Spike in pollution to ignite the bursting of COVID-19 second wave is more dangerous than spike of SAR-CoV-2 under environmental ignorance in long term: a review

Biswaranjan Paital\textsuperscript{1} \& Kabita Das\textsuperscript{2}

Received: 25 May 2021 / Accepted: 7 August 2021 / Published online: 14 August 2021
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

Abstract
Specific areas in many countries such as Italy, India, China, Brazil, Germany and the USA have witnessed that air pollution increases the risk of COVID-19 severity as particulate matters transmit the virus SARS-CoV-2 and causes high expression of ACE2, the receptor for spike protein of the virus, especially under exposure to NO\textsubscript{2}, SO\textsubscript{2} and NO\textsubscript{x} emissions. Wastewater-based epidemiology of COVID-19 is also noticed in many countries such as the Netherlands, the USA, Paris, France, Australia, Spain, Italy, Switzerland China, India and Hungary. Soil is also found to be contaminated by the RNA of SARS-CoV-2. Activities including defecation and urination by infected people contribute to the source for soil contamination, while release of wastewater containing cough, urine and stool of infected people from hospitals and home isolation contributes to the source of SARS-CoV-2 RNA in both water and soil. Detection of the virus early before the outbreak of the disease supports this fact. Based on this information, spike in pollution is found to be more dangerous in long-term than the spike protein of SARS-CoV-2. It is because the later one may be controlled in future within months or few years by vaccination and with specific drugs, but the former one provides base for many diseases including the current and any future pandemics. Although such predictions and the positive effects of SARS-CoV-2 on environment was already forecasted after the first wave of COVID-19, the learnt lesson as spotlight was not considered as one of the measures for which 2nd wave has quickly hit the world.

Keywords Future pandemics \cdot Future waves of COVID-19 \cdot Pollution spike \cdot Spike protein of SARS-CoV-2 \cdot Total environmental management \cdot Waterborne COVID-19

Introduction
All viral pandemics usually exhibit multiple waves (Maragakis 2021; Róka et al. 2021). The intensity of the contagiousness of viral pathogens depends on numerous factors (Tayech et al. 2020). However, subsequent waves of pandemics can be prevented using preventive measures.

Vaccination, social distancing, hand sanitization practices and use of face mask have been considered few of the main approaches to prevent the outbreak of COVID-19. Above steps can be taken at individual level, and lockdowns and shutdowns are few of the government approaches that were employed to break the chain of the virus SARS-CoV-2. Complete or partial failure to adapt above approaches is considered to be the main reasons why many countries including Kyrgyzstan, Australia, South Korea, Israel, New Zealand, India, Japan, Spain, the UK, the USA and Iran have witnessed the 2nd wave of the disease (Dargahi et al. 2021a, 2021b; Sarailoo et al. 2021; Vosoughi et al. 2021; Zandian et al. 2021, Fig. 1). Although about 3,839,816,037 people have been vaccinated against the viral disease as on 2 August 2021, some or many of the failure preventive measures are responsible to raise the total number of infection by SARS-CoV-2 to 198,022,041 out of which 4,223,460 lives has been swallowed by the virus as on 2 August 2021 (WHO 2021).
After adapting stricter actions such as vaccination, lockdowns, and other associated health measures, few of the above countries have successfully defended the 2nd wave, but many countries such as India have been battling hard to control the infection and death under the disease (Fig. 2). India had won the war against COVID-19 when its 1st wave hit the country in approximately March 2020 (Coccia 2021; Das and Paital 2020; Das et al. 2021; Paital 2020; Paital et al. 2020a, b).

![Total number of active cases per million people in the respective months (million)](image)

Fig. 1 Global status of the first and second wave of COVID-19 outbreak by the mid-April 2021. The first wave (red arrows) seemed to be decreased to its lowest value by the end of December 2020, while the second wave (purple arrows) has been started almost in all countries and now been observed to move with full speed of contamination. Although most of the countries have experienced the peak of the first wave between June 2020 and December 2020, the second wave is hitting almost all the countries at this time point. Still the trend of COVID-19 infection per million population is high in America, followed by Europe, Asia, Eastern Mediterranean countries, Africa and Western Pacific regions. Numbers of infection has been shown in inserts (Source WHO 2021 under creative common attribution).

![Real-time data for the total number of cases verses the total number of deaths in India in COVID-19 up to the last week of April 2021](image)

Fig. 2 Real-time data for the total number of cases verses the total number of deaths in India in COVID-19 up to the last week of April 2021. Data indicate that the peak in both death and infection rate was observed in the country during August to September 2020, and then the graph took a long jump in linear scale in March to May 2021 (Worldometers, 2021).
Sarkodie and Owusu 2021). The 1st wave had given enough experience to each country to use the learnt lesson as spotlight for the prevention of the 2nd and subsequent waves of COVID-19 (Mousazadeh et al. 2021). Then what made the countries to suffer so severely under the 2nd wave is the biggest question and has been addressed by many experts up to certain extend (Bhuyan 2021). Failure to set strategies for peak and non-peak timings, imbalance between demand and supply of COVID-19 logistics especially oxygen, failure to hold a planned and quick vaccination programme, and failure to take strong measures to follow COVID-19 guidelines are the reasons for which countries such as India are suffering from the disease outbreak under 2nd wave to a bigger extend (Bhuyan 2021).

The above points are the cons, but none has discussed the pro of the event in countries such as India and Brazil that strive very hard to protect their people from infection and death especially during the 2nd wave of the disease. Overall, out of the confirmed 198,022,041 infections and 4,223,460 deaths counting 2.13% fatality rate, Brazil has 19,797,086 confirmed infections and 553,179 deaths that contributed to 2.79% fatality rate (Karami et al. 2021; Pivato et al. 2021; Worldometers 2021). Concomitantly, in India, the value is 1.34% out of the 31,572,344 total number of infections and 423,217 confirmed deaths in COVID-19 as on 2 August 2021 (WHO 2021). The criticism rose against India by the prestigious journal Nature that the country is known for ignoring its scientific advices made by experts for the prevention of COVID-19 before or during the 2nd wave and did not use the opportunities it had before hit by the 2nd wave (Editorial 2021). The main question here remained unclear that is lifting of lockdowns and unsatisfactory manhandle of COVID-19 logistics and situations had pushed the country to suffer the most? Many scientific articles have forecasted to use the lesson learnt from the 1st wave as spotlight to handle subsequent waves (Fig. 1).

Mainly, the possibility of the relation between environmental pollution especially air and water pollution and COVID-19 has been ignored everywhere (Fig. 3). Although the improvement of environment under the lockdowns is largely documented (Paital 2020; Paital et al. 2020b, Table 1), involvement of the environment to enhance the rate and severity of infection of COVID-19 has been ignored (Lee et al. 2021; Paital and Agrawal 2020; Paraskevis et al. 2021). Involvement of the environment especially air and water for the 2nd wave was predicted but was not considered by any country seriously to prevent the disease (Róka et al. 2021). Ignorance of such forecasting and environmental protection activities which could lead to the quick 2nd wave of the disease is the central focus of this review article.

The level of CO₂ has already crossed the threshold of 400 ppm, but nowhere any substantial step has been taken to prevent it. Likewise, chemical pollutions in air, water, and soil are increasing day by day that would provide a platform to develop many SARS-CoV-2 and many potent viruses that can swipe the life of any particular species from the world very quickly. It is because the environmental chemistry is always detrimental for the development and/or survival of any, virus and this could be the reason why the SARS-CoV-2 is getting mutated very quickly when it travels (via infected human hosts) from one country to another that have different climatic (and polluted) set up (He et al. 2021). Therefore, the spike in environmental disorders including pollution must be checked for the long-term benefit; otherwise, such spike could be more dangerous in the future than the marker spike protein of the SARS-CoV-2 virus that attaches to the receptor ACE2 dominantly present on respiratory epithelial cell surface of human host. This has been discussed for the first time in this review article.

More clearly, handling the spike in pollution at several parts especially in urban and semiurban areas is more important for long-term benefits. The spike protein of the SARS-CoV-2 may be handled within limited time period with vaccination or appropriate medicines (if discovered against SARS-CoV-2 in future) or repurposing the available antibiotics, anti-malarial or anti-cancer drugs. However, many diseases including the present COVID-19 get aggravated under the spike in NO₂, SO₂ and PM₃.₅ emissions in many countries, and such diseases found to get intensified both the terms of infection and severity under polluted environments in human and non-human hosts (Paital and Agrawal 2020). In one hand, polluted environments act to diminish disease resistance capacity (by immuno-suppression, specific organ dysfunction such as lungs etc.) in hosts, and on the other hand, these also create ambient conditions for growth and propagation of many pathogens. For example, infection and severity of SARS-CoV-2 is high in human under frequent exposure to the increased PM₂.₅, SO₂ and NO₂ emissions because exposure to all of these gases especially NO₂ and SO₂ is responsible to increase in expression of ACE 2 in human respiratory epithelial cells, and ACE 2 acts as receptor for the spike proteins of SARS-CoV-2 to get attached to the host cell surface having ACE 2. Specific disease including the current pandemic COVID-19 may be handled in future after few months or years, but such environmental pollutions need to be handled for long-term benefits to avoid such pandemics or endemics. Emphasis was given to discuss the above point in this current article with an objective that it will add to the existing researches on COVID-19.

Air and water pollution verses COVID-19

Pollution acts as a general inducer of immunity reduction for all diseases including the current contagious disease COVID-19. Air, water, sound and soil pollution have been prevailing in many parts of the world above the threshold values (Paital
### Table 1. Positive effects of COVID-19 after its first wave

| Events                                      | Place of occurrence | Reason                                                                 |
|---------------------------------------------|---------------------|------------------------------------------------------------------------|
| Decrease in vehicular and industrial operations. Less or discharge of exhaustion gases | Worldwide, especially 40% reduction in NO\(_2\) emissions in Wuhan, China. Reduction in CO\(_2\) by 10–20% in 27 countries. Reduction in NO\(_2\), SO\(_2\), and CO\(_2\) by 30–50% in Italy, France, and Spain. | Reduction in vehicular and industrial operations. Less or discharge of exhaustion gases |
| Decrease in emissions of greenhouse gases   | Worldwide, especially 44% decrease in NO\(_2\) emissions, 20% in China, and 10–20% in Europe. | Reduction in vehicular, flight, and industrial operations. |
| Increase of O\(_3\) layer                    | Worldwide, especially increase of O\(_3\) (24% in Nice, 14% in Rome, 27% in Turin, 2.4% in Valencia, 36% in Wuhan, 20% in Sao Paulo, 50% in Barcelona, 11% in London, 17% in 22 Indian cities, 36% in Beijing-Tianjin-Hebei region and 15% in Almaty) | Increase of O\(_3\) layer Worldwide especially increase of O\(_3\) |
| Reduction of noise pollution                | Worldwide, reduction in vehicular, flight, and industrial operations | Reduction of noise pollution Worldwide Reduction in vehicular, flight and industrial operations |
| Reduction in electricity consumption        | Worldwide, overall 10% reduction worldwide and 30% in Italy, 15% in France, 12% in Germany, 15% in Spain, 20% in India and 15% in the UK | Reduction in electricity consumption Worldwide Overall 10% reduction |
| Reduction in traffic                       | Worldwide, especially 50% reduction in New York City, 75% in Madrid etc. | Reduction in traffic Worldwide especially reduction in 50% in New York City |

The main aspect of air pollution with respect to COVID-19 is the relation between the expression of the receptor protein ACE2 in human respiratory cells under exposure to NO\(_2\) and SO\(_2\) emissions and the infection and severity in the disease. Like COVID-19, two more epidemics were observed in China and Saudi Arabia in 2003 and 2012, respectively. They were called as SARS and MERS, respectively. Interestingly, SARS was caused by a strain of the coronavirus family and was called as SARS-CoV-1. SARS-CoVs have the “spike” protein that act as receptor for interacting with the ACE2 of (non)human host (Paial and Agrawal 2020). The internalisation process of coronavirus indicates that they get attached to the cells via spike protein-ACE2 complex and release their RNA genome into the host cells. It has been established that the expression of ACE2 has a strong positive correlation with the exposure to air pollutants such as NO\(_2\) and SO\(_2\) (Paial and Agrawal 2020, Fig. 4). The infection and severity in COVID-19 depends on the viral load in the patient’s body which could be increased with the increase in exposure to air pollution. Therefore, it is pertinent that the infection and severity of COVID-19 would be high under air pollution as observed in India and Italy (Fig. 4).

Similar could be the case with wastewater contamination by the SARS-CoV-2. Many reports have defined the presence of SARS-CoV-2 in wastewater bodies (Medema et al. 2020; La Rosa et al. 2020; Wu et al. 2020; Wurtz et al. 2020; Ahmed et al. 2020; Randazzo et al. 2020; Rimoldi et al. 2020; Rimoldi et al. 2020; Langone et al. 2021; Tran et al. 2021). The main source could be the release of the daily waste from the infected patients to the drainage, sewerage and finally their release without treatment to the nearest river or water reservoir (Róka et al. 2021). Therefore, wastewater-based epidemiology has been proved, and SARS-CoV-2 in its present form or in future mutated form h could be more dangerous. The robustness of the protocol followed by the above
Researchers to measure the viral load was very high as they have quantified the N gene in SARS-CoV-2 RNA using RT-qPCR. It is observed that using oligonucleotides, real-time PCR methods are now accepted as one of the gold standard methods to study and identify the expression level of genes that act as markers for identification of SARS-CoV-2. Examples of such genes are RdRP, E and N genes. The authors established that the limit of detection of the above genes was $10^{-10}$ to $10^{-1}$ (atto) M for RdRP, 10−(a (femto) to 10−(f (100 atto) M for E gene and 10−(1 to 10−to (10 atto) M for N gene (Cho et al. 2020). This standard method can be used to monitor the environmental contamination to identify any emergent of more potent (SARS-CoV-2) viral strain. If agreed to the above and other similar results, a total environmental approach is essential to save us from deadly microbes. This was predicted by Róka et al. (2021) and many others predicted too early.

Availability of the virus indicates their survivability in water. In many countries, the water hygienic condition is very poor, and people use water for their daily work including drinking from rivers and pools that are commonly contaminated with many pathogens including SARS-CoV-2. If such water is used for washing face, bathing, washing clothes and even for drinking after nominal purification (passing though multilayers of clothes), then the chance of infection could be high. This could be the reason when people get confusion why they are tested COVID-19 positive although they maintain social

![Fig. 3 Relation between air pollution and COVID-19 status in New Delhi, India. Air pollution indices were low in August 2020 amid COVID-19-induced lockdowns in New Delhi, India. As the lockdowns was lifted, the predicted massive gas exhaustion from reopening industries, vehicular traffics, etc. was able to uplift the air pollution status (a). Again the loose lockdowns along with disobeying of COVID-19 guidelines were able to lift the gas exhaustion in February 2021. That provided a sound background for speedy infection (b), causality and mortality in March 2021. The pattern still continues in April and May 2021 (c). The main factors such as particulate matters (PM) could be the reason to increase a sharp rise in COVID-19 infection by acting as vehicle of transmission while SO$_2$, NO$_2$ and CO could be the contributing factor to increase the infection rate and/or severity in the disease by up regulating the angiotensin converting enzyme 2 in the epithelia cells of respiratory cells that acts as the receptor for the SARS-CoV-2, especially for its spike protein (Paital and Agrawal 2020). The raw data were collected from Bing (2021) and NAQI (2021) under creative common attribution license.](image)
distancing, sanitization and mask as preventive measures. Therefore, the proper treatment of solid and liquid wastes released from infected patients must be done before they are released to environment in general and water bodies in particular.

Pollution and COVID-19 severity, examples

Airborne

Environment has a definite role in protecting us from several diseases including the current or future pandemic (Róka et al. 2021; Roviello and Roviello 2021; Khan et al. 2021; He and Han 2021). Sever intensity of air pollution dominant area in patches or in whole countries in China, India, Italy, Brazil and many other countries has been witnessed during pre-COVID-19 time periods (The World Bank 2021). Organisations such as WHO and many other have issued notices regarding control measures of air pollution and restriction of the water contamination by COVID-19. This fact has been supported by experimental data (Róka et al. 2021). In Italy, Spain, France and Germany, out of the initial mortality of 4443 recorded in the beginning of COVID-19 outbreak, about 78% deaths (accounting 3487 deaths) were strongly correlated with the area where NO2 pollution was high (Ogen 2020). Similar higher rate of infection and mortality in COVID-19 was also observed in Northern Italy where air pollution was the highest compared to other parts of the country (Conticini et al. 2020, Fig. 4). For example, levels of SARS-CoV-2 virus were supposed to be high in the environment at the Po Valley of Northern Italy where both air pollution and COVID-19 were at the peak as compared to the other parts (Di-Cerbo 2020).

So, air pollution was strongly suggested to be considered risky for the easy spreading of COVID-19 (Martelletti and Martelletti 2020).

Similar link between epidemics caused by SARS-CoV-1 in China in 2003 was also positively correlated with air pollution (Li et al. 2017, 2018, 2020). The observed association between air pollution and COVID-19 was pushed organisations such as WHO, who had earlier rejected the theory of airborne nature of COVID-19 till late 2019 and finally had declared COVID-19 as airborne disease in late 2020 (Chen et al. 2021a; WHO 2020). Therefore use of multi-layered mask to prevent infection from the exclusive viral circulation in air during its 2nd wave has been suggested. Special measures should be taken in areas predominant with NO2 pollution due to its strong association with ACE2 expression (Fig. 4). This idea seems to be employed globally for the prevention of observed 2nd or subsequent waves of the disease (Fig. 5). Similarly, 0.38% higher mortality could also be noticed with an increase

Table 2  Prediction model for air pollution emission in every 5-year gap up to 2050.

| Pollutants | 2015  | 2020  | 2025  | 2035  | 2040  | 2045  | 2050  |
|------------|-------|-------|-------|-------|-------|-------|-------|
| SO2        | 104.1 | 96.9  | 89    | 83.5  | 79.9  | 75.8  | 71.1  | 68.3 |
| NOx        | 136.7 | 137   | 141.5 | 146.7 | 154.1 | 165.3 | 169.6 | 175.7|
| NH3        | 57.1  | 56.8  | 58.5  | 57.6  | 57.7  | 59.2  | 58.6  | 58.2 |
| VOCs       | 164.8 | 131.7 | 136.6 | 141   | 146.4 | 157.4 | 160.4 | 164.3|
| BC         | 5.3   | 4.8   | 5     | 5     | 5     | 5.2   | 5.1   | 4.9  |
| OP         | 16.4  | 14.9  | 15.4  | 15.6  | 15.5  | 16.5  | 15.9  | 15.5 |
| CO         | 1159.9| 717.9 | 790.3 | 844.9 | 887.7 | 1001.4| 1016.4| 1035 |

The data are presented as million metric tons per year. Sulphur dioxide (SO2), nitrous oxide (NOx), ammonia (NH3), volatile organic compounds (VOCs), black carbon (BC), organic particulates (OP) and carbon monoxides (CO) are presented in the table. Data are considered from the real-time sources for 2015 to 2020, and prediction was done after considering several pros and cons associated with the emission in global basis. The graphs are given free per click at www.statica.org by Tiseo (2021) and were converted into tabular form.
COVID-19 was also drastically low or nil at such places. It clearly suggests that the air quality along with the medical facility needs to be improved to give checkmate to COVID-19 from its 2nd wave and also from the upcoming waves.

The central and state governments of India had imposed strict lockdowns in the state; as a result, many environmental improvements were noticed, for example, as observed in the capital of India during its 1st wave of COVID-19 (Paital 2020). Without vaccination, the country and its capital had able to defend the disease quite efficiently in an unseen manner with only using drug repurposing care and imposing social distancing and allied preventive measures against COVID-19. However, once the government had lifted the lockdowns and allowed opening of industries and allied activities, a spike of air pollution was observed to be faster. And it could be one of the reasons for the observing high spike in pollution with a deadly entry of the 2nd wave of the disease (Fig. 7). Although multiple waves are common in contagious pandemics, such serious and more potent viral infection was unexpected during its hitting in 2nd wave and has been positively correlated with the increase in air pollution. Many reports have documented the vice versa relation, i.e. improvement of the environment via COVID-19-induced lockdowns (Maji et al. 2021; Mahato et al. 2020; Sharma and Balyan 2020, Table 1). Since the 3rd wave of COVID-19 in India is forecasted (Sharma 2021), one of the take home messages must be “to avoid regenerating nature on to fight better against the disease” (Paital 2020; Róka et al. 2021). So, by accessing clean air (Paital 2020; Paital et al. 2020a, b; Paital and Agrawal 2020) or by restricting the wastewater-based epidemiology of the current pandemic, India could fight better against the 2nd wave of COVID-19 (Róka et al. 2021).

**Water contamination with SARS-CoV-2**

Similar to the airborne nature of COVID-19, water contamination and pollution with its causative agent, i.e. the RNA of SARS-CoV-2, were also noticed in wastewater and reservoirs (Singh et al. 2021). Basically, water source is contaminated from the wastewater released from COVID-19 hospitals/care centres and from households where home isolation of infected people is adapted. If the wastewater from such sources is released without treatment to any water sources, RNA of SARS-CoV-2 present in the cough, stool, urine, faecal matter, etc. of infected people that carry the RNA is believed to contaminate water bodies. It has been predicted early by many including Róka et al (2021). The first report that describes about the presence of the RNA of SARS-CoV-2 in water was in the Netherlands in March 2020 (Medema et al. 2020). Then, half numbers of water samples out of the total twelve influent sewage collected from the Wastewater Treatment Plants in Milan and Rome, Italy was tested positive for the presence
The test was done with a high precision molecular test with specific primers (La Rosa et al. 2020). Subsequently, similar reports were documented from Massachusetts, USA, in March 2020 (Wu et al. 2020); Paris, France (Wurtzer et al. 2020); in Brisbane, Australia (Ahmed et al. 2020); Region of Murcia, Spain (Randazzo et al. 2020); Milan Metropolitan Area, Italy; and Switzerland (Rimoldi et al. 2020), during March to April 2020 although the copy number or cycle threshold value in RT-PCR test was different at different places (Rimoldi et al. 2020). The same was reported in Hong Kong, China, in 2003 during SARS epidemics (McKinney et al. 2006). Subsequently, detection of the active viral RNA in river, lakes, groundwater, drinking water reservoirs, recreational water utilities and wastewater has been reported worldwide especially in countries that utilises adapt less or no hygienic knowledge, technology and approaches (Langone et al. 2021). Therefore, the water transmission of COVID-19 is quite clear.

Lack of knowledge or adaptation of the standard cleaning and disinfection procedures along with removal or killing or inactivation of microbiota in wastewater could be the contributing factors (Kitajima et al. 2020; Romano-Bertrand et al. 2020). The source usually belongs to excreta, urine and mucous during sneezing of infected patients, wastewaters from COVID-19 hospitals, sewage sludge, etc. The mechanism of faecal-oral, faecal-fomite or faecal-aerosol/droplet transmission of SARS-CoV-2 is now accepted (Sun and Han 2021; Amirian 2020; Xiong et al. 2020). It is because similar observations were also noticed in the case of SARS-CoV-1 in China during 2003 (Wang et al. 2005; McKinney et al. 2006).
2006). Therefore, in future, COVID-19 may also be accepted as waterborne disease if the current strains or any of its mutant forms will fulfil all the criteria to infect people (Dai et al. 2021). It is because only detection of virus via water bodies may not be sufficient to declare it as waterborne communicable disease.

In India, the wastewater surveillance also indicated SARS-CoV-2 contamination, and therefore, different models were put forth to combat the disease (Sivakumar 2020; Saadat et al. 2020). Major portion of Indian population resides in rural area, and most of them have minimum idea about the health hygienic issues especially drinking water hygiene, and therefore they contract many diseases (Viswanathan and Kumar 2019). Several religious belief and actions (such as Kumbha festival allowed 3.5 million people at Uttar Pradesh during the 2nd wave of pandemic and no one was found with mask and no one was found to follow COVID-19 guideline in the festival, Khare 2021) also manifest such activities (Vortmann et al. 2015). Water bodies of many rivers that are strongly correlated with religious belief such as the human rebirth after consumption of raw water of Ganga and Yamuna rivers are bright examples in the country (Rani et al. 2014). Scientifically, such water bodies home for many infectious microbes and infection have been detected after consuming Ganga water directly with religious mood (Vortmann et al. 2015). Dead human bodies are flown in Ganga River with belief to get rebirth or for booking place in heaven after death. Recently, under the high peak of COVID-19, dead bodies within polythene kit have been detected in Ganga River although the government did not identify about the source and cause of the deaths (under COVID-19?) under any infected disease (Pandey 2021). Under such conditions, the easy environmental transmission of COVID-19 cannot be ruled out in India.

Fig. 7 Severity of COVID-19 under industrial and vehicular activities. Under the high industrial and vehicular traffics, air pollutants such as NO$_2$, NOX, PM$_{2.5}$, SO$_2$, and CO can decrease the immunity and increase the chance of infection and/or severity of COVID-19. Mainly, the virus can increase the lung fibrosis decreasing the chance of survivability of the patients. The relation that exists among air pollutants, ACE2 expression and reduction of immunity can increase the lung fibrosis that positively correlated with mortality rate in COVID-19 (Adapted after Paital and Agrawal, 2021). Lifting of lockdowns and high industrial and vehicular activities to make up the loss incurred during the first wave of COVID-19 could be the deciding factor. So, environmental policy to check pollution especially air pollution is suggested.
Environmental issues exist worldwide including India. Different environmental troubles observed in the air (historical CO$_2$, NO$_x$ and NOx, SO$_x$PM2.5, PM10 emissions, e-waste generation, carbon emissions from fossil fuel and cement, exposure to household solid fuel pollution, deaths from air pollution), water (oil spills worldwide, oil tanker disasters, the lowest access to drinking water, arsenic contamination in drinking water, water contamination with micro plastic and plastic derivatives, waste accumulation) and soil (municipal solid waste, e-waste generation and disposal, generation of plastic, dump sites management) can have obvious impacts on COVID-19 (McKinney et al. 2006; Tiseo 2021; Langone et al. 2021; Rimoldi et al. 2020; Kitajima et al. 2020; Romano-Bertrand et al. 2020). India has already been criticised for not obeying the scientific advices to control COVID-19 (Bhuyan 2021). Such troubles are evident in India, as examples are well documented in its metro cities such as New Delhi and Mumbai. Therefore, establishment of stricter national environmental policies and their execution in general and in her metro cities in particular is suggested.

**Soil contamination with SARS-CoV-2**

As per the data of UNICEF, open defecation is still an issue although India has declared on 2nd October 2012 that all the villages in the 36 States and Union Territories are open defecation free (The Hindu 2021; UNICEF 2021). Open defecation practice is also followed in the case of township area by many uneducated people in India and in many other countries that could lead to the contamination in the total environment especially soil in the area (Sun and Han 2020). Therefore, the faecal matter, urine and other waste like mucous during sneezing from the infected patients could reach the soil and the virus can find a suitable micro or macro host to remain in the soil. Although such studies are not done but infection from waste of patients cannot be
ruled out as the faecal matter and urine of the patients are found to carry the active viral RNA in them (Heller et al. 2020).

**Current and future pandemics under environmental ignorance**

Although the environmental transmission of SARS-CoV-2 was debatable initially, the wastewater surveillance has proved the fact in late 2020 and the concept must be accepted (Dai et al. 2021). Early detection of SARS-CoV-2 in solid waste, water and atmosphere has been noticed, and the role of the total environment, i.e. air, water and soil, has been studied, and the attribution of such environmental factors to the transmission of the virus has been accepted (Fig. 8, Heller et al. 2020). Mode of transmission via the environment and the risk of contracting the disease have been linked to the quality on viral infectivity and viral load. The model of faecal-oral or bio-aerosols although advocated it lacks robust evidence, but the possibility is never denied (Huraimel Al et al. 2020). Rather it is strongly advocated that the main three primary
routes of transmission of the virus from faecal matters may be via water, to surfaces or to places occupied with insect vectors. Therefore, ignoring the environmental pollution may lead to a devastating state by the present or any future SARS-CoV-2 strain or its mutants or by similar and/or more potent viruses (Paital and Agrawal 2020; Dai et al. 2021).

The environmental changes have always acted as biggest power to mutate the genome of organisms including human beings (Zamai 2020). The genome of microbes has always shown its susceptibility to quick mutation under the climatic changes especially under pollution (Zhang et al. 2019). Studies from the last 2 decades have shown that heavy air pollution also triggers many molecular mechanisms including methylation, and gene editing responsible to mutate many genomes and water pollution (having molecular active pollutants including carcinogens and pathogens) has also imposes similar effects (Vineis and Husgafvel-Pursiainen 2005; Somers and Cooper 2009; Zanobetti et al. 2011; Santibáñez-Andrade et al. 2017; Rider and Carlsten 2019; Gruzieva et al. 2019). Pollution also affects several biochemical and molecular pathways ranging from mitochondrial energetics to modulating mitochondrial DNA pattern (Breton et al. 2019).

Internationally, almost all countries had lifted lockdowns and allowed international movements by the end of 2020. It allowed the virus SARS-CoV-2 to travel across each corner of the world via infected people where it gets exposed to many harsh environmental conditions including pollution. This is the reason why at least six strains of the SARS-CoV-2 had been observed by the end of August 2020. Many of them are with new pathogenic characteristics and high severity of infection that resulted into high mortality rates (Università di Bologna 2021). Single-nucleotide variants in the SARS-CoV-2 spike receptor-binding domain protein were predicted to be responsible to emerge the virus for its dominant lineage harbouring the S477N receptor-binding domain mutation as seen in Australia in 2020 (Chen et al. 2021b). It has been warned that the single-nucleotide polymorphism could allow at least 143 variants of the virus which could make difficulties to tackle them all with the current treatment schedule (Giovanetti et al. 2021). So, spike in pollution could impose the spike in mutation in SARS-CoV-2 that could result in their high virulent capacity (Ufnalska and Lichtfouse 2021).
Following the pattern of evolution of the virus, countries such as India and those struggling with the hard hit of the 2nd wave of the virus have already predicted for its 3rd wave (Zheng et al. 2021). And, the potential for the severity was announced to be many folds as compared to its first two waves (Sharma 2021). If such climatic issues persist, it has been predicted that around 1 million organisms will be extinct in the next decade and it also can lead to activate about 1.7 million viruses which are enough potent to establish many such pandemics (IPBES 2021). And, it is possible that the human race can be one of the extant species in coming years (IPBES 2021). Hence, keeping environments free from pollution must be done under the present and future climatic changes. It will allow survivability of human beings and other organisms on the earth.

There are several approaches discussed elsewhere to avoid air (Leutert 1986; Hilpert et al. 2019; Bhargava 2021; EPA 2021) and water pollution especially for the treatment of wastewater to get rid of the virus (Wu et al. 2021). Many conventional non-expensive and techno-mediated measures are available to clean water and air (Jackson and Lines 1972; Iriti et al. 2020). Different adsorption (Peterson et al. 2016), chemical (Zhao et al. 2016), biological (Zhang et al. 2015) and physical technologies for the removal of NO₂, SO₂, NOx and similar toxic gases can be employed at the emission sectors (Iriti et al. 2020, Fig. 9). A clean environment can prevent many diseases and disorders and balance the ecosystems as it was observed during the 1st wave of COVID-19 (Geary et al. 2020, Table 2). Statistical analysis has revealed the fact that a strong positive correlation between air pollution and COVID-19 infection, severity and morbidity exists in Italy, the USA, the Philippines, Denmark, Chile, Brazil, Mexico, India, China, Peru and in many other countries. For example, in the USA, 15% more morbidity in COVID-19 has occurred in areas dominated with fine-particle pollution. Similarly, a significant 12 and 4.5% higher death rate was observed in COVID-19 infection in Lombardy and Emilia Romagna regions of northern Italy that experience more air pollution. Therefore, environmental action and execution in interdisciplinary mode are required from the policy-makers and environmentalists to prevent a big loss to the earth ecosystems in the name of industrialization and modernization (Das and Paital 2021).

**Conclusion**

The approaches must be interdisciplinary taking the views of all sections of people to tackle the pandemics. Then expert’s analysis must be done to adapt regional, national or international specific rules to revive the nature in order to survive from the current and any such future pandemics (Fig. 10). The spike in environmental pollution could be more dangerous in the near future. Increasing industrial activities for human comfort is good but extremely bad when it is done at the cost of polluting nature. No one knows if nature will engineer more potent virus than SARS-CoV-2 to protect herself and to protect every ecosystem and their inhabitants at the cost of human race. Nature never allows a single dominant species in the earth as seen in the case of the dinosaurs and many others in the past. Therefore, national and international policymakers need to work in collaboration with the environmentalists to formulate and implement stricter environmental rules avoiding the scientific myth in the name of modernisation for human comfort. Otherwise, the spike of the environmental pollution could be more dangerous than the spike protein of the SARS-CoV-2 for which the ongoing outbreak of the COVID-19 is persisting. Spike in environmental troubles could welcome more dangerous pandemics than COVID-19 in the future, or it can also make the current pandemic more furious in its future waves that are clear from the current condition observed in Indian and many other counties where pollution is predominated.

**Acknowledgements** Generous help rendered by the Falguni Panda, Samir G. Pati and Shahikant Dash is highly acknowledged. Central Instrumentation Facility of OUAT to use ICP-OES is also acknowledged.

**Availability of data and materials** All data generated or analysed during this study are included in this published article [and its supplementary information files].

**Author contribution** BRP designed the review outline, collected and analysed data, did statistics, interpreted the data regarding the environmental parameters and wrote the MS. KD had conceptual contribution for the study, has analysed the data, writes the MS and proofreads the MS.

**Funding** Scheme number ECR/2016/001984 by SERB, DST, Govt. of India and 1188/ST, Bhubaneswar, dated 01.03.17, ST-(Bio)-02/2017 and DST, Govt. of Odisha, India, to BRP are acknowledged. Scheme number 36 Seed/2019/Philosophy-1, letter number 941/69/OSHEC/2019, dt 22.11.19 by Department of Higher Education, Govt. of Odisha, IN to KD is acknowledged.

**Declarations**

**Ethical approval** Not applicable.

**Consent to participate** Not applicable.

**Consent to publish** Not applicable.

**Competing interests** The authors declare no competing interests.

**References**

Ahmed W, Angel N, Edson J, Bibby K, Bivina A, O’Brien JW, Choi PM, Kitajima M, Simpson SL, Li J, Tscharke B, Verhagen R, Smith WJM, Zaugg J, Dierens L, Hugenholz P, Thomas KV, Mueller JF (2020) First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: a proof of concept for the wastewater surveillance of COVID-19 in the community. Sci Total Environ 728: 138764. https://doi.org/10.1016/j.scitotenv.2020.138764
Amriani ES (2020) Potential fecal transmission of SARS-CoV-2: current evidence and implications for public health. Int J Infect Dis 95:363–370. https://doi.org/10.1016/j.ijid.2020.04.057

AQICN (2021) World air pollution statistics top 10 best and worst air quality in World. https://aqicn.org/statistics/. Accessed 02.05.2021

Bhargava R (2021) Environmental pollution: environmental pollution: sources, causes Sources, causes, effect and effect and control. https://www.iitr.ac.in/wf/web_ua_water_for_welfare/education/proceeding_of_short-term_training/diploma/Environmental_Sciences_May_24-28_2007/Lecture_notes_ENV_Pollution-rb.pdf. Accessed 13.05.2021

Bhuyan A (2021) Experts criticise India’s complacency over COVID-19. Lancet 397(10285):1611–1612. https://doi.org/10.1016/S0140-6736(21)00983-4

Bing (2021) COVID-19 Tracker, New Delhi. https://www.bing.com/covid/local/delhi_india?vert=graph. Accessed on 02.05.2021

Breton CV, Song AY, Xiao J, Kim SJ, Mehta HH, Wan J, Yen K, Sioutas C, Lummann F, Xue S, Morgan TE, Zhang J, Cohen P (2019) Effects of air pollution on mitochondrial function, mitochondrial DNA methylation, and mitochondrial peptide expression. Mitochondrion 46:22–29. https://doi.org/10.1016/j.mito.2019.04.001

Chen B, Jia P, Han J (2021b) Role of indoor aerosols for COVID-19 viral transmission: a review. Environ ChemLett 19:1953–1970. https://doi.org/10.1007/s10311-020-01174-8

Cho H, Jung YH, Cho HB, Kim HT, Kim KS (2020) Positive control investigation of SARS-CoV-2 virus in environmental surface. Environ Res 196:110948. https://doi.org/10.1016/j.envres.2021.110948

Das K, Paital B (2020) First week of social lockdown versus medical care against COVID-19 - with Special Reference to India.Curr Trend Biotechnol Pharmacol 14(2):196–216. https://doi.org/10.5530/cbtp.2020.2.20

Das K, Paital B (2021) Future call for policy making to speed up interdisciplinary between natural and social sciences and humanities in countries such as India. Heliyon. 7(3):e06484. https://doi.org/10.1016/heliyon.2021.e06484

Das K, Pingali MS, Paital B, Panda F, Pati SG, Singh A, Varadwaj PK, Samanta SK (2021) A detailed review of the outbreak of COVID-19. Font BioSci Landmark 6:149–170. https://doi.org/10.52586/4931

Di-Cerbo A (2020) Air pollution and SARS-CoV-2 in the Po Valley: possible environmental persistence? Minerva Med. https://doi.org/10.23736/S0026-4806.20.06586-6

Editorial (2021) India, Brazil and the human cost of side-lining science. Nature 593(7857):7–8. https://doi.org/10.1038/d41586-021-01166-w

EPA (2021) Greenhouse Gas Emissions. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data. Accessed on 13.05.2021

Geary WL, Bode M, Doherty TS, Fulton EA, Nimmo DG, Tulloch AIT, Tulloch VJD, Ritchie EG (2020) A guide to ecosystem models and their environmental applications. Nat Ecol Evol 4(11):1459–1471. https://doi.org/10.1038/s41550-020-01298-8

Giovanetti M, Benedetti F, Campisi G, Cicozzi A, Fabris S, Cecarelli G, Tambone V, Caruso A, Angelletti S, Zella D, Cicozzi M (2021) Evolution patterns of SARS-CoV-2: Snapshot on its genome variants. Biochem Biophys Res Commun 538:88–91. https://doi.org/10.1016/j.bbrc.2020.10.102

Guzziou O, Xu CI, Yousef P, Relton C, Merid SK, Breton CV, Gao L, Volk HE, Feinberg JI, Ladd-Acosta C, Bakulski K, Auffray C, Lemonnier N, Plusquin M, Ghantous A, Herceg Z, Nawrot TS, Pizzi C, Richardi L, Rusconi F, Vineis P, Kogevinas M, Felix JF, Duijs J, den Dekker HT, Jaddoe VWV, Ruiz JL, Bustamante M, Antó JM, Sunyer J, Vrijheid M, Gutzkow KB, Grazulieviciene R, Hernandez-Ferrer C, Annesi-Maesano I, Lepeule J, Boussqet J, Bergström A, Kull I, Söderhäll C, Kere J, Gehring U, Brunekreef B, Just AC, Wright RJ, Peng C, Gold DR, Kloog I, DeMeo DL, Pershagen G, Koppelman GH, London SJ, Baccarelli AA, Melén E (2019) Prenatal particulate air pollution and DNA methylation in newborns: an epigenome-wide meta-analysis. Environ Health Perspect 127(5):57012. https://doi.org/10.1289/EHP5422

Hadlington S (2021) Air pollution model predicts 6.6 million deaths by 2050. https://www.chemistryworld.com/news/air-pollution-model-predicts-66-million-deaths-by-2050–8956.article. Accessed 13.05.2021

He S, Han J (2021) Electrostatic fine particles emitted from laser printers as potential vectors for airborne transmission of COVID-19. Environ Chem Lett 19:17–24. https://doi.org/10.1007/s10311-020-01069-8

He S, Han J, Lichtfouse E (2021) Backward transmission of COVID-19 from humans to animals may propagate reinfections and induce vaccine failure. Environ Chem Lett 19:763–768. https://doi.org/10.1007/s10311-020-01140-4

Heller L, Mota CR, Greco DB (2020) COVID-19 faecal-oral transmission: are we asking the right questions? Sci Total Environ 729:138919. https://doi.org/10.1016/j.scitotenv.2020.138919

Hilpert M, Johnson M, Kimourotzoglou MA, Domingo-Relloso A, Peters A, Adria-Mora B, Hernández D, Ross J, Chillrud SN (2019) A new approach for inferring traffic-related air pollution: use of radar-calibrated crowd-sourced traffic data. Environ Int 127:138–159. https://doi.org/10.1016/j.envint.2019.03.026

Huraimel Al K, Alhosani M, Kunhabdulla S, Stietiya MH (2020) SARS-CoV-2 in the environment: modes of transmission, early detection and potential role of pollutions. Sci Total Environ 744:140946. https://doi.org/10.1016/j.scitotenv.2020.138919

IPBES (2021) IPBES-8 Plenary on 14 th June 2021. https://www.ipbes.net/event/ipbes-8-plenary. Accessed 15.05.2021

Iriti M, Piscitelli P, Missoni E, Miani A (2020) Air pollution and health: discipline between natural and social sciences and humanities in countries such as Italy. Heliyon. 6(3):e04158. https://doi.org/10.1038/d41586-021-01166-w

Jackson CJ, Lines GT (1997) Measures against water pollution in the fermentation industries. Pure Appl Chem 29(1):381–393. https://doi.org/10.1351/pac197229010381
Karami C, Normohamadmi A, Dargahi A, Vosoughi M, Zandian H, Jeddi F, Mokhtari SA, Moradi-Asl E (2021) Investigation of SARS-CoV-2 virus on nozzle surfaces of fuel supply stations in North West of Iran. Sci Total Environ 780:146641. https://doi.org/10.1016/j.scitotenv.2021.146641

Khan AH, Tirth V, Fawzy M, Mahmoud AED, Khan NA, Ahmed S, Ali SS, Akram M, Hameed L, Islam S, Das G, Roy S, Dehghani MH (2021) COVID-19 transmission, vulnerability, persistence and nanotherapy: a review. Environ Chem Lett 19:2773–2787. https://doi.org/10.1007/s10311-021-01229-4

Khare V (2021) India’s Kumbh festival attracts big crowds amid devastating second Covid wave. https://www.bbc.com/news/world/asia-56770460. Accessed 21.05.2021

Kitajima M, Ahmed W, Bibby K, Carducci A, Gerba CP, Hamilton KA, Haramoto E, Rose JB (2020) SARS-CoV-2 in wastewater: state of the knowledge and research needs. Sci Total Environ 739:139076. https://doi.org/10.1016/j.scitotenv.2020.139076

La Rosa G, Iaconelli M, Mancini P, Bonanno Ferraro G, Veneri C, Sabia G (2021) Urban environments and COVID-19 in three Eastern states of the United States. Sci Total Environ 779:146334. https://doi.org/10.1016/j.scitotenv.2021.146334

Leutert G (1986) Massnahmenengegen die Luftverschmutzung [Measures against air pollution]. Soz Praventivmed German 31(1):23–26. https://doi.org/10.1007/BF02103741

Li W, Xu L, Liu X, Zhang J, Lin Y, Yao X, Gao H, Zhang D, Chen J, Wang W, Harrison RM, Zhang X, Shao L, Fu P, Nenes A, Shi Z (2017) Air pollution-aerosol interactions produce more bioavailable iron for ocean ecosystems. Sci Adv 3(3):e1601749. https://doi.org/10.1126/sciadv.1601749

Li T, Hu R, Chen Z, Li Q, Huang S, Zhu Z, Zhou LF (2018) Fine particulate matter (PM2.5): the culprit for chronic lung diseases in China. Chronic Dis Transl Med 4(3):176–186. https://doi.org/10.1016/j.cdtm.2018.07.002

Li M, Wang X, Lu C, Li R, Zhang J, Dong S, Yang L, Xue L, Chen J, Wang W (2020) Nitrated phenols and the phenolic precursors in the atmosphere in urban Jinan, China. Sci Total Environ 714:136760. https://doi.org/10.1016/j.scitotenv.2020.136760

Mahato S, Pal S, Ghosh KG (2020) Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Sci Total Environ 730:139086. https://doi.org/10.1016/j.scitotenv.2020.139086

Maji KJ, Namdeo A, Bell M, Goodman P, Nagendra SMS, Barnes JH, De Vito L, Hayes E, Longhurst JW, Kumar R, Sharma N, Kuppili SK, Alshetty D (2021) Unprecedented reduction in air pollution and corresponding short-term premature mortality associated with COVID-19 lockdown in Delhi, India. J Air Waste Manag Assoc 1–17. https://doi.org/10.1080/10962247.2021.1905104

Maragakis L (2021) Coronavirus second wave? Why cases increase. https://www.hopkinsmedicine.org/health/conditions-and-diseases/coronavirus/first-and-second-waves-of-coronavirus. Accessed 10.05.2021

Martelletti L, Martelletti P (2020) Air pollution and the novel covid-19 disease: a putative disease risk factor. SN ComprClin Med 15:1–5. https://doi.org/10.1007/s42399-020-00274-4

McKinney K, Gong Y, Lewis TG (2006) Environmental transmission of SARS at amoy gardens. J Environ Health 68:26–30

Medema G, Heijnen L, Italianer R, Brouwer A (2020) Presence of SARS-coronavirus - 2 RNA in sewage and correlation with reported COVID-19 prevalence in the early stage of the epidemic in The Netherlands. Environ Sci Technol Lett Acs Estlet 7:511–516. https://doi.org/10.1021/acs.estlett.0c00357

Mousazadeh M, Paital B, Naghdali Z, Mortezania Z, Hashemi M, KaramatiNiragh E, Aghababaei M, Ghorbankhani M, Lichtfouse E, Sillanpää M, Hashim KS, Emamjomeh MM (2021) Positive environmental effects of the coronavirus 2020 episode: a review. Environ Dev Sustain 23:1–23. https://doi.org/10.1007/s10668-021-01240-3

NAQI (2021) National air quality index in Delhi. https://app.cpcbccr.com/AQI_India/. Accessed 02.05.2021

Ogen Y (2020) Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci Total Environ 726:138605. https://doi.org/10.1016/j.scitotenv.2020.138605

Paital B (2020) Nurture to nature via COVID-19, a self-regenerating environmental strategy of environment in global context. Sci Total Environ 729:139088. https://doi.org/10.1016/j.scitotenv.2020.139088

Paital B, Agrawal PK (2020) Air pollution by NO2 and PM2.5 explains COVID-19 infection severity by overexpression of angiotensin-converting enzyme 2 in respiratory cells: a review. Environ Chem Lett 1–18. https://doi.org/10.1007/s10311-020-01091-w

Paital B, Das K, Parida KS (2020a) Inter nation social lockdown versus medical care against COVID 19, a mild environmental insight with special reference to India. Sci Total Environ 728:138914. https://doi. org/10.1016/j.scitotenv.2020.138914

Paital B, Das K, Behera TR (2020b) Social lockdown and ecological intervention for the prevention of the community spread of COVID-19. Cancer Res Stat Treat 3(3):667–669. https://doi.org/10.4103/CRST.CRST_222_20

Pandey A (2021) Bodies found buried in sand on banks of Ganga in Uttar Pradesh’s Unnao. https://www.ndtv.com/india-news/bodies-found-buried-in-sand-by-ganga-river-in-uttar-pradeshs-unnao-2440517. Accessed 13.05.2021

Paraskevis D, Kostagi E, Alygizakis N, Thomaidis NS, Cartalis C, Tsiodras S, Dimopoulos MA (2021) A review of the impact of weather and climate variables to COVID-19: In the absence of public health measures high temperatures cannot probably mitigate outbreaks. Sci Total Environ 768:144578. https://doi.org/10.1016/j.scitotenv.2020.144578

Peterson GW, Mahle JJ, DeCoste JB, Gordon WW, Rossin JA (2016) Extraordinary NO2 Removal by the Metal-Organic Framework UIO-66-NH2 AngewChemInt. Ed Engl 55(21):6235–6238. https://doi.org/10.1002/anie.201601782

Piva A, Amoruso I, Formenton G, Di Maria F, Bonato T, Vanin S, Marion A, Baldwin T (2021) Evaluating the presence of SARS-CoV-2 RNA in the particulate matters during the peak of COVID-19 in Padua, northern Italy. Sci Total Environ 784:147129. https://doi.org/10.1016/j.scitotenv.2021.147129

Randazzo W, Truchado P, Cuevas-Ferrando E, Simón P, Allende A, Sánchez G (2020) SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area. Water Res 181:115942. https://doi.org/10.1016/j.watres.2020.115942

Rani N, Vajpayee P, Bhatti S, Singh S, Shanker R, Gupta KC (2014) Quantification of Salmonella Typhi in water and sediments by molecular-beacon based qPCR. Ecotoxicol Environ Saf 108:58–64. https://doi.org/10.1016/j.ecoenv.2014.06.033

Rider CF, Carlsten C (2019) Air pollution and DNA methylation: effects of exposure in humans. Clin Epigenetics 11(1):131. https://doi.org/10.1186/s13148-019-0713-2

Rimoldi SG, Stefan F, Gigantiello A, Polesello S, Comandatore F, Mileo D, Maresca M, Longobardi C, Mancon A, Romeri F, Pagani C, Cappelli F, Roscioli C, Moja L, Gismondo MR, Salerno F (2020) Presence and infectivity of SARS-CoV-2 virus in wastewater and rivers. Sci Total Environ 744:140911. https://doi.org/10.1016/j.scitotenv.2020.140911
Róka E, Khayer B, Kis Z, Kovács LB, Schuler E, Magyar N, Málnási T, Oravecz O, Pályi B, Pándics T, Vargha M (2021) Ahead of the second wave: early warning for COVID-19 by wastewater surveillance in Hungary. Sci Total Environ 786:147398. https://doi.org/10.1016/j.scitotenv.2021.147398

Romano-Bertrand S, AhoGilele LS, Grandbastien B, Lepelletier D (2020) French society for hospital hygiene. Preventing SARS-CoV-2 transmission in rehabilitation pools and therapeutic water environments. J Hosp Infect 105(4):625–627. https://doi.org/10.1016/j.jhin.2020.06.003

Roviello V, Roviello GN (2021) Lower COVID-19 mortality in Italian forested areas suggests immunoprotection by Mediterranean plants. Environ Chem Lett 19:699–710. https://doi.org/10.1007/s10311-020-01063-0

Saadat S, Rawhani D, Hussain CM (2020) Environmental perspective of COVID-19. Sci Total Environ 728:138870. https://doi.org/10.1016/j.scitotenv.2020.138870

Santibañez-Andrade M, Quezada-Maldonado EM, Osornio-Vargas Á, Sánchez-Pérez Y, Garcia-Cuellar CM (2017) Air pollution and geometric instability: the role of particulate matter in lung carcinogenesis. Environ Pollut 229:412–422. https://doi.org/10.1016/j.envpol.2017.06.019

Sarailoo M, Matin S, Vossoughi M, Dargahi A, Gholizadeh H, Damavandi MR, Abbasi-Ghahramanloo A, Kamran A (2021) Investigating the relationship between occupation and SARS-CoV-2. Work 68(1):27–32. https://doi.org/10.3233/WOR-205066

Sarkodie SA, Owusu PA (2021) Global effect of city-to-city air pollution, health conditions, climatic & socio-economic factors on COVID-19 pandemic. Sci Total Environ 778:146394. https://doi.org/10.1016/j.scitotenv.2021.146394

Sharma M (2021) When is a third wave of COVID-19 likely to hit India? Experts dissect possible factors. https://www.indiatoday.in/epidemic-coronavirus-outbreak/story/india-third-wave-of-covid-19-vaccine-prevention-1799504-2021-05-06. Accessed 13.05.2021

Sharma AK, Balyan P (2020) Air pollution and COVID-19: is the connection in our weight? Indian J Public Health 64(Supplement):S132–S134. https://doi.org/10.4103/ijph.IJPHEP_466_20

Singh S, Kumar V, Kapoor D, Dhanjal DS, Bhatia D, Jan S, Singh N, Romero R, Ramamurthy PC, Singh J (2021) Detection and disinfection of COVID-19 virus in wastewater. Environ Chem Lett 19:1917–1933. https://doi.org/10.1007/s10311-020-01212-1

Sivakumar B (2020) COVID-19 and water. Stoch Env Res Risk A 35:1–4. https://doi.org/10.1007/s00439-020-01837-6

Somers CM, Cooper DN (2009) Air pollution and mutations in the germline: are humans at risk? Hum Genet 125(2):119–130. https://doi.org/10.1007/s00439-008-0613-6

Sun S, Han J (2020) Open defecation and squat toilets, an overlooked risk of fecal transmission of COVID-19 and other pathogens in developing communities. Environ Chem Lett 19–2. https://doi.org/10.1007/s10311-020-01143-1

Sun S, Han J (2021) Unflushable or missing toilet paper, the dilemma for developing communities during the COVID-19 episode. Environ Chem Lett 19:711–717. https://doi.org/10.1007/s10311-020-01064-z

Tayech A, Mejri MA, Makhlouf I, Mathlouthi A, Behm DG, Chaouachi A (2020) Second wave of COVID-19 global pandemic and athletes’ confinement: recommendations to better manage and optimize the modified lifestyle. Int J Environ Res Public Health 17(22):8385. https://doi.org/10.3390/ijerph17228385

The Hindu (2021) Is rural India 100% open defecation-free like Swachh Bharat data concludes? https://www.thehindu.com/data/data-match-is-rural-india-100-open-defecation-free-like-swachh-bharat-data-concludes/article30460909.ece. Accessed 21.05.2021

The World Bank (2021) Nitrous oxide emissions (thousand metric tons of CO2 equivalent). https://data.worldbank.org/indicator/EN.ATM.NOXE.KT.CE?end=2012&start=1970&view=chart. Accessed 13.05.2021
Xiao F, Tang M, Zheng X, Liu Y, Li X, Shan H (2020) Evidence for gastrointestinal infection of SARS-CoV-2. Gastroenterology 158(6):1831–1833.e3. https://doi.org/10.1053/j.gastro.2020.02.055

Zamai L (2020) Unveiling human non-random genome editing mechanisms activated in response to chronic environmental changes: I. Where might these mechanisms come from and what might they have led to? Cells 9(11):2362. https://doi.org/10.3390/cells9112362

Zandian H, Sarailoo M, Dargahi S, Gholizadeh H, Dargahi A, Vosoughi M (2021) Evaluation of knowledge and health behavior of University of Medical Sciences students about the prevention of COVID-19. Work 68(3):543–549. https://doi.org/10.3233/WOR-203395

Zanobetti A, Baccarelli A, Schwartz J (2011) Gene-air pollution interaction and cardiovascular disease: a review. Prog Cardiovasc Dis 53(5):344–352. https://doi.org/10.1016/j.pcad.2011.01.001

Zhang J, Li L, Liu J (2015) Thermophilic biofilter for SO2 removal: performance and microbial characteristics. Bioresour Technol 180:106–111. https://doi.org/10.1016/j.biortech.2014.12.074

Zhang T, Shi XC, Xia Y, Mai L, Tremblay PL (2019) Escherichia coli adaptation and response to exposure to heavy atmospheric pollution. Sci Rep 9(1):10879. https://doi.org/10.1038/s41598-019-47427-7

Zhao Y, Hao R, Yuan B, Jiang J (2016) Simultaneous removal of SO2, NO and Hg through an integrative process utilizing a cost-effective complex oxidant. J Hazard Mater 301:74–83. https://doi.org/10.1016/j.jhazmat.2015.08.049

Zheng S, Fu Y, Sun Y et al (2021) High resolution mapping of nighttime light and air pollutants during the COVID-19 lockdown in Wuhan. Environ Chem Lett. https://doi.org/10.1007/s10311-021-01222-x

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.