Indoor Air Quality Monitoring Systems and COVID-19

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Abstract Coronavirus pandemic is proven as wreaking havoc with the rising number of cases since its first identification in Wuhan, China. This invisible threat has taken approximately 1.06 M lives with more than 36.5 M cases worldwide as on October 9th, 2020. World Health Organization (WHO) estimated the mortality rate for COVID-19 to be around 3–4% with higher risk to the people that have underlying medical conditions such as respiratory disease, diabetes, cancer, heart disease, asthma, and kidney disease. Numerous public health experts have defined a clear link between coronavirus death rates and long-term exposure to air pollution, especially PM$_{2.5}$ and NO$_2$ levels. Medical health experts are working hard to find a reliable treatment for COVID-19. The need for real-time monitoring systems to promote indoor air quality is another critical concern that demands the attention of the research community. The main contribution of this study is to present the connection between COVID-19 pandemic, public health and indoor air quality while addressing the importance of real-time monitoring systems for public health and wellness. This chapter presents the necessity of developing indoor air quality monitoring systems for hospitals, schools, offices and homes for enhanced health and well-being.

Keywords COVID-19 • Coronavirus • Public health • Indoor air quality • Monitoring systems
1 Introduction

The novel coronavirus disease 2019 (COVID-19) outbreak in Wuhan, Hubei Province, China has now become a worldwide panic with a rapid spread in 216 countries and territories [1, 2]. The total number of confirmed cases has now increased above 36.5 M with the death toll of more than 1.06 M [1]. The first case of coronavirus was reported in China in December 2019, and it was declared as a pandemic by the World Health Organization (WHO) on March 11th, 2020 [3]. As compared to MERS and SARS, this disease has spread more rapidly around the globe due to increased adaptation of the virus in different environments [4]. As this virus can spread from an infected person, contaminated surfaces and objects, several countries have installed a lockdown [5]. Considering the impact, leading economists have already predicted a shrink of the global economy due to novel coronavirus, leaving more burden on developing countries with limited resources [6, 7]. In this scenario, slowing down the impact of COVID-19 is critical to promote public health and well-being. Medical health experts are making hard efforts to find a reliable treatment for COVID-19 patients. Moreover, it has become equally relevant to understand the inherent causes of the rising number of deaths.

1.1 COVID-19 and Underlying Illness

The data obtained from Italy and China state that most of the deaths due to COVID-19 were reported among persons with some severe underlying health conditions such as chronic lung disease, cardiovascular disease, diabetes mellitus, obesity, hypertension, asthma and severe respiratory health issues [8–12]. Figure 1 shows the association between COVID-19 cases and underlying health conditions. A study presented by [13] report that coronavirus patients belonging to the cities with a higher level of air pollution before the outbreak of this pandemic are more likely to die from this new infection as compared to the patients in the cleaner parts of the world. The study was conducted over 3087 counties in the United States while covering 98% of the population. Furthermore, the results show a higher mortality rate for people with long-term exposure to PM$_{2.5}$ levels. The repeated exposure to dust and harmful gases presented in the environment adversely affects respiratory and cardiovascular systems [14–17]. Consequently, it is further linked to the severity of COVID-19 cases with worse symptoms of infection among people affected by air pollution [13, 18, 19]. The recent study [13] reveals that an increase of only 1 µg/m$^3$ in PM$_{2.5}$ is responsible for 8% increase in the COVID-19 death rate (95% confidence interval [CI]: 2%, 15%). The above stats report that it is equally important to address the inherent causes of the rising mortality rate due to this virus [20]. Moreover, the impact of this virus is linked to the immunity levels of the patients [21]. Therefore, it is crucial to find measures to improve the overall
community lifestyle. These efforts will improve the chances of survival of patients affected by a pandemic and open new opportunity to save the world from such invisible attacks in the future.

1.2 Indoor Air Pollution

The impact of indoor air pollution (IAP) on human beings is almost 2–5 times higher as compared to outdoor air pollution [22]. As people spend nearly 90% of their time indoors (homes, offices, schools and hospitals), they are more affected by the pollutants present in the building environment [23]. Even in the present scenario, when most of the countries have announced complete lockdown to implement social distancing for reducing the spread of COVID-19, people are spending most of their time indoors. As a result, the risk of IAP has increased several times, contributing to a considerable fall in the immunity due to rising chances of respiratory health problems [24, 25]. The impact is even worsening the underlying symptoms of other chronic health problems such as cancer, heart disease, kidney disease, diabetes and asthma [26]. Consequently, making people more vulnerable to the spread of COVID-19 disease [27].

Fig. 1 Association between COVID-19 and underlying health conditions
Table 1 shows data about coronavirus deaths from the United States (Released by New York City Health on May 13th, 2020) [28]. These stats reveal a 75% share of total deaths in the USA because of underlying conditions.

Figure 2 presents a relationship between COVID-19 deaths cases and underlying conditions in the UK on 19th March 2020 [29].

In hospitals, the number of patients is increasing every day. The regular monitoring of air pollution levels is critical to avoid the chances of worsening of disease symptoms [30]. The beforementioned facts demand the installation of real-time indoor air quality (IAQ) monitoring systems. These systems can provide relevant real-time data to support the evaluation of air pollution levels in the buildings. Furthermore, the application of IAQ monitoring systems ensures better efficiency of ventilation systems to promote a healthy lifestyle [31, 32]. IAQ monitoring has

| Age           | Number of deaths | With underlying conditions | Without underlying conditions | Unknown (if any underlying cond.) |
|---------------|------------------|----------------------------|-------------------------------|-----------------------------------|
| 75 + years old| 7,419            | 5,236                      | 2                             | 2,181                             |
| 65–74 years old| 3,788            | 2,801                      | 5                             | 982                               |
| 45–64 years old| 3,413            | 2,851                      | 72                            | 490                               |
| 18–44 years old| 601              | 476                        | 17                            | 108                               |
| 0–17 years old | 9                | 6                          | 3                             | 0                                 |
| Total         | 15,230           | 11,370 (75%)               | 99 (0.7%)                     | 1,551 (24.7%)                     |
been a crucial field of concern for a broad community of researchers around the world. Moreover, it is critical to perform an in-depth analysis of the topic to find out reliable answers to prevent exposure risk. Therefore, IAQ monitoring systems are crucial in the current pandemic scenario as an enhanced instrument to ensure the quality of the building ventilation systems.

The objective of this study is to bridge the gap between COVID-19, public health and indoor air quality while addressing the need for real-time monitoring systems. Furthermore, this work can be useful for public health professionals, researchers, students, industry experts and policymakers around the world.

2 Indoor Air Quality and COVID-19

Air quality in hospitals is considered a significant risk factor for a wide range of health consequences among patients and working staff who visit the premises. Several studies link the spread of infections, not just COVID-19, but also other existing diseases with IAQ [33–36]. Numerous researchers have also investigated the sources, levels, characteristics, and measures of bioaerosol in hospitals [37, 38]. Furthermore, medical facilities, COVID-19 patient quarantine centres, and nursing homes are equally affected by IAP. The use of chemical-rich detergents, cleaning solutions and medical treatments can also worsen the risk of infections [39]. Li et al. investigated the relationship between bioaerosol and ventilation arrangements. They recommended that adequate flow of fresh air into the hospital premises could regulate the bioaerosol level to a considerable extent [40]. Several hospitals have traditional ventilation systems that drive air from patient areas to the remaining circulation areas.

Consequently, airborne pathogens can easily spread the virus to the entire area leading to nosocomial outbreaks. The use of adequate ventilation systems with a reliable prediction of future airflow patterns is required to address this problem. Airflow patterns prediction is crucial to ensure enhanced ventilation and control in the buildings. It not only reduces the travel of pathogens in the operating environments but also minimizes the energy consumptions in the hospital areas.

2.1 COVID-19: Association to Biomass Usage

The critical concern to COVID-19 outbreak and IAQ levels is associated with the lifestyle of people in the middle and low-income countries. Globally, 2.8 billion people, 41% of the households, rely on solid fuels, including biomass and coal for their routine heating and cooking needs [41]. There is strong evidence between household air pollution and potential health problems such as stillbirth, low birth weight, lung cancer, cataract, chronic obstructive pulmonary disease, acute lower respiratory infections, asthma, cardiovascular disease, and chronic bronchitis [42–
The underlying metabolic health is further linked to the rising number of COVID-19 cases [46, 47].

Migrant workers and refugees that are living in fragile conditions are more vulnerable to COVID-19. Almost 80% of refugees live in middle and low-income countries. These people spend most of their time in poorly ventilated houses while using solid fuels as continuous sources of cooking and heating. Moreover, these rooms do not have adequate chimneys that could take smoke outside [48]. Due to lack of evidence, the policymakers rarely prioritize actions to control an outbreak of COVID-19 on such groups. However, from a research point of view, it is essential to explore the association between COVID-19 and biomass smoke. Rigorous testing with real-time surveillance of IAQ must be performed in all such communities to take vigorous actions to control the situation.

2.2 COVID-19 and Ventilation Issues

IAQ measures are equally necessary for modern housing facilities due to excessive use of chemical-rich detergents, deodorants, and cleaning products [26]. Although modern residential complexes are equipped with advanced ventilation arrangements, and consequently, there are still lesser options for circulation of fresh air. The defective ventilated buildings tend to accommodate kitchen odours, residues of scents, perfumes and other chemical-rich consumer products for longer time [49]. Steinemann et al. reported 37 different consumer products, including cleaning agents, laundry products and air freshener that are directly linked to the development of volatile organic compounds (VOCs). Repeated exposure to VOCs is further related to decreased lung function and oxidative stress while causing severe airways inflammation [50]. Win-Shwe et al. report a close connection between indoor chemical sensitivity reactions and VOCs exposure to immune dysfunction [51]. In a recent study, Giamarellos-Bourboulis et al. reported that patients with immune dysregulation are more likely to experience severe respiratory failure by COVID-19 [52]. Tay et al. also studied the interaction between the immune system and COVID-19. This study reports a subsequent contribution of the dysfunctional immune response of the human body to the progression of viral disease [53]. Therefore, the developed nations are not protected from the impact of COVID-19 due to poor health quality of the residents.

Figure 3 shows the combined effect of COVID-19 and IAP on human beings. The real-time monitoring of IAQ, along with adequate measures for enhanced ventilation facilities promote the overall health and well-being in the community. Consequently, these systems promote public health and make people less vulnerable to infectious diseases such as COVID-19.
Public health experts advised people to stay indoors as much as possible to reduce the spread of COVID-19. However, the current home isolation requirements can further increase the exposure to IAP. Moreover, people that are already affected by chronic respiratory diseases and are spending more time in the poorly ventilated homes are, therefore, more exposed to the disease symptoms. The situation also promotes an adverse impact on their immunity levels. Consequently, these patients are more vulnerable to this novel coronavirus.

Furthermore, the patients that are already admitted in the hospitals may also experience a rise in disease symptoms due to inadequate ventilation arrangements. In particular, in low-income countries where medical care centres are equipped with limited facilities.

More hospital admissions, frequent emergency room visits, and increased movements of staff members also result in poor IAQ, leaving existing patients in a higher risk of mortality due to COVID-19 [54, 55]. These critical scenarios require a reliable solution for regular monitoring of IAQ in hospitals, apartments, offices, and other indoor public spaces. It can serve as a preventive tool to control the...
inherent cause (respiratory health problems, low immunity levels and other underlying symptoms) behind increased mortality rate due to COVID-19 [56]. The requirements are not restricted to monitoring systems. There is a critical need for real-time IAQ prediction systems that can provide advance notifications about expected changes in indoor pollutant levels. The latest technologies such as the Internet of Things (IoT) [57, 58] and Wireless Sensor Networks (WSN) [59, 60] provide a versatile platform for the development and implementation of IAQ monitoring systems. Furthermore, the potential of Artificial Intelligence (AI), Fuzzy Logic (FL) and Machine Learning (ML) can be utilized to make predictions for enhanced real-time control and management [61–63].

The real challenge in the development of real-time monitoring systems is in the selection of accurate sensors for measuring indoor pollution levels [64]. Industry experts have designed multiple sensor units for measuring numerous pollutant levels. However, real-time implementation requires critical analysis over power efficiency, cost-effectiveness and reliability of these sensing technologies [65]. Reports reveal a rising concern of IAQ levels and their health impacts on low income and middle-income countries [66]. Roberton et al. also analyzed the indirect effects of COVID-19 pandemic on low income and middle-income countries [67]. Consequently, it is essential to perform a critical analysis of the use of adequate sensing technologies.

3.1 Existing Solutions for IAQ Monitoring

Researchers around the world are already working in this direction. Numerous authors have presented several competitive solutions to deal with the rising health concerns due to reduced IAQ levels [23].

Marques et al. designed a cost-effective air quality supervision system using IoT for enhanced living conditions in indoor environments [68]. They used IoT architecture for designing a Wi-Fi module named as iAir. This module includes a multi-gas sensor (MiCS-6814) and an ESP8266 microcontroller. This system is capable enough to detect several harmful gases in indoor environments, including propane, ethanol, carbon monoxide, and nitrogen dioxide.

Idrees et al. also designed an edge computing-based IoT system for low-cost air pollution monitoring for measuring six different pollutant levels, including O₃, SO₂, NO₂, CO, PM₂.₅ and PM₁₀ [69]. It was efficient enough to reduce the computational requirements on sensing nodes by almost 70% while ensuring a considerable reduction of 23% in the overall power consumption.

Tiele et al. presented a low-cost and portable monitoring device for measuring IAQ levels. This system focused on the impact of total VOCs, PM₁₀, PM₂.₅, CO, CO₂, temperature, and humidity as well [70]. The experimental results show successful monitoring of IAQ parameters, and the proposed system also ensures easy installation.
Yu et al. followed an advanced system for improving IAQ levels while providing in-depth analysis on monitoring, prediction and pre-action [71]. The authors used ARIMA model for improving the accuracy of the system while predicting IAQ trends. They also utilized fuzzy-logic based decision modelling for designing an energy-efficient feedback control mechanism.

These studies show the scope of real-time monitoring systems for management of IAP levels. Such systems can be installed in modern apartments, rural homes, hospitals, cafeterias, schools, and offices to monitor IAQ. Several researchers designed IAQ monitoring and prediction systems that could provide instant notifications via SMS or email for the rise of pollutant levels above desired threshold levels [23, 72]. Figure 4 provides a general architecture of IAQ monitoring system.

These IAQ monitoring systems can be further linked to monitoring the impact of IAP on COVID-19 patients in medical care centres. The caregivers and medical health experts are also vulnerable to COVID-19 spread. Since they visit patient care units multiple times; an automated monitoring system can provide real-time analysis remotely. These systems can also be installed in coronavirus quarantine centres and residential apartments to monitor the IAQ conditions. It is possible to install low-cost sensors to address PM, CO₂, and NO₂ levels while ensuring a cost-effective solution for low and middle-income countries. Low-cost sensors can reduce the financial burden on government and policymakers during this pandemic [73–75].

Moreover, these sensors have enough accuracy to provide qualitative analysis on IAQ for taking preventive steps. The IAQ monitoring using cost-effective sensors enable the correct evaluation of ventilation procedures on time. Consequently, the exposure risk is decreased, and unhealthy IAQ scenarios can be avoided. Smart sensing technologies provide a reliable solution to help medical health experts,
caregivers, policymakers, and government authorities to provide better control on inherent causes of rising mortality rate due to coronavirus pandemic.

Currently, without effective treatments or medicines to reduce the ongoing pandemic ventilation is suggested as a critical element to face the spread of the SARS-CoV-2 virus [76, 77]. Nevertheless, it is relevant to understand that outdoor air used for ventilation can also have low air quality which tends to happen especially for underserved communities facing environmental injustice scenarios. The use of cost-effective sensors is recommended for qualitative assessment of the ventilation conditions and can help in maintaining healthy indoor conditions for the occupants.

4 Conclusion

The lack of information, unfamiliarity with COVID-19, conflicting information and human perception are critical aspects for rising threats of this pandemic. As people these days are spending more time indoor, repeated exposure to low air quality can pose a severe threat to their respiratory health and immunity levels while making them more vulnerable to the attack of virus. Consequently, it is critical to address the concern ahead of time to reduce the rate of fatalities worldwide. In this study, the impact of COVID-19 on patients with underlying medical health conditions, especially respiratory disease, was analyzed. This study also established a link between IAQ and the rising threat of pandemic while proposing the need for real-time monitoring and predictions systems for enhanced living environments. The evidence presented in this study show potential of smart sensing technologies to ease the burden of global mortality rate due to COVID-19.

This chapter has the following outcomes:

- Provides valuable information about the association between COVID-19 and underlying illnesses.
- Discuss the impact of IAQ on public health while providing insights about relevant chronic health problems.
- Highlight the importance of IAQ monitoring for enhanced patient health and healthy building environment.
- Present details about existing research in the field of IAQ monitoring system development.
- Provide baseline information for the upcoming researchers and policymakers to deal with the pandemic and associated IAQ challenges.

The findings of this work are useful not just for research point of view, but also to develop new policies for establishing robust control measures for the spread of COVID-19. Furthermore, it proposes new guidelines for following adequate safety measures related to IAQ levels during this pandemic attack.
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