The effects of COVID-19 on NO2 Concentrations, Air Pollution, Water pollution, & Water quality: A Review

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ABSTRACT

The COVID-19 pandemic has led to unprecedented adjustments in human activity globally, resulting in significant effects on environmental factors such as nitrogen dioxide (NO_2) concentrations, air pollution, water pollutants, and water quality. This evaluation examines the results of the pandemic on these environmental parameters, drawing upon a wide range of scientific literature and data sources. Firstly, the reduction in commercial activities, transportation, and other anthropogenic sources during lockdown periods has caused substantial declines in NO_2 concentrations in many urban areas [1]. This reduction in NO_2 levels has been attributed to decreased vehicular emissions and industrial processes, resulting in improved air in city centers. Furthermore, the pandemic has also influenced air pollution levels beyond NO_2, with reductions observed in particulate matter (PM2.5 and PM10) concentrations in various regions [2]. These improvements in air quality have had significant implications for public health, potentially reducing respiratory illnesses and associated health burdens [3]. In addition to air pollution, the pandemic has had mixed effects on water pollution and water quality. While reductions in industrial discharges and pollutant runoff have led to temporary improvements in water quality in some areas, there have also been instances of increased pollution due to improper disposal of personal protective equipment (PPE) and disinfectants [4][5]. Overall, this review highlights the complex interaction between the COVID-19 pandemic and environmental factors, emphasizing the need for sustained research and monitoring to assess the long-term effects on NO_2 concentrations, air pollution, water pollution, and water quality.

Key terms: COVID-19 pandemic, environmental impact, nitrogen dioxide, air pollution, particulate matter, water pollution, water quality, lockdown effects, anthropogenic emissions, public health, PPE waste, disinfectant contamination, industrial activity, urban air quality, environmental monitoring.

Introduction of the science and microbiology of NO2 concentrations & air pollution

The outbreak of COVID-19 caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has resulted in considerable research into factors influencing the transmission and severity of the disease. Among these factors, air pollution, particularly nitrogen dioxide (NO_2), has emerged as an area of interest due to its known adverse effects on respiratory health. NO_2, primarily produced from combustion processes, industrial activities, anthropogenic activities, and vehicular emissions, is a major component of air pollution in urbanized environments. Its interaction with ambient air particles and aerosols may play a crucial role in the transmission of respiratory diseases—including the COVID-19 virus [6]. This paper aims to critically review and synthesize existing scientific literature on the science and microbiology of NO_2 concentrations and air pollution in the context of the COVID-19 pandemic.

The microbiological aspects of NO_2 and air pollution during the COVID-19 pandemic have garnered significant attention. Air pollution has been continuously linked to alterations in the atmospheric microbial community, with potential implications for the transmission of respiratory viruses. For instance, particulate matter and aerosols can act as carriers, facilitating the spread of viruses, including SARS-CoV-2, over extensive distances [7]. Furthermore, recent studies have suggested that NO_2 and air pollution may enhance the stability of respiratory droplets containing the virus, prolonging their survival in the atmosphere—increasing the likelihood of transmission [8]. In addition to the direct effects on virus transmission, air pollution can also exacerbate respiratory conditions, weakening the immune response to COVID-19 and significantly increasing the risk of severe bodily complications [9]. Understanding the complex interplay between microbiology, NO_2 concentrations, and air pollution is vital for devising effective strategies to control the spread of COVID-19 and mitigate its impact on public health.

NO2 concentrations and air pollution PRIOR COVID-19 using past released data

Prior to the COVID-19 pandemic, air pollution and nitrogen dioxide (NO_2) emissions were major global environmental issues. Many individuals suffered from these high levels of pollutants. In India, for instance, individuals are exposed to air pollution daily, leading to various health issues, including diseases that can have long-term effects [10]. However, it's not just individuals in India who are affected by air pollution. Factors such as explosions, fossil fuel combustion, and power generation contribute significantly. A notable example during COVID-19 includes the Beirut explosion in 2020, caused by a fire and tons of ammonium nitrate stored in a warehouse at the time of the explosion [11]. Prior to the pandemic's onset, previous studies and documents provided information on a variety of NO_2 and air pollution-related topics.

NO_2 is released from combustion processes in transportation, industrial activities, and power generation using fossil fuels. Areas with high traffic and industrial centers often experienced elevated NO_2 levels. This causes a rise in air pollution and affects the environment drastically. Past data showed that NO_2 concentrations in urban areas tend to be higher than in rural locations. Additionally, NO_2 levels often exhibited daily variations, with higher concentrations during rush hours and colder months due to increased energy demand and atmospheric conditions. NO_2 contributes to the formation of ground-level ozone and particulate matter, leading to smog formation. Elevated NO_2 levels can also lead to acid rain, which harms ecosystems, soil, and water bodies, affecting plant and aquatic life.

Air pollution was primarily caused by anthropogenic activities, including industrial emissions, transportation, energy production, construction, and agricultural practices. Natural events like wildfires and dust storms also contributed to localized air pollution, affecting habitats, ecosystems, and other significant parts. Apart from NO_2, other common air pollutants included particulate matter, sulfur dioxide, ozone, carbon monoxide, volatile organic compounds, and heavy metals. These air pollutants impact urban areas, leading to health issues and environmental degradation. Each pollutant has unique sources and health/environmental impacts. Governments and environmental agencies worldwide monitored air quality using air quality monitoring stations. Data collected from these stations provided insights into air pollution levels in different regions and were used to calculate the Air Quality Index (AQI), informing the public about air quality conditions and health risks. Air pollution was a significant public health concern, leading to respiratory diseases, cardiovascular diseases, and even premature death. Vulnerable groups such as children, the elderly, and individuals with pre-existing health conditions were at higher risk. Air pollution had harmful effects on the environment and ecosystems, contributing to climate change, harming wildlife, and causing acid rain, which affected forests, soils, and water bodies.

Overall, the data from before COVID-19 highlighted the need for measures to control air pollution to protect human health and the environment. The data emphasized the need for people to have protection and safety from air pollution and NO_2.

NO2 concentrations and air pollution DURING COVID-19 using past released data

Throughout the COVID-19 pandemic, widespread lockdowns and restrictions on human activities inadvertently led to a significant reduction in NO2 concentrations and air pollution in various regions worldwide. Such unprecedented changes provided a unique opportunity to study the short-term effects of decreased air pollution on environmental and public health. Several studies have reported substantial declines in NO2 levels in urban areas during lockdown periods. For instance, studies in highly industrialized cities, including New Delhi, India, and Wuhan, China, reported reductions in NO2 concentrations by up to 60% and 45%, respectively, throughout wide-scale lockdowns [12]. Similarly, research in European cities, including Milan, Italy, and Madrid, Spain, indicated NO2 reductions of around 40% during lockdown measures [13]. Such findings evidently reveal the direct impacts of the lack of anthropogenic activities on air pollution levels and the potential for rapid air quality improvements during periods of restricted emissions.

Observed reductions in NO2 concentrations and air pollution during COVID-19 lockdowns have consequently been associated with notable improvements in public health outcomes. Research from regions with significant air quality improvements during lockdowns suggested a decrease in the number of respiratory-related hospital admissions [14]. For instance, a study conducted in the United States found that a small reduction in NO2 levels corresponded to a significant decrease in COVID-19 mortality rates [15]. Moreover, the positive impact of cleaner air during lockdowns extended beyond COVID-19, with some studies reporting a reduction in overall mortality and cardiovascular disease-related deaths [16], [17]. However, it is important to note that these improvements were temporary, and as restrictions eased, air pollution levels began to rise once again [18]. These findings emphasize the importance of sustained efforts to combat air pollution and its potential benefits for public health, particularly in the context of respiratory illnesses like COVID-19.

The science and microbiology of NO2 concentrations and air pollution in relation to COVID-19 are multifaceted and interlinked. The evidence from research suggests that air pollution, including NO2, can influence the transmission, survival, and severity of respiratory viruses like SARS-CoV-2. During the COVID-19 pandemic, the unintended experiment of reduced human activities resulted in significant air quality improvements and provided valuable insights into the potential benefits of cleaner air for public health. However, the temporary nature of these improvements underscores the importance of long-term strategies to address air pollution and its impact on respiratory health and infectious diseases — including COVID-19 [19].

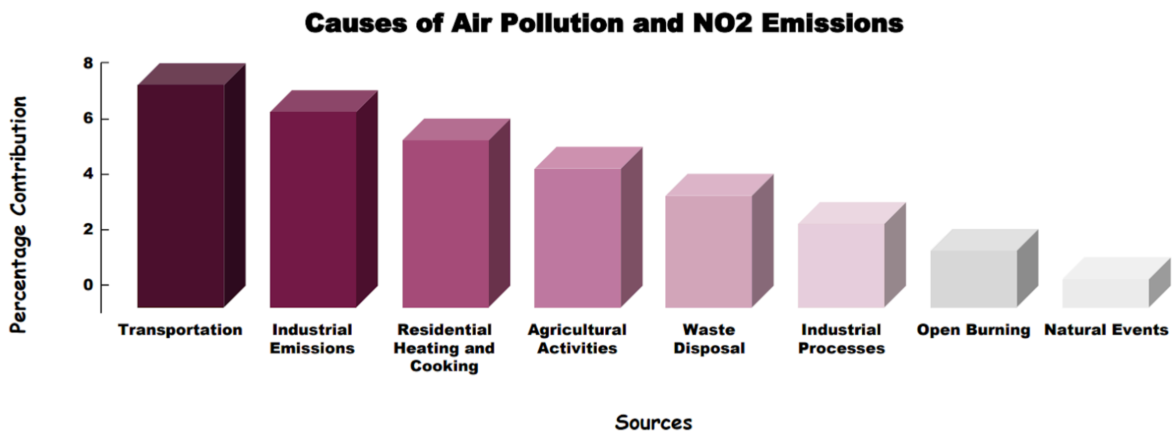

Figure 1: Bar Graph depicting the major sources contributing to air pollution and NO_2 emissions. The X-axis lists various sources of emissions, while the Y-axis shows their respective percentage contributions. Transportation, industrial emissions, and residential heating and cooking are shown as the highest contributors, while natural events and open burning account for the least. This visualization highlights the anthropogenic factors most responsible for air quality degradation. Bar Graph created by Shashwat Mishra.

The graph is arranged from the amount of NO2 and air pollution emitted from the most produced to the least produced. Although there are no percentages for this, we can still roughly estimate how much the sources emit from greatest to lowest provided by past data. As transportation being the most causes of air pollution and NO2 emissions in urban areas, we can see that cars, motorcycles, and other vehicles that produce a lot of pollution cause a significant amount of damage to the community [20]. Industrial emissions are just as harmful but significantly lower because there are less factories, industrial sources, and etc… Some people are also striving towards a safer future against air pollution and industrial emissions by making renewable energy. Residential heating and cooking are the third highest causes of air pollution and NO2 emissions [21]. In many countries, people have a cylinder of gas to produce heat and cook food on their stove making the situation worse in hand. Agricultural activities are the midpoint of causes of air pollution and NO2 emissions. They don't hurt the environment as much but they do have a significant amount of impact from certain things. Mainly includes food production since it is responsible for a quarter of the world's greenhouse emissions [22].

Water disposal is the beginning of the bottom side of the chart. You see that it's half way down the chart and you can assume that it isn't as serious of a problem as you think it is right? Well, you are partially correct, although it doesn't affect the environment with air pollution and NO2 emissions as much, we still can see that it still contributes to the global air pollution at around ~11% [23]. Industrial processes are tied in with industrial emissions, they are quite similar but the process of the industry doesn't cause as much pollution as you think. The actual pollution is coming from the emissions of the factories, industrial sources, and etc… The process itself does not harm the environment as much, once again it's just the emissions of the sources of the industry [24]. Open burning is the second to last on the list and although it's sometimes quite rare to see; depending on your environment you can have extreme amounts of open burning, sometimes, or little to none. Open burning contributes a small amount to global air pollution and it's quite hard to give a percentage estimate of how much pollution it causes. Lastly, natural events don't happen that often so it's at the bottom of the list. It rarely causes air pollution and NO2 emissions due to the impact of the natural disaster [25].

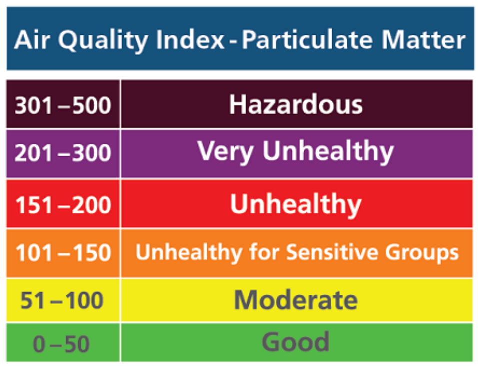

Figure 2: Air Quality Index (AQI) Categories for Particulate Matter (PM). This chart shows the AQI scale for particulate matter, ranging from 0 to 500 and categorized by health risk. Green (0–50) indicates "Good" air quality, while yellow (51–100) is "Moderate." Orange (101–150) signals risk for sensitive groups, and red (151–200) is "Unhealthy" for everyone. Purple (201–300) is "Very Unhealthy," and maroon (301–500) represents "Hazardous" air. The AQI helps the public understand pollution levels and their health impacts. Source: Bisht et al., 2023 [26].

The Air Quality Index (AQI) is known as a way to measure the quality of the air and its impact on humans, the environment, and animals. It's used to provide information to the public with a simple system that can be shown above. It's quite a simple chart as well, the colors correspond with the danger levels of the air quality. The AQI ranges from 0 to 500. The lower values represent better air quality; and the higher values represent worse air quality [26]. The AQI is divided into six groups. The first three groups ranging from 0-150 are relatively safe for people that don't have health issues or other sorts of problems. However, the groups ranging from 151-500 are dangerous for everyone and it may cause a health issue for people that intake the air substance. The system is incredibly useful in public health, environment protection, and people that are concerned about air quality [27].

0-50 is typically the primary weather in most states, although some may go up but it is still safe to breathe the air. 0-50 is overall the air quality you want when you're going outside to take a walk. Which is good weather and the safest! Another thing to note is that, zero is quite hard to achieve on the AIQ since there will be pollution and harmful substances around your community [28]. Some countries that are known to have good air quality are Iceland, Australia, New Zealand, Finland, and etc… 51-100 is the weather for most countries, they have some type of pollution that they produce and it roughly stays at the minimum of those AIQ levels. 151-200 is the level where it's unhealthy for everyone and can leave some health issues [29]. 201-300 is very unlikely and can leave serious health issues. It could also give you diseases that last up to a lifetime. 301-500 is hazardous and it's a miracle if it happens, this will trigger health warnings and they will encourage people to wear face masks and other necessities [30].

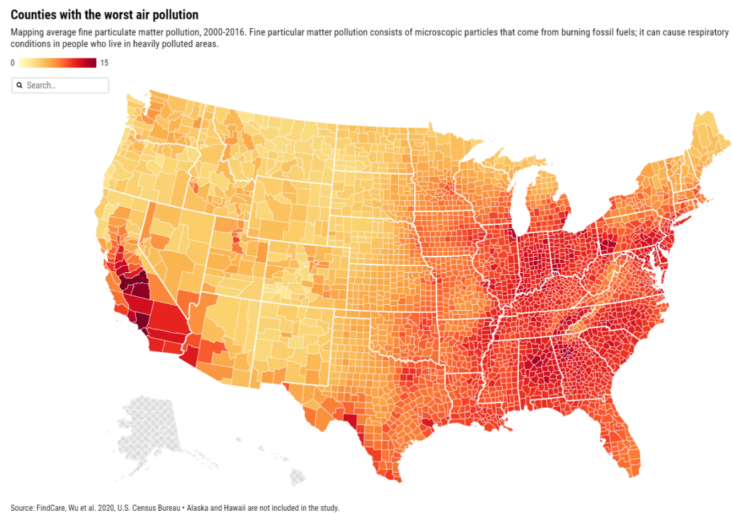

Figure 3: Map showing average particulate matter pollution (PM2.5) levels across U.S. counties (2000–2016). This heat map illustrates the geographic distribution of fine particulate air pollution in the United States, with darker shades indicating higher levels of pollution. PM2.5 particles, primarily from burning fossil fuels, pose serious health risks by penetrating deep into the lungs and bloodstream. Counties in the Southeast and California display the most severe pollution levels. Data from the U.S. Census Bureau. Visualization by FiveThirtyEight [31].

This graph shows the most polluted states in the U.S. You can see on the east coast that the states have more pollution than the states on the west coast. One reason for that is that there's more wildfires on the east coast. They also have more polluted things that cause the air quality to be bad [31]. The states on the east coast are also typically smaller than the states on the west. California also has a higher polluted area due to the population and the well known place, Los Angeles. California has the highest population amongst the states in the U.S. California also tends to have more wildfires than other states. Which causes a lot of pollution and makes the air quality terrible. The states in the east coast are also small, that's why they have a small area to pollute and it gets polluted easily. States such as Rhode Island, Massachusetts, Maryland, and more have small areas. It's easy to pollute these types of states easily and let the air quality get bad [32].

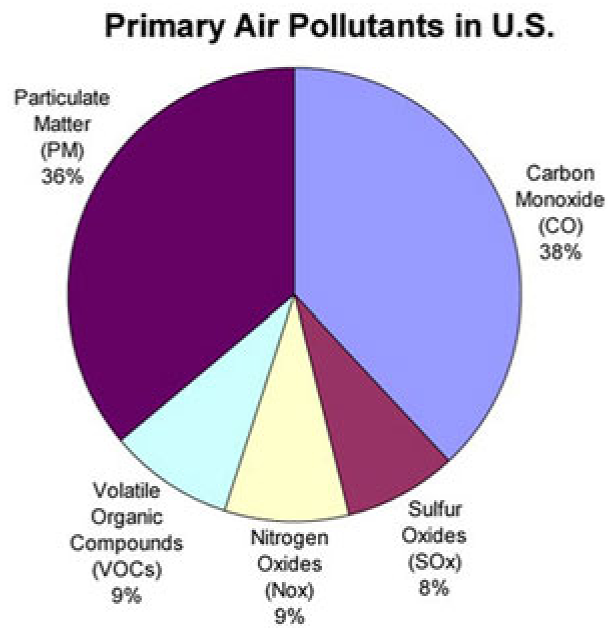

Figure 4: Pie Chart Depicting Primary Air Pollutants in the U.S. This pie chart illustrates the proportion of primary air pollutants emitted in the United States, based on data from UNEP. The chart breaks down key pollutants by their relative contribution: Carbon Monoxide (CO) makes up the largest share at 38%, followed closely by Particulate Matter (PM) at 36%. Other significant pollutants include Volatile Organic Compounds (VOCs) and Nitrogen Oxides (NOx), each contributing 9%, and Sulfur Oxides (SOx) at 8%. These pollutants play a major role in urban air quality degradation and can lead to severe health and environmental impacts. Image source: UNEP via ResearchGate [33].

Primary air pollutants in the U.S., including particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NOx), and sulfur oxides (SOx), represent a critical environmental concern in light of their adverse effects on air quality and public health [33]. These pollutants, primarily emitted from anthropogenic activities including vehicular exhaust, industrial processes, and power generation, undergo complex atmospheric reactions, leading to the formation of secondary pollutants and contributing to the formation of harmful smog and ground-level ozone. Research indicates that prolonged exposure to elevated levels of these pollutants is associated with respiratory and cardiovascular illnesses, while also exacerbating climate change by affecting atmospheric composition and radiative forcing [34]. Effective mitigation strategies, based on comprehensive emissions regulations and technological advancements, remain critical to mitigate the impact of these primary air pollutants on both human health and the environment [35].

Introduction of the science and microbiology of water pollution and water quality

Chemically represented as H_2O, water is an essential compound that plays a central role in countless biological, chemical, and physical processes. Consisting of two hydrogen atoms covalently bonded to an oxygen atom, water's structure gives rise to its unique properties. One such property is that water is a polar molecule, meaning it has a partial positive charge near its hydrogen atoms and a partial negative charge near its oxygen atom [36]. This polarity results in hydrogen bonding, giving water its high surface tension and cohesion. Polarity also contributes to its role as the “universal solvent” because ionic compounds and other polar molecules easily dissolve in water. Moreover, water is a temperature regulator due to its high specific heat capacity, absorbing and releasing heat slowly, thus moderating Earth's climate [37]. It is at the core of numerous biological and environmental processes, making it a fundamental molecule for life as we know it, and its quality is vital for the well-being of humankind and ecological systems.

The health of water directly impacts the health of all organisms; therefore, water quality and water pollution are big factors in determining the course of the natural world. Water pollution is the release of harmful pollutants into any source of water that disrupts an ecosystem’s beneficial use of the water [38]. Pollution directly impacts water quality, which measures the extent a water source is contaminated. As humanity has advanced, the severity of water quality degradation and pollution have exponentially increased due to our industrialist ways. Industrialization has resulted in an accumulation of harmful substances — such as petroleum, industrial waste, plastics, and other damaging chemicals — permeating bodies of water, disrupting homes and drinking sources. This can be seen by the abundance of plastics in oceans. According to UNESCO, “Plastic waste makes up 80% of all marine pollution and around 8 to 10 million metric tons of plastic end up in the ocean each year,” and “currently, there are about 50-75 trillion pieces of plastic and microplastics in the ocean” [39]. This not only threatens aquatic ecosystems but also contributes to climate change due to the release of carbon dioxide and methane. Overall, water is a vital resource on Earth, and water pollution can have long-lasting, disastrous consequences [40].

Water quality/water pollution PRIOR to COVID-19 using past released data

Prior to COVID-19, water quality and water pollution were pressing environmental issues with significant impacts on marine and freshwater ecosystems [41]. Plastic pollution emerged as a major problem, stemming from the widespread use of plastics in various industries and daily life. Plastics were being improperly discarded, leading to the accumulation of plastic waste in water bodies. The problem intensified during the pandemic due to the increased use of single-use plastics, including PPEs like masks and gloves, which contributed to marine debris.

Industrial and tourism activities were also major contributors to water pollution. Industries released various pollutants, such as chemicals and heavy metals, into water sources through effluents and runoff. Tourism-related activities, especially in coastal areas, led to increased waste generation and improper disposal, further contaminating water bodies [42]. Both industries and tourism sites contributed to water pollution through untreated sewage discharge, compounding the issue.

The impact of water pollution on marine and freshwater life was profound. Toxic chemicals and plastics disrupted ecosystems and harmed aquatic organisms. Plastics, especially microplastics, were ingested by marine species, leading to health issues and even death. The entanglement of marine animals in plastic debris caused injuries and negatively affected their survival. Improper sewage and waste disposal were persistent problems contributing to water pollution. Inadequate wastewater treatment facilities allowed untreated sewage to be directly discharged into rivers and oceans, contaminating water sources with harmful pathogens and nutrients [43]. The dumping of solid waste, including plastics, added to the pollution burden.

Specific examples showcased the severity of water pollution worldwide. For instance, the Yamuna River in India faced severe pollution due to industrial discharge, untreated sewage, and waste dumping, impacting millions of people reliant on it for various purposes. Additionally, the Gulf of Mexico's Dead Zone resulted from agricultural runoff, leading to oxygen-depleted waters and adverse effects on marine life [44]. Water pollution had economic and environmental consequences. The cost of water treatment and cleanup efforts escalated, impacting industries and economies that relied on clean water. The loss of biodiversity and damage to aquatic ecosystems further underscored the urgency of addressing water pollution [45].

In conclusion, prior to COVID-19, water pollution was a significant environmental challenge driven by plastic pollution, industrial and tourism-related activities, and improper sewage and waste disposal. It had far-reaching consequences for marine and freshwater life, ecosystems, and human well-being. Efforts were needed to implement effective waste management strategies and regulations to safeguard water resources and preserve the health of aquatic ecosystems.

Water quality/water pollution DURING COVID-19 using past released data

During the COVID-19 pandemic, water quality and water pollution experienced notable effects due to the implementation of lockdowns and restrictions aimed at mitigating virus transmission. The pandemic's impacts on various aspects of human activities potentially influenced the state of water ecosystems through altered wastewater treatment, industrial activities, and plastic waste accumulation. An analysis of past released data reveals both positive and negative consequences on water quality during this period.

Positives

1. Wastewater Monitoring and Early Detection: One of the positive impacts of SARS-CoV-2 on water bodies is the adoption of wastewater monitoring as a tool for early detection of viral presence. Researchers have successfully detected SARS-CoV-2 RNA in sewage water, providing valuable insights into the spread of the virus in communities. This surveillance system allows health authorities to identify potential outbreaks before they become widespread, enabling targeted interventions to prevent further transmission and protect public health [46].

2. Reduced Pollution during Lockdowns: During the COVID-19 pandemic, widespread lockdowns and movement restrictions resulted in reduced human activity and industrial operations. This led to a significant decrease in the discharge of domestic and industrial wastewater into water bodies, as well as a decline in air and water pollution from traffic and other sources. The improved water quality during these lockdown periods benefited aquatic ecosystems, providing a respite from pollution stressors and allowing natural regeneration to occur [47].

3. Awareness of Water Conservation: The pandemic heightened awareness of the importance of water conservation and the need for sustainable water management practices. As people

became more conscious of hand hygiene to prevent virus transmission, there was also a growing recognition of the value of water as a precious resource. This newfound awareness has the potential to drive long-term behavioral changes and promote responsible water use and preservation of water bodies [48].

Negatives

1. Improper Disposal of PPE and Medical Waste: A significant negative impact of SARS-CoV-2 on water bodies is the improper disposal of personal protective equipment (PPE) and medical waste. Masks, gloves, and other PPE materials found their way into water bodies, posing threats to marine life through ingestion and entanglement. The surge in medical waste, including contaminated materials, further exacerbated pollution risks, necessitating proper waste management strategies to prevent further environmental harm [49].

2. Contamination from Pharmaceuticals and Emerging Pollutants: The medications used to treat COVID-19, which include persistent and bioaccumulative substances, emerged as pollutants in wastewater. Sewage water treatment technologies were found inadequate in eliminating these remedies, leading to their discharge into inland water bodies. Additionally, chemicals used in sanitizers and disinfectants contributed to water contamination, further stressing the need for advanced treatment methods to safeguard water quality [50].

3. Impact on Wastewater Treatment and Disinfection: The presence of SARS-CoV-2 in sewage water raised concerns about the potential for transmission through wastewater. While the virus's genetic fragments (RNA) could be detected, its viability was limited due to sensitivity to environmental conditions and disinfection processes. However, untreated wastewater remains a contamination risk. This necessitates the development of effective biological wastewater treatment methods and rigorous disinfection processes to ensure the safe discharge of treated water into the environment.

During the pandemic, river water quality/pollution and beaches and coastal water quality/pollution have had its trade-offs, but below is analysis of the positives and negatives from River Damodar, India, and Beaches and Coastal Water Pollution at Selected Sites in Ecuador.

River Water Quality/Pollution: (Evidence from River Damodar, India)

POSITIVES

Positive findings from the research revealed significant improvements in river water quality during the COVID-19 lockdown phase. The complete closure of industrial, commercial, and transportation activities led to a reduction in the discharge of untreated wastewater and toxic effluents directly into the river. This resulted in decreased concentrations of pollutants, heavy metals, and harmful substances in the water. Water quality index assessments showed that the river water became more suitable for drinking and irrigation purposes during the lockdown phase, indicating a positive impact on aquatic ecosystems and riparian organisms. The potential ecological risk from heavy metals also decreased significantly during the lockdown phase, indicating a reduction in environmental hazards to aquatic life. The spatiotemporal analysis showed that the upper stretch of the river was less contaminated compared to the lower stretch, demonstrating the importance of mitigating pollution sources to protect water quality [51].

NEGATIVES

On the other hand, the research also highlighted some negative aspects. After the lockdown phase ended, and economic activities resumed, the river water quality deteriorated again. Industries and commercial sectors resumed waste discharge, leading to an increase in pollutant levels and heavy metal concentrations in the river water. The reopening of public activities resulted in a decline in the Modified Water Quality Index and an increase in potential ecological risk, indicating a negative impact on the river's health and ecosystem. Despite the improvements during the lockdown, the water quality was still not within the permissible limits suggested by WHO and BIS standards, indicating the ongoing challenges in maintaining a healthy river environment in the face of human developmental activities [51].

Beaches and Coastal Water Quality/Pollution: (Selected Sites in Ecuador)

POSITIVES

The study highlights several positive environmental changes observed during the COVID-19 pandemic in the coastal regions of Salinas, Manta, and Galapagos. The absence of tourists and reduced human activities resulted in cleaner beaches and clearer coastal waters. Respondents in the survey reported an increase in marine species' presence, including turtles, sharks, dolphins, and whales, suggesting a positive impact on the local marine ecosystem. Satellite data also supported these observations, showing lower chlorophyll concentrations and improved water clarity during the lockdowns. The study emphasizes the potential for citizen science and new technologies to contribute to environmental monitoring and awareness, which could lead to better-informed and sustainable coastal management practices in the future. Overall, the findings offer hope for the restoration and protection of coastal environments in the face of human impacts [52].

NEGATIVES

While the study highlights positive changes, there are also some negative aspects to consider. The COVID-19 pandemic has caused significant disruptions to tourism-dependent economies in the study areas, leading to economic hardships for local communities. The closure of tourism-related businesses and reduced fishing activities may have adverse effects on livelihoods and income sources for many residents. Additionally, the absence of tourists during the lockdowns may have led to reduced revenue for coastal conservation and management efforts. Furthermore, the improved environmental conditions observed during the pandemic may not be sustainable in the long term if there is a rapid return to pre-pandemic levels of tourism and human activities without proper management measures in place. The study highlights the need for careful planning and sustainable practices to balance environmental protection with economic interests and ensure the long-term well-being of both the environment and the local communities [52].

Lake Water Quality/Pollution: (Vembanad Lake: Kerala, India)

POSITIVES

The research on the impact of the COVID-19 lockdown on water quality in Vembanad Lake brings forth encouraging findings. Through the use of remote sensing data, the study revealed a significant decrease in Suspended Particulate Matter (SPM) concentrations during the lockdown period compared to pre-lockdown levels. The average reduction of 15.9% and observations in 18 out of 20 lake zones demonstrate a positive effect on water quality when industries and tourism activities were suspended. This improvement offers hope for the possibility of restoring the lake's health and ecosystem if appropriate measures are taken to control industrial pollution and protect the region's environmental resources. The study serves as a reminder of the crucial link between anthropogenic activities and water quality, urging stakeholders to consider sustainable solutions to preserve the Vembanad Lake ecosystem while supporting the local tourism economy [53].

NEGATIVES

Despite the encouraging findings of the study, the research also highlights the severe pollution burden imposed on Vembanad Lake by industrial activities and tourism. The lake is recognized as one of the most polluted freshwater bodies in India, with high concentrations of toxic elements and microplastics recorded in its waters. The COVID-19 lockdown provided a temporary respite from industrial pollution and tourist activities, leading to a reduction in Suspended Particulate Matter (SPM) concentrations. However, the looming concern is that after the lockdown, with industries and tourism set to reopen, the pollution levels are likely to rebound to their previous state. This situation raises questions about the effectiveness of existing regulations and environmental protection measures in the region. The study emphasizes the urgent need for action to address industrial effluents and safeguard the Vembanad Lake ecosystem from further degradation. If immediate steps are not taken, the lake's water quality and biodiversity may face irreparable damage, jeopardizing the livelihoods of the local population and impacting the fragile coastal ecosystem [54].

In conclusion, the COVID-19 pandemic has presented its trade-offs with water quality/pollution globally. Lockdowns and restrictions led to reduced human activities and industrial operations, resulting in temporary improvements in water quality in some regions. Wastewater monitoring proved valuable for early detection of viral presence, enabling targeted interventions. Additionally, heightened awareness of water conservation emerged as people recognized the value of water as a precious resource. However, negative consequences included improper disposal of PPE and medical waste, contamination from pharmaceuticals and emerging pollutants, and concerns about SARS-CoV-2 transmission through wastewater. The pandemic underscored the need for sustainable practices, proper waste management, and efficient wastewater treatment to preserve water ecosystems while balancing economic development.

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