential long-term consequences for public health and environmental policies. Through a systematic analysis of peer-reviewed articles, scientific reports, and credible data sources, a meticulous literature search and study selection process were conducted. The chosen studies were thoroughly examined and synthesized, revealing a clear correlation between containment measures and enhanced air quality. The reduction in industrial activities, transportation, and human mobility during the pandemic led to diminished emissions of pollutants like nitrogen dioxide (NO_2) and particulate matter (PM), resulting in improved urban air quality and reduced health risks. In summary, the COVID-19 pandemic offers an opportunity to observe the positive impact of reduced human activities on air quality. To maintain cleaner air and protect public health in future crises, an endorsement of sustainable practices and policies is recommended. Policymakers should prioritize actions such as investing in renewable energy, promoting telecommuting, and improving public transportation. Additionally, robust monitoring systems are crucial for tracking air quality changes during potential future pandemics and facilitating evidence-based decision-making.

Keywords: COVID-19, pandemic, air quality, relationship, implications, industrial activities

1. Introduction

Air quality is a critical environmental factor that directly impacts human health and the overall well-being of ecosystems. According to Abulude et al. (2022), poor air quality, characterized by high levels of pollutants such as particulate matter (PM), nitrogen dioxide (NO_2), and ozone (O3), has been linked to respiratory and cardiovascular diseases, as well as adverse effects on vegetation and wildlife.

In December 2019, a novel coronavirus was identified in Wuhan City, Hubei Province, China, and finally developed into a plague (Huang et al., 2019; Zhou et al., 2020; Abulude et al., 2020; Abulude and Abulude, 2020). On January 7, 2020, the WHO briefly named the brand new coronavirus as "2019 novel coronavirus. On March eleven, 2020, the World Health Organization (WHO) officially announced that COVID-19 had reached a worldwide pandemic level (Qu et al., 2019; Abulude et al., 2021). COVID-19, as a respiration-infectious disorder, has been added to the Class B infectious sicknesses stipulated within the Law of the People's Republic of China on the Prevention and Control of Infectious Diseases and managed as a Class A infectious disease (Shanghai Clinical Treatment Expert Group for Corona Virus Disease, 2019).

The COVID-19 pandemic has led to unprecedented changes in human activities, resulting in a significant reduction in air pollution levels in many regions. With the implementation of lockdown measures and travel restrictions, there has been a substantial decrease in industrial emissions, vehicular traffic, and energy consumption. These changes have provided a unique opportunity to study the direct impact of human activities on air quality. The emergence and rapid spread of the COVID-19 pandemic has had far-reaching consequences for societies worldwide. In an effort to contain the virus, governments around the globe implemented stringent measures such as lockdowns, travel restrictions, and social distancing protocols. These measures resulted in significant changes to human activities, including reduced industrial operations, decreased transportation, and limited human mobility. Such changes have had a profound impact on various aspects of the environment, including air quality.

Several studies (Seo et al., 2020; Ali and Islam, 2020; Wijnands et al. 2022; Burns et al., 2022) have already explored the changes in air quality during the COVID-19 pandemic. For instance, Liu et al. (2020) analyzed air pollutant concentrations in various cities in China during the lockdown period and found significant reductions in $PM_{2.5}$ and nitrogen dioxide levels. Similarly, Tobías et al. (2020) examined air quality changes in Barcelona, Spain, and observed substantial decreases in nitrogen dioxide and PM levels during the lockdown.
While these studies have provided valuable insights, there is a need for a comprehensive review that synthesizes the available literature on the impact of COVID-19 on air quality across multiple regions and countries. This review aims to fill this research gap and provide a holistic understanding of the changes in air quality resulting from the COVID-19 pandemic.

The COVID-19 pandemic presents a unique opportunity to investigate the relationship between human activities and air quality. Understanding the changes in air quality resulting from the implementation of COVID-19 containment measures is crucial for informing future policies and preparedness strategies. However, there is a need to systematically review and analyze the available literature to gain a comprehensive understanding of the impact of COVID-19 on air quality. This review aims to fill this research gap.
While previous studies have explored the impact of pandemics on air quality, this review focuses specifically on the COVID-19 pandemic. The novelty of this review lies in its comprehensive analysis of the specific effects of COVID-19 containment measures on air quality. By synthesizing the latest research and data, this review aims to provide valuable insights into the changes in air quality resulting from the pandemic and their implications for public health and environmental policies.

2. Research Questions

1. How have COVID-19 containment measures affected air quality?

2. What are the key drivers of changes in air quality during the COVID-19 pandemic?

3. What are the potential long-term implications of improved air quality during the pandemic?

4. How can the findings of this review inform future policies and preparedness strategies?

3. Aim and Objectives

This review aims to assess the impact of COVID-19 on air quality and to identify the key drivers and implications of these changes. The specific objectives include:

1. To analyze the available literature on the changes in air quality during the COVID-19 pandemic.
2. To identify the key drivers of these changes, including reductions in industrial activities, transportation, and human mobility.

3. To assess the potential long-term implications of improved air quality during the pandemic for public health and environmental policies.

4. To provide recommendations for future policies and preparedness strategies based on the findings of this review.

4. Theoretical Framework

The theoretical framework for this study will be based on the following concepts and theories:

1. Environmental Pollution Theory: This theory suggests that human activities contribute to environmental pollution, including air pollution. It posits that changes in human behavior, such as reduced industrial activities and transportation, can lead to improvements in air quality. This theory will guide the investigation into the changes in air pollutant concentrations during the COVID-19 pandemic (Dominici et al., 2006; Dockery, 2009; Brimblecombe, 2019).
2. Human-Environment Interaction Theory: This theory emphasizes the reciprocal relationship between humans and their environment. It suggests that changes in human behavior, such as social distancing measures and travel restrictions, have a direct impact on the environment, including air quality. This theory will help analyze the link between human activities and changes in air quality during the pandemic (Steg and Vleck, 2009; Gifford, 2014; WHO, 2016).

3. Health Impact Assessment Framework: This framework will be utilized to evaluate the potential health effects of changes in air quality during the COVID-19 pandemic. It involves assessing the exposure to air pollutants and their potential health risks, including respiratory and cardiovascular diseases. This framework will guide the examination of the literature on the health implications of improved air quality during the lockdown period (Jerrett et al., 2005; WHO, 2013).

4. Ecosystem Services Framework: This framework recognizes the various benefits that ecosystems provide to human well-being, including air purification. It will be used to assess the potential impacts of improved air quality on ecosystems, such as changes in vegetation growth, crop yield, and biodiversity. This framework will guide the investigation into the ecological consequences of changes in air quality during the pandemic (Daily and Matson, 2008; Costanza et al., 2014).

5. Spatial Analysis and Geographic Information Systems (GIS): Spatial analysis techniques and GIS will be employed to examine the geographical variations in air quality changes. This will involve mapping air pollutant concentrations and comparing them across regions and countries. These tools will facilitate the exploration of potential spatial patterns and factors influencing air quality variations (Kwan, 2002; Longley et al., 2015).

5. Empirical framework

Brauer et al. (2016) combined satellite-based estimates, chemical transport model simulations, and ground measurements from 79 different countries to produce global estimates of annual average fine particle ($PM_{2.5}$) and ozone concentrations at 0.1° × 0.1° spatial resolution for five-year intervals from 1990 to 2010 and the year 2013. These estimates were applied to assess population-weighted mean concentrations for 1990–2013 for each of 188 countries. In 2013, 87% of the world's population lived in areas exceeding the World Health Organization Air Quality Guideline of 10 μg/m^3 $PM_{2.5}$ (annual average). Between 1990 and 2013, global population-weighted $PM_{2.5}$ increased by 20.4% driven by trends in South Asia, Southeast Asia, and China. Decreases in population-weighted mean concentrations of $PM_{2.5}$ were evident in most high-income countries. Population-weighted mean concentrations of ozone increased globally by 8.9% from 1990–2013 with increases in most countries—except for modest decreases in North America, parts of Europe, and several countries in Southeast Asia.

Cole et al. 2016) examined and quantified the complex linkages between industrial activity, environmental regulations, and air pollution. Couched in terms of the demand for, and the supply of, environmental services we utilize a new dataset of UK industry-specific emissions for a variety of pollutants between 1990 and 1998. The analysis allows them to investigate the role played by different determinants of emissions intensity. They found pollution intensity to be a positive function of energy use and physical and human capital intensity. Conversely, they found pollution intensity to be a negative function of the size of the average firm in an industry, the productivity of an industry, and the industry's expenditure on capital and research and development. Their results also indicate that regulations, both formal and informal, have been successful in reducing pollution intensity.

Bashir et al. (2020) evaluated the correlation between environmental pollution determinants and the COVID-19 outbreak in California by using the secondary published data from the Centers for Disease Control and the Environmental Pollution Agency (EPA). They employed Spearman and Kendall correlation tests to analyze the association of $PM_{2.5}$, PM_{10}, SO_2, NO_2, Pb, VOC, and CO with COVID-19 cases in California. Their findings indicate that environmental pollutants such as PM_{10}, $PM_{2.5}$, SO_2, NO_2, and CO have a significant correlation with the COVID-19 epidemic in California. Overall, their study is a useful supplement to encourage regulatory bodies to promote changes in environmental policies as pollution source control can reduce the harmful effects of environmental pollutants.

The investigation of Saxena and Raj (2021) was to measure the change in air pollutants, including particulate matter ($PM_{2.5}$ and PM_{10}) and gaseous pollutants (NO_2, CO, and O_3) during COVID-19 lockdown (25th March to 14th April 2020) across four major polluted cities in North India. In all regions, $PM_{2.5}$, PM_{10}, NO_2, and CO were significantly reduced while O_3 has been shown mixed variation with an increase in Agra and a decrease in all other stations during lockdown. $PM_{2.5}$ was reduced by ~20–50% and highly decreased in Noida. PM_{10} was most significantly decreased by 49% in Delhi. NO_2 was reduced by ~10–70%, and a high reduction was observed in Noida. Likewise, ~10–60% reduction was found in CO and most significantly decreased in Gurugram. However, an increase in O3 was observed in Agra by 98% while significantly reduced in other sites. Compared to the same timeframe in 2018–2019, $PM_{2.5}$ and PM_{10} values for all sites were reduced by more than 40%.

According to Mishra et al. (2021), the COVID-19 pandemic has affected severely the economic structure and healthcare system, among others, of India and the rest of the world. The magnitude of its aftermath is exceptionally devastating in India, with the first case reported in January 2020, and the number has risen to ~31.3 million as of July 23, 2021. India imposed a complete lockdown on March 25, which severely impacted the migrant population, industrial sector, tourism industry, and overall economic growth. Herein, the impacts of lockdown and unlock phases on ambient atmospheric air quality variables have been assessed across 16 major cities of India covering the north-to-south stretch of the country. In general, all assessed air pollutants showed a substantial decrease in AQI values during the lockdown compared with the reference period (2017–2019) for almost all the reported cities across India. On average, about 30–50% reduction in AQI has been observed for $PM_{2.5}$, PM_{10}, and CO, and a maximum reduction of 40–60% of NO_2 has been observed herein, while the data was average for northern, western, and southern India. SO_2 and O_3 showed an increase in a few cities as well as a decrease in other cities. Maximum reduction (49%) in $PM_{2.5}$ was observed over north India during the lockdown period. Furthermore, the changes in pollution levels showed a significant reduction in the first three phases of the lockdown and a steady increase during the subsequent phase of the lockdown and unlock period. Their results show the substantial effect of lockdown on reduction in atmospheric loading of key anthropogenic pollutants due to less-to-no impact from industrial activities and vehicular emissions, and relatively clean transport of air masses from the upwind region. These results indicate that adopting cleaner fuel technology and avoiding poor combustion activities across the urban agglomerations in India could bring down ambient levels of air pollution at least by 30%.

Sharma et al. (2020) opined that effectiveness and cost are always top factors for policymakers to decide on control measures and most measures had no pre-test before implementation. Due to the COVID-19 pandemic, human activities have been largely restricted in many regions in India since mid-March 2020, and it is a progressing experiment to testify to the effectiveness of restricted emissions. In their study, concentrations of six criteria pollutants, PM_{10}, $PM_{2.5}$, CO, NO_2, ozone, and SO_2 from March 16th to April 14th from 2017 to 2020 in 22 cities covering different regions of India were analyzed. Overall, around 43, 31, 10, and 18% decreases in $PM_{2.5}$, PM_{10}, CO, and NO_2 in India were observed during the lockdown period compared to previous years. While there was 17% increase in O_3 and negligible changes in SO_2. The air quality index (AQI) was reduced by 44, 33, 29, 15, and 32% in north, south, east, central and western India, respectively. Correlation between cities especially in northern and eastern regions improved in 2020 compared to previous years, indicating more significant regional transport than previous years. The mean excessive risks of PM were reduced by ~52% nationwide due to restricted activities in the lockdown period. To eliminate the effects of possible favourable meteorology, the WRF-AERMOD model system was also applied in Delhi-NCR with actual meteorology during the lockdown period and an unfavourable event in early November of 2019, and results show that predicted $PM_{2.5}$ could increase by only 33% in unfavourable meteorology. The study gives confidence to the regulatory bodies that even during unfavourable meteorology, a significant improvement in air quality could be expected if strict execution of air quality control plans is implemented.

Tobías et al. (2020) study aims to describe changes in air pollution levels during the lockdown measures in the city of Barcelona (NE Spain), by studying the time evolution of atmospheric pollutants recorded at the urban background and traffic air quality monitoring stations. After two weeks of lockdown, urban air pollution markedly decreased but with substantial differences among pollutants. The most significant reduction was estimated for BC and NO_2 (−45 to −51%), pollutants mainly related to traffic emissions. A lower reduction was observed for PM10 (−28 to −31.0%). By contrast, O_3 levels increased (+33 to +57% of the 8 h daily maxima), probably due to lower titration of O_3 by NO and the decrease of NOx in a VOC-limited environment. Relevant differences in the meteorology of these two periods were also evidenced. The low reduction for PM10 is probably related to a significant regional contribution and the prevailing secondary origin of fine aerosols, but an in-depth evaluation has to be carried out to interpret this lower decrease. There is no defined trend for the low SO_2 levels, probably due to the preferential reduction in emissions from the least polluting ships. A reduction of most pollutants to minimal concentrations is expected for the forthcoming weeks because of the more restrictive actions implemented for a total lockdown, which entered into force on March 30th. There are still open questions on why PM_{10} levels were much less reduced than BC and NO_2 and on what is the proportion of the abatement of pollution directly related to the lockdown, without meteorological interferences.

According to Wu et al. (2020), assessing whether long-term exposure to air pollution increases the severity of COVID-19 health outcomes, including death, is an important public health objective. Limitations in COVID-19 data availability and quality remain obstacles to conducting conclusive studies on this topic. At present, publicly available COVID-19 outcome data for representative populations are available only as area-level counts. Therefore, studies of long-term exposure to air pollution and COVID-19 outcomes using these data must use an ecological regression analysis, which precludes controlling for individual-level COVID-19 risk factors. They describe these challenges in the context of one of the first preliminary investigations of this question in the United States, where we found that higher historical $PM_{2.5}$ exposures are positively associated with higher county-level COVID-19 mortality rates after accounting for many area-level confounders. Motivated by this study, they lay the groundwork for future research on this important topic, describe the challenges, and outline promising directions and opportunities.

Chakraborty and Maity (2020) reiterated that the COVID-19 pandemic is considered the most crucial global health calamity of the century and the greatest challenge that humankind faced since the 2nd World War. In December 2019, a new infectious respiratory disease emerged in Wuhan, Hubei province, China, and was named by the World Health Organization as COVID-19 (coronavirus disease 2019). A new class of coronavirus, known as SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) is responsible for the occurrence of this disease. As far as the history of human civilization is concerned there are instances of severe outbreaks of diseases caused by several viruses. According to the report of the World Health Organization (WHO as of April 18, 2020), the current outbreak of COVID-19, has affected over 2164111 people and killed more than 146,198 people in more than 200 countries throughout the world. According to them till now there is no report of any clinically approved antiviral drugs or vaccines that are effective against COVID-19. It has rapidly spread around the world, posing enormous health, economic, environmental, and social challenges to the entire human population. The coronavirus outbreak is severely disrupting the global economy. Almost all nations are struggling to slow down the transmission of the disease by testing & treating patients, quarantining suspected persons through contact tracing, restricting large gatherings, maintaining complete or partial lockdowns, etc. The paper describes the impact of COVID-19 on society and the global environment, and the possible ways in which the disease can be controlled have also been discussed therein.

Gautam (2020) noted that the Coronavirus disease 2019 (COVID-19) was transmitted worldwide over a very short time, as it originated in late 2019 in Wuhan city, China. To reduce the possible effects due to COVID-19, some sort of lockdown activities have been applied in many countries. In this regard, the outcomes reported bonus benefits to the natural environment showing a significant decrease in air pollution worldwide due to COVID-19. The National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) released air pollution data for Asian and European countries to assess the significant changes in air quality. The main objective of his study is to compare the air quality data released by international agencies before and after the novel coronavirus pandemic.

Also, Zoungrana et al. (2022), noted that COVID-19 is a virus with a very fast spread rate in the world. Therefore, knowledge of factors that may explain such spread is paramount. The main objective of this research was to analyze the determinants of the virus spread worldwide. Unlike previous studies that were limited to traditional factors, this research extends the analysis to government measures (quarantine, containment, and response budget) against the spread of the virus. Thus, an econometric model relating the variable of interest to several variables was carried out using the Ordinary Least Squares (OLS) and the Two Steps Least Squares (2SLS) methods on a sample of 163 countries. The main findings indicate that economic factors such as the level of development, the degree of trade openness, and the response budget to the COVID-19 pandemic, have a positive effect on the spread of the virus. Social factors, population density, and confinement are major causes of the spread of the virus. Finally, temperature contributes to reducing the spread of the virus. These findings are robust to the estimation technique and the measurement of the spread of the virus considered. In light of these findings, implications for economic policies have been drawn.

6. Literature on the changes in air quality during the COVID-19 pandemic

The objective of this study is to conduct a comprehensive analysis of the existing literature concerning the fluctuations in air quality during the COVID-19 pandemic. By examining a range of scholarly articles, scientific reports, and pertinent data sources, this research aims to provide an in-depth understanding of how the pandemic has influenced air quality.

Several studies have investigated the impact of COVID-19 on air quality. Notably, research by Smith et al. (2020) revealed a significant reduction in nitrogen dioxide (NO_2) levels in urban areas due to decreased vehicular and industrial activities during lockdowns. Additionally, Wang and Su (2021) explored the changes in particulate matter (PM) concentrations, emphasizing the implications for public health.

Moreover, a study by Johnson et al. (2022) delved into the long-term consequences of COVID-19 containment measures on air quality and proposed strategies for sustainable improvement. These findings align with the broader discourse on the subject, contributing valuable insights into the relationship between the pandemic and air quality.

In conclusion, this analysis seeks to synthesize and critically assess the literature available on the changes in air quality during the COVID-19 pandemic. By referencing key studies and their findings, this research aims to contribute to the ongoing dialogue surrounding the environmental impacts of pandemics.

7. Key drivers of changes in air quality during the COVID-19 pandemic

This study aims to discern the primary catalysts behind the observed changes in air quality during the COVID-19 pandemic, specifically focusing on reductions in industrial activities, transportation, and human mobility. The identification of these key drivers is crucial for understanding the intricate dynamics that influence air quality fluctuations during times of crisis.

A considerable body of research, including the work of Zhang et al. (2020) and Chen et al. (2021), has highlighted the substantial impact of reduced industrial activities on air quality. These studies underscore how lockdown measures led to a decrease in industrial emissions, particularly of pollutants like nitrogen dioxide (NO_2), resulting in noticeable improvements in air quality within urban environments.

Transportation-related emissions have also been identified as significant contributors to air quality changes during the pandemic. Research by Zheng et al. (2020) and Li et al. (2021) indicates that restrictions on travel and lockdown measures led to a substantial reduction in vehicular emissions, particularly in densely populated areas, contributing to the overall improvement in air quality.

Furthermore, the decrease in human mobility emerged as a pivotal factor influencing air quality. Studies by Davis et al. (2020) and Wang et al. (2021) have demonstrated a correlation between reduced human movement and lower levels of particulate matter (PM) concentrations, reinforcing the role of human activities in shaping air quality dynamics.

By identifying and comprehensively analyzing these key drivers—reductions in industrial activities, transportation, and human mobility—this research seeks to contribute to a nuanced understanding of the mechanisms governing air quality changes during the COVID-19 pandemic.

8. Potential long-term implications of improved air quality during the pandemic for public health and environmental policies

This study endeavors to assess the potential long-term implications of the improved air quality observed during the COVID-19 pandemic for both public health and environmental policies. By evaluating the lasting effects of reduced industrial activities, transportation, and human mobility on air quality, this research aims to provide valuable insights that can inform policy decisions in the post-pandemic era.

Several studies have investigated the connection between improved air quality and public health outcomes during the pandemic. Notably, the work of Huang et al. (2020) and Adams and Ghose (2021) underscores the positive impact of reduced air pollution on respiratory health and associated health risks. These studies suggest that sustained improvements in air quality could lead to long-term benefits for public health, particularly in terms of mitigating respiratory illnesses.

In addition to public health considerations, the research of Zhang et al. (2021) and Wang and Yuan (2022) delves into the broader environmental policy implications of enhanced air quality during the pandemic. The findings suggest that sustained reductions in emissions could contribute to achieving long-term environmental goals, such as lowering carbon footprints and promoting sustainable development.

By synthesizing these studies and critically evaluating their findings, this research aims to offer a comprehensive assessment of the potential long-term implications of improved air quality during the COVID-19 pandemic. Understanding these implications is crucial for shaping effective public health strategies and environmental policies in the aftermath of the crisis.

9. Recommendations for future policies and preparedness strategies

Drawing upon the findings of this review regarding the impact of the COVID-19 pandemic on air quality, several recommendations for future policies and preparedness strategies emerge. These recommendations aim to guide policymakers and stakeholders in fostering sustainable practices and safeguarding air quality during future crises.

10. Investment in Renewable Energy Sources

The reduction in industrial and transportation-related emissions during the pandemic underscores the potential benefits of transitioning to renewable energy sources. Policies should prioritize investments in clean and sustainable energy alternatives (Smith et al., 2020).

11. Promotion of Telecommuting and Remote Work Options

The increase in remote work during the pandemic contributed to reduced commuting and, consequently, lower air pollution. Encouraging telecommuting and remote work options through supportive policies can be instrumental in maintaining improved air quality (Wang et al., 2021).

12. Enhancement of Public Transportation Infrastructure

Strengthening public transportation infrastructure can discourage the use of private vehicles, leading to lower emissions. Policies should prioritize the development of efficient and accessible public transportation systems (Li et al., 2021).

13. Implementation of Robust Monitoring Systems

Establishing comprehensive monitoring systems to track air quality changes during pandemics is essential for evidence-based decision-making. Such systems, as advocated by Johnson et al. (2022), enable timely responses and informed policymaking.

14. Integration of Environmental Considerations in Crisis Preparedness Plans

Future preparedness strategies should integrate environmental considerations, recognizing the impact of containment measures on air quality. Incorporating such factors into crisis preparedness plans ensures a more holistic approach to managing pandemics (Chen et al., 2021).

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