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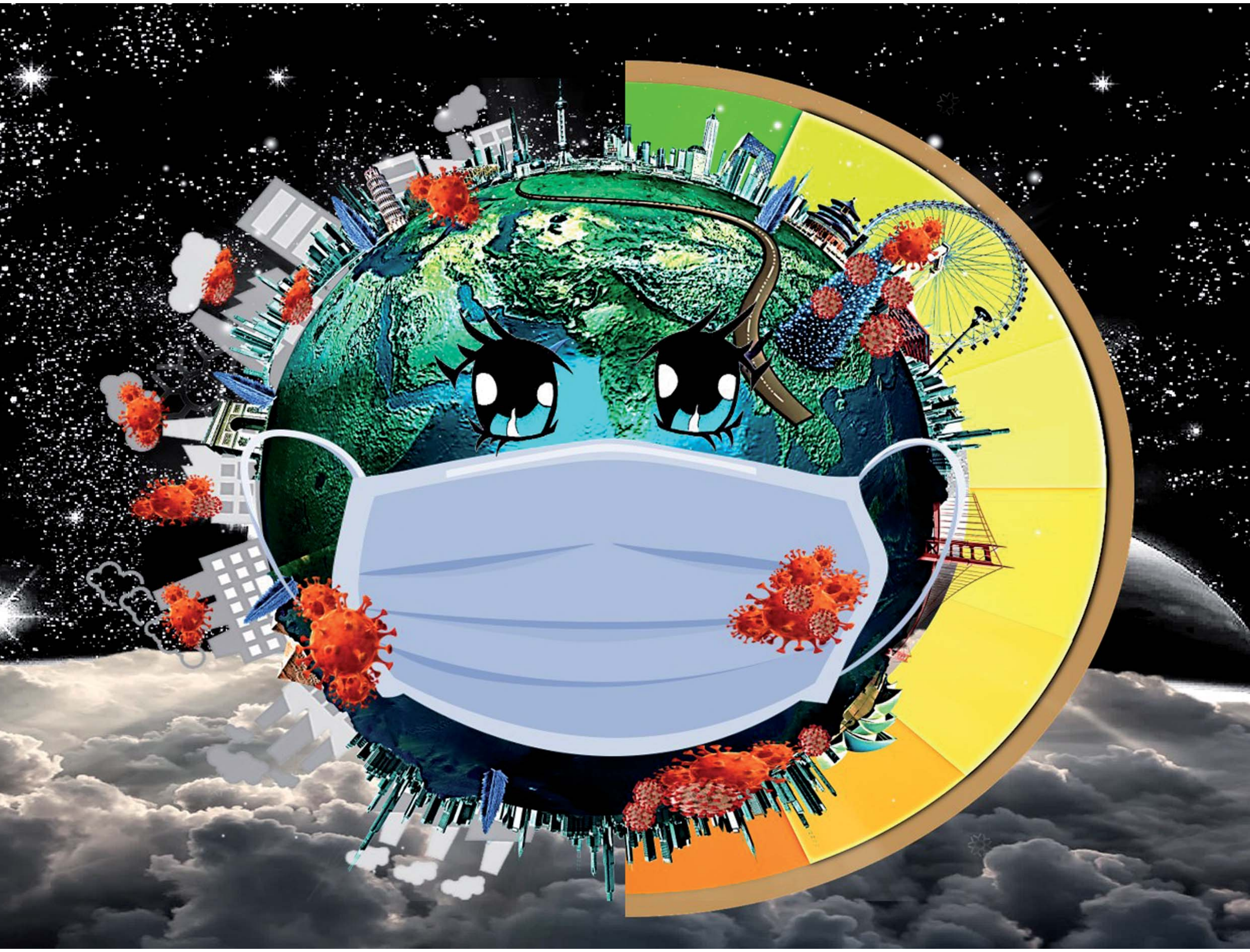

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Influence of the SARS-CoV-2 pandemic: a review from the climate change perspective

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Ever since the global outbreak of Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2/COVID-19) in the early part of 2020, there is no doubt that the SARS-CoV-2 pandemic has placed great tension globally and has affected almost all aspects of human endeavors. There are presently several research studies on the atmospheric environmental and economic effects of this dreaded virus. Supposedly, the responses ought to have also present innovations that would advance scientific research to mitigate its impacts since most of the ensuing consequences impact the atmospheric climatic conditions. Even when it appears that economic events would possibly return in no time, the circumstances will change. Specifically, from the existing literature, it appears that not much has been done to study the influence of the SARS-CoV-2 pandemic on climate change. Hence, this present review article will explore the possible connection between the SARS-CoV-2 pandemic and climate change. The utilization of various scientific domains for climate change studies during the SARS-CoV-2 pandemic and exploring the positive influences of the SARS-CoV-2 pandemic and measures to avoid the negative impacts on climate change owing to SARS-CoV-2 have also been discussed.

Environmental significance

This perspective article highlights some possible relationships between climate change/environmental issues and the SARS-CoV-2/COVID-19 pandemic and *vice versa*. This work is of direct significance to the environment owing to the current situation of SARS-CoV-2/COVID-19, as SARS-CoV-2 has both positive and negative effects on the environment, which is initially dealt with in this work. Further, the public health perspective of climate change due to the SARS-CoV-2 pandemic and the utilization of scientific domains for climate change studies during the SARS-CoV-2 pandemic, namely, nanotechnology, materials science, public health, biotechnology, and environmental engineering, is also discussed. Furthermore, this work also discusses measures to avoid a negative impact on the climate due to SARS-CoV-2. Moreover, it will possibly recommend innovations that would advance future scientific research suggestions to mitigate the impact of the SARS-CoV-2 pandemic *vis-à-vis* climate change.

1. Introduction

Severe Acute Respiratory Syndrome Coronavirus-2 [SARS-CoV-2/COVID-19 (coronavirus disease, 2019)] is a type of infectious disease, majorly caused by the SARS-CoV-2 virus; it was first recognized in Wuhan, China at the end of December 2019 but was declared a pandemic by the World Health Organization (WHO) on March 11, 2020.[1–3] Most regions of the world were seriously hit by the epidemic that followed as the medical facilities (hospitals and emergency health services) became overloaded with numerous patients in key healthcare centers.[4–7] Several regions of the world, especially the developed nations (such as the US, Italy, and France), were severely affected by the pandemic from March 2020 to about July 2020. Elective measures were taken and personal visits of patients were stopped to decrease the risk of transmitting the disease, and the utilization of personal protective equipment (PPE) was promoted majorly for health practitioners as they were in direct contact with the infected patients.[3,8,9] As initial social distancing, lockdown, and other procedures for containing the virus reduced, a gradual re-opening of most medical facilities and other sectors of the society's economy were started. Nevertheless, this was momentarily trailed by another upsurge in early June 2020 in the cases that needed back-pedaling to even more preventive measures. From all these, it became obvious that this deadly virus is with us for a lengthy haul, a marathon that we would possibly run for the upcoming months or years.[10,11] The outbreak of SARS-CoV-2 is a piercing aide-memoire that epidemics (or pandemics, as the case may be) like other infrequently occurring disasters have occurred in

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the past and would possibly continue to ensure in the future.[3,12] Even if there are no possible ways of preventing dangerous viruses from evolving, there should be appropriate measures to mitigate their impacts and/or effects on humanity. One of the successful methods that helped to stop the spread of the virus was the worldwide lockdown, where all international and domestic transportation was restricted, and people were forced to stay inside their homes. Only the basic requirements were available, such as groceries, hospitals, and health centers. This worldwide lockdown gave a refreshed start to the environment as low carbon footprint was generated; less fossil fuel was burnt, which helped reduce pollution from the environment and helped reform the depleted ozone layer. The present occurrence of SARS-CoV-2 has also caused serious economic and societal impact globally, resulting in a change of regular activities such as agricultural, climatic, and industrial. Hence, these critical issues now require global effort in addressing some of the pandemic-associated issues affecting humanity[1] as SARS-CoV-2 has affected the world in two different ways: emissions of greenhouse gasses (GHGs), energy, climate and quality of air, as well as globalization, poverty, food, and biodiversity, as illustrated in Fig. 1; these impacts are said to be widespread and long-lasting.[13] Further, the "Intergovernmental Panel on Climate Change (IPCC)" reports suggest that the climate change is considered as modifications in climatic progressions that are particularly credited directly or indirectly to the activities of creatures (humans to be specific), which changes the structure and configuration of global atmospheric conditions, and is in

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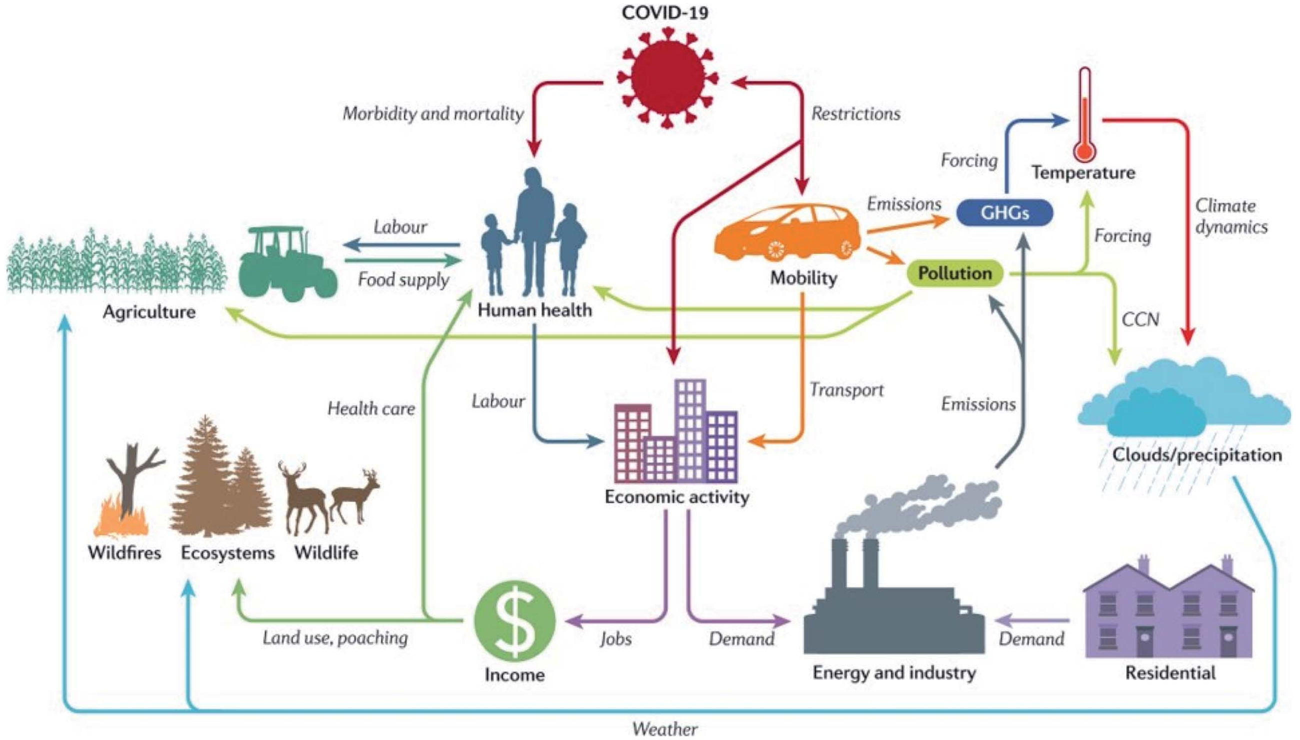

Fig. 1 A schematic illustration of two different pathways showing the capability for multi-dimensional Earth System response to SARS-CoV-2: emissions, energy, climate, and air quality; globalization, poverty, food, and biodiversity. These interactions are affected differently in different regions and on different timescales [CCN-cloud condensation nuclei; GHGs-greenhouse gases] (reprinted by permission from Springer Nature: Springer Nature; Nature Reviews Earth & Environment; The COVID-19 lockdowns: a window into the Earth System, N. S. Diffenbaugh *et al.*, 2020).[13]

addition to the natural inconsistency in the climate detected over a comparable period of time.[14,15]

At this moment, climate change has been recognized as one of the greatest stimulating issues confronting several sectors in our society.[16,17] These issues of climate change have appeared to be more severe in the agricultural domain since most of these agricultural activities or processes depend on climate-sensitive processes and *vice versa*.[17] Therefore, it has been reported that immediate development in the extent of the variability in the climatic conditions has larger consequences when compared to the longer-term variability in the average climatic values, and the appropriate prominence of adoption and adaptation is climate risk management and supervision.[18] As a result of the incessant increase in the SARS-CoV-2 pandemic globally, several regions and peoples are now adopting enthusiastic procedures in mitigating the spread of this dreaded virus. Researchers and scientists are also doing their best to find lasting solutions to its negative consequences. According to Campbell. 2020,[19] these efforts and measures, such as the encouragement of persons to adopt "social distancing", the imposition of travel restrictions, authorizing closures of learning institutions and commercial activities, and observing the procedures laid down as prescribed by the WHO for its prevention, may decrease the spread of the virus; regrettably, not all are finding protection in the ensuing seclusion.

Reportedly, several allusions have been made with respect to the time limit of the pandemic's outbreak. It is somehow difficult to estimate its continuing effects, even though several regions have been greatly affected by numerous pandemics previously. However, it is hard to evaluate the continuing behavioral, social, political, economic, or general implications because these aspects have not been given substantial attention in the past. Therefore, the studies in existence show that the foremost historic pandemics of the preceding millennium have characteristically been linked with ensuing low proceeds from resources.[20,21] Normally, there is a possible tendency to become less concerned with investing for a period after a pandemic and more concerned with redeeming the assets, leading to the reduction of economic growth.[20] As a result of the present circumstances, saving capital implies negative returns; it is somehow uncertain that it would be as convenient as it had been previously. The various human-caused events have been reported to generate substantial pressure on the decreasing natural resources and environmental services existing on the planet, combined with the incessant population, have a severe influence on the climate globally.[18,22,23] Therefore, various researchers and scientists from diverse domains of study must employ multi-disciplinary approaches that require the overall creation of suitable advanced approaches and natural practices that would assist in mitigating the various consequences such as the effects of weather variables on radio communication systems,[22–25] as well as assist in managing and adapting with the already present change in the climate.

Humans live in a contemporary society that appears to be more concerned around convenience than about what would occur in the near future. The global outbreak of the SARS-CoV-2 pandemic has caused the closure of several sectors of our economy, resulting in an unprecedented interruption of commerce and other activities in several sectors.[19–21] From some reports, the SARS-CoV-2 pandemic circumstances enhanced the air quality in several urban locations, decreased greenhouse gas emissions (GHGs), reduced water and noise pollution, and decreased the pressure on tourism destinations, which helped in ecological refurbishment. Correspondingly, there have been some adverse environmental implications, such as an upsurge of medical waste, random utilization and dumping of gloves, sanitizers (and other disinfectants), masks, and the problem of crude wastes unceasingly imperiling the atmospheric environment. It appears that economic events would possibly return in the near future and the circumstances would change.

Hence, this concise review intends to highlight some possible relationships between climate change and the SARS-CoV-2 pandemic and *vice versa*. This study was executed by reviewing several existing publications from the literature, case studies, and other information from reports of certified websites, as well as government and non-government establishments. This first part of the paper (section one) is the introduction section covering the review's background. The other sections of this paper are structured as follows: attempts to explore the relationship between climate change and the SARS-CoV-2 pandemic (both positive and negative) will be focused on in section two. Section three will briefly discuss the public health perspective of climate change owing to the SARS-CoV-2 pandemic. The utilization of scientific domains for climate change studies during the SARS-CoV-2 pandemic (such as nanotechnology and nanobiotechnology, material science, chemical sciences, epidemiology, public health, biotechnology, as well as biomedical and environmental engineering) will be discussed in section four. Section five will concentrate on the measures to avoid negative impacts on the climate due to SARS-CoV-2, while section six, the last section, will conclude the study and possibly recommend innovations that would advance future scientific research suggestions to mitigate the impact of the SARS-CoV-2 pandemic *vis-à-vis* climate change. Fig. 2 illustrates the hierarchy diagram, which represents the various aspects represented in this review study.

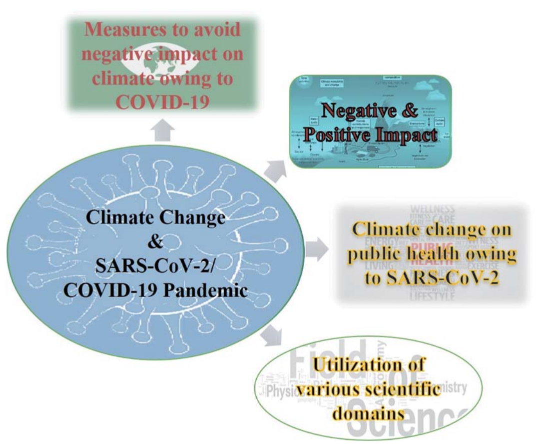

Fig. 2 The hierarchy diagram representing the main aspects presented in this study.

2. Possible relationship between climate change and the SARS-CoV-2 pandemic

Several measures were taken to monitor and manage the spread of the SARS-CoV-2 and the breakdown of most economic activities that substantially influenced the environmental situations of the world.[26] Supposedly, these influences on the environmental situations have been both positive and negative.[26] Inclusively, the ongoing pandemic has instigated enormous global socio-economic interruption, which has affected the atmospheric environment directly or indirectly, such as the improvement of the quality of air and water, decrease in noise pollution, and refurbishment of ecosystems.[27,28] As a result of the restriction of movement and the breaking of economic and social activities, air, water, and soil quality has been reportedly improved in several urban regions when observed globally.[26] But at the same time, the amplified utilization of personal protective equipment (PPE), such as goggles, hand gloves, face masks, and face shields, as well as their random dumping, has generated new environmental or ecological problems.[29–31]

Consequently, this generation of a massive quantity of medical wastes has adversely influenced the atmosphere. In these situations, this present study was planned to explore the ecological consequences (both positive and negative) of the ongoing pandemic worldwide, specifically related to climate change, and suggest likely strategies as prospects for mitigating climate change and ecological safety sustainability in general. Fig. 3 shows the different positive and negative impacts of the SARS-CoV-2 pandemic on the environment.

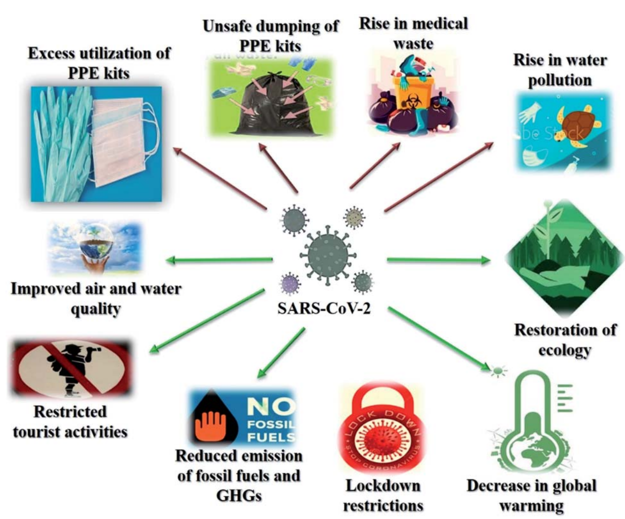

Fig. 3 Positive and negative impacts of the SARS-CoV-2 pandemic on the environment.

2.1 Positive environmental consequences and impacts of the SARS-CoV-2 pandemic

2.1.1 Decrease in air pollution and release of greenhouse gases (GHGs). As industrial and transportation activities were halted, it brought an unexpected drop in the emissions of GHGs when compared to the pre-COVID-19 era. The degree of pollution of air in several regions of the world was comparatively reduced by half (50%) due to the measures employed for the management of this dreaded virus.[7,28,32–34] United States Environmental Protection Agency[35] reports that 80% emission of GHGs such as NO_2 is due to motor vehicle exhaust caused due to the burning of fossil fuels.[35] These emitted GHGs (specifically NO_2) cause respiratory ailments and are also responsible for acid rain, thus interfering with H_2O and O_2.[35] In affirmation of this, the European Environmental Agency (EEA) suggested that due to the reduction in industrial and transportation activities, the emissions of NO_2 dropped from 30% to 60% in most European regions such as Paris, Rome, Milan, Berlin, Barcelona, and Madrid.[36] K. Berman, J. D. Edisu, 2020[37] reported a decline of about 25.5% in the emissions of NO_2 in the US during the COVID-19 era compared to the preceding era. Also, M. D. Adams, 2020,[38] reported a reduction in the level of NO_2 in Canada (Ontario, to be specific) from about 4.5 ppb to about 1.0 ppb. According to L. Y. K. Nakada and R. C. Urban, 2020,[39] about 54.3% reduction of NO_2 was detected in Brazil (Sao Paulo, to be specific). Similarly, a reduction in the degrees of NO_2 and particulate matter (PM) 2.5 by nearly 70% in India (Delhi, to be specific) was also reported.[40]

Supposedly, automobiles and aviation are the largest contributors to the emission of GHGs and contribute nearly 72% and 11%, respectively, in the transportation sector.[32] This measure of flight reduction taken universally for the control of SARS-CoV-2 is also had a dramatic influence on the aviation sector as most nations restricted intercontinental travelers from entrance and exit in their respective regions, and this assisted in the reduction of global emissions of CO_2, which has definitive consequences on the atmospheric environment.[41,42] Generally, the considerably less utilization of fossil fuels reduces the emissions of GHGs and assists in the mitigation of global changes in atmospheric conditions (climate change).[23,43] As reported by the International Energy Agency (IEA), the global demand for petroleum (oil and gas) has comparatively dropped to about 435 000 barrels in the quarters of the year 2020, when compared to a similar period in the year 2019.[36] Also, the global utilization of coal has reduced drastically due to less energy demand during the SARS-CoV-2 lockdown era. Reportedly, global coal-based power production in regions such as China is the main consumer of coal.[33] From a report from a UK-based meteorological and policy internet site (Carbon Brief), the current impacts of the SARS-CoV-2 pandemic have reduced the CO_2 emissions in China. Their report also anticipated that the SARS-CoV-2 pandemic could reduce the level of CO_2 by 4% and above the universal total in 2019.[44]

2.1.2 Decrease in water pollution. Water pollution is a common issue, especially in developing regions such as Asia and Africa, where industrial and domestic wastes are sometimes dumped into water (ocean and rivers) without been treated or purified.[16,45–47] During the COVID-19 era, industrial pollution's primary sources have comparatively shrunk, which has helped reduce the pollution weight.[47] Accordingly, there has been a great improvement in the quality of water in most regions of the world.[48]

Furthermore, due to the imposed restrictions on crowd gathering, tourist activities and water events were restricted in several locations.[3,49,50] Many solid wastes that are produced from manufacturing and construction activities, which are also accountable for land (soil) and water pollution, were reduced relatively. In addition, due to the lessening of export-import commercial activities, the movement of merchant ships and other containers (vessels) has reduced universally, consequently reducing emissions and water pollution.

2.1.3 Decrease in noise pollution. Noise pollution is defined as the increase in sound produced from diverse human actions such as construction work, machines, and automobiles, resulting in an adverse level of consequences in the living organisms.[3] Typically, noise pollution causes negative effects on the physiological health and affects people with cardiovascular conditions and hypertension.[51] Reportedly, about 360 million persons are disposed to hearing loss due to noise pollution globally.[52] According to WHO prediction, in Europe, more than 100 million people are sensitive toward high degrees of noise, far above the recommended limit. According to M. Solan *et al.*, 2016,[53] anthropogenic noise pollution has caused adverse influences on wildlife by altering the balance in prey and predator discovery and evasion. Similarly, unwanted sound affects invertebrates negatively, which helps control the environmental processes that are dynamic for balancing the ecosystem. Nevertheless, the lockdown and isolation procedures and the restricted economic activities, transportation, and communication, due to the SARS-CoV-2 pandemic eventually reduced the degree of noise in most urban locations worldwide.[3,28]

2.1.4 Ecological refurbishment and adjustment of tourist locations. Owing to technological advancements and enhanced transport systems, the tourism sector (which also encouragingly contributes to universal gross domestic product) has seen an outstanding evolution.[54] It is assumed that the tourism sector is accountable for some amount of the emissions of GHGs globally,[55] about 8%.[54] According to Islam, S. M. D. Bhuiyan, 2016,[45] visitors to tourist locations dump several wastes, damaging and creating an imbalance in the ecosystem. As a result of the SARS-CoV-2 outbreak and movement restrictions, there has been a reduction in the number of tourists globally.[3,56]

2.2 Negative environmental consequences and impacts of the SARS-CoV-2 pandemic

2.2.1 Upsurge in the generation of hazardous and infectious biomedical wastes. Owing to the outbreak of SARS-CoV-2, there has been a relative upsurge in the generation of hazardous and infectious biomedical wastes universally.[28] This sudden increase in hazardous and infectious wastes due to biomedical events (such as bandages, waste medicines/drugs, gloves, masks, needles, syringes, and used tissues) and their appropriate administration has become a critical problem for both local and national waste management authorities all over the world. Hence, N. van Doremalen *et al.*, 2020[57] reported that these hazardous and infectious biomedical wastes should be managed appropriately to decrease additional infection and environmental abundance, which is presently an issue of great apprehension globally.

Some of the measures to properly dispose biomedical waste, especially hazardous and infectious wastes generated during SARS-CoV-2, as reported and adopted from some existing studies,[58–60] are:

• There should be some modifications in the plans and management procedures, such as increasing the occurrence of these generated waste collection procedures on a diurnal or weekly basis. This will drastically reduce the menace of transmission of infections from biomedical waste in our medical facilities.

• There should be a clear demarcation amongst the modifications in biomedical waste generation and waste arrangements within the SARS-CoV-2 pandemic era.

• Furthermore, establishing new wards, especially SARS-CoV-2 wards with highly-infectious waste, are among the greatest new challenges and should be managed appropriately by modifying the routine activities.

• Also, the separation of SARS-CoV-2 waste from other biomedical waste in addition to the regular disinfection (fumigation) of SARS-CoV-2 hazardous and infectious wastes will assist in the reduction of waste produced; therefore, the possibility of transmitting diseases from waste mass will also be reduced.

2.2.2 Utilization of safety equipment and random disposal. In protecting oneself from this dreaded viral infection (SARS-CoV-2), most people presently utilize several PPE kits, namely, hand gloves, face masks/medical masks, and other safety kits, which increase the quantity of biomedical waste. According to J. Calma, 2020,[61] trash quantity in the US has been rising due to the increased utilization of PPE; there is a comparative increase in the manufacture and utilization of plastic-based PPE globally, which is due to the SARS-CoV-2 outbreak.[21,30] However, due to the lack of waste management knowledge of infectious and hazardous biomedical wastes, most people dump them carelessly in public places;[56,62] such random dumping generates congestion in waterways and contributes relatively to environmental effluence.[3,21] According to Fadare, O. · O. Okoffo, 2020,[30] plastic-based PPE made mainly from polypropylene is one of the major sources of environmental micro-plastic fibers.

2.2.3 Generation of municipal/metropolitan solid waste and recycling reduction. An upsurge in municipal/metropolitan waste generation, directly and indirectly, has adverse environmental consequences (such as air, land and water pollution).[45] Due to the SARS-CoV-2 outbreak and movement restrictions in most nations, there is a rise in the quest for online/internet shopping for home distribution, which eventually increases domestic waste quantity from dispatched package ingredients.[63] According to Ma *et al.*, 2020,[64] recycling waste is an operative means of preventing pollution, as well as conserve energy and natural resources. As a result of the SARS-CoV-2 outbreak, most countries suspended recycling the waste to decrease the spread of the infections of this deadly virus.[3,28] There is increasing landfilling and global atmospheric environmental pollutants owing to the interruption of routine municipal/metropolitan waste management, recovery of waste, and recycling waste.

2.3 Other environmental consequences and impacts of the SARS-CoV-2 pandemic

Presently, a huge quantity of sanitizers (disinfectants) is being utilized globally to annihilate the SARS-CoV-2. Such widespread utilization of these disinfectants could destroy some non-targeted useful species, generating an imbalance in the entire ecosystem.[26,45] Thus other measures in the treatment of wastewater are crucial, majorly for most developing countries, where municipal/metropolitan wastewater is exhausted into adjoining rivers or ocean (aquatic bodies) without any form of purification.[56] Most countries such as China have now reinforced the decontamination process (*via* the increasing utilization of chlorine) to avert the spread of SARS-CoV-2 *via* wastewater. Nevertheless, unnecessary utilization of chlorine in water purification could produce detrimental by-products.[3]

Reportedly, climate change processes and influences are regularly subject to most human actions, such as these aforementioned environmental consequences and impacts of SARS-CoV-2 and it is alleged that continuing measurements and analysis of various climate variables would assist in mitigating the ensuing consequences.[17,22] According to Ukhurebor *et al.*, 2020,[18] the strictness of climate change influences intensifies with time, and the quest for precise and expert meteorological predictions from various economic and other sectors has resulted in the continuous advancement of the meteorological sectors, mostly in developed regions. According to a recent report from the "World Meteorological Organization (WMO)", the global response to the crisis ensuing as a result of the SARS-CoV-2 pandemic has had a minute influence on the continuous upsurge in atmospheric concentrations of CO_2. The present carbon emissions have dropped dramatically as a result of the imposition of travel restrictions, authorizing closures of learning institutions and commercial activities, and the observance of the procedures laid down; apparently, this has only slightly reduced the global rise in concentrations.[65] Further, the editorial report in "the Lancet countdown on health and climate change" highlights the urgent necessity for responses to these two major crises to be aligned in order to tackle them successfully.[66] The question that would easily come to mind is the role of technology (nanotechnology and nanobiotechnology, to be precise) to mitigate these crises?

From satellite-based observation systems in models for climatic studies, technology has been demonstrated to be a crucial aspect for enumerating the variation in the environmental and atmospheric processes, and these ground-breaking approaches have afforded a basis from which the influences of climate change on public health could be moderated and mitigated. The developments in biosensor mechanisms and computational modeling have allowed air quality to be checked real-time closely. Pollution monitoring is crucial because studies on modeling from regions such as the US have proven that historically advanced exposure to the air-borne contaminant is positively linked with advanced SARS-CoV-2 death rates (however, the relationship could be confounded by specific/individual-extent risk influences such as culture and ethnicity).

Apart from the air quality, reviewing the meteorological influences on the SARS-CoV-2 pandemic could help seasonal forecast variation in its spread. According to Dr Rachel Lowe of the London School of Hygiene and Tropical Medicine, "…since SARS-CoV-2 has emerged only recently as a human pathogen, there is still uncertainty as to whether its transmission will vary seasonally in different parts of the world. If modeling studies reveal sufficient evidence that seasonality in SARS-CoV-2 transmission is linked to meteorological variables such as temperature and humidity, weather forecasts could be used to provide early warnings of increased risk and support response strategies successfully".[66]

Mostafa *et al.*[67] reported and employed containment procedures during the SARS-CoV-2 pandemic that has caused both desirable (positive) and undesirable (negative) environmental influences. The desirable environmental influences are hardly sustainable, and a decline in them is anticipated to ensue after the lockdown as previously. Consequently, stricter measures should be put in place to protect the environment. Going forward, subsequent sections of this review will concentrate on the public health perspective of climate change owing to the SARS-CoV-2 pandemic and the utilization of some scientific domains for climate change studies during the SARS-CoV-2 pandemic, such as nanotechnology and nanobiotechnology, material science, molecular biology, chemical sciences, epidemiology, public health, biotechnology, as well as biomedical and environmental engineering.

2.4 Quantitative insights of SARS-CoV-2 impact on the environment

As reported in a science daily, the SARS-CoV-2 pandemic has had a devastating influence on the entire human race. As of March 2021, the reported confirmed cases were appropriately 117 million, and the number of associated deaths had risen to about 2.6 million. The SARS-CoV-2 virus has transformed the mode of living and working-related issues for both humans and the environment as various health factors and the means of securing the limitations keep more persons mostly indoor. These consequential changes in human behavior are in no doubt impacting the environment in several ways, as described *via* the comparisons of remote sensing data (RSD) before and throughout/during the pandemic era collected by various environmental agencies such as the National Aeronautics and Space Administration (NASA), United States Geological Survey (USGS), European Space Agency (ESA), earth-observing satellites (EOS), and American Geophysical Union (AGU). According to reports from several researchers from various institutions presented at the virtual press conference on 7th December 2020 at the AGU's 2020 fall summit, the environment is rapidly varying, and the timing of these variations appear to show that the SARS-CoV-2 pandemic may possibly be one of the major reasons. The rates of deforestation are changing in most regions, air as well as other environmental pollutions are significantly dropping/lessening, the quality of water is improving, and snows are becoming heavier in some places since the era of the SARS-CoV-2 pandemic.[68]

As reported by the news room of the WHO, there is no clear evidence of a direct relationship between climate change and the advent or spread of the SARS-CoV-2 virus. Also, the WHO stated that almost all existing pandemics originated in nature (wildlife, to be specific) and points to signs that human actions could partially drive the advent of most diseases. Consequently, it is more certain to say that climate change could indirectly affect the responses to the pandemic by undermining the environmental factors of health and engaging extra pressure on the health systems. But what is most important now, since the disease is now well-known in the human populace, that more efforts should focus on decreasing transmission and treating those patients that have contacted the disease; procedures such as enhanced surveillance of communicable diseases and better protection of the entire natural ecosystem could assist in reducing the menace of future occurrences.[7,68–72]

At present, there is hardly any convincing evidence that either weather or climate, as the case may be, have a strong influence on the transmission of the SARS-CoV-2 virus. The sources of the SARS-CoV-2 virus have been spread in all parts of the world, from cold and dry regions to warm and humid climate regions. The SARS-CoV-2 virus is alleged to be primarily transmitted directly from individual to individual *via* close contact or *via* respiratory droplets formed when an infected individual sneezes or coughs. Persons could also be infected by touching surfaces exposed or affected by the virus; however, this is not a main route of transmission. Although some essential climate variables such as temperature and humidity could possibly influence the duration of survival of the virus outside of the living organisms, these consequences are expected to be minor when compared to the extent of contact between individuals.[27,73,74]

Pollution, especially air pollution, is one of the critical health menaces confronting the human race.[70] It has apparently led to the death of about 7 million persons annually and is mainly responsible for about 33.33% of all demises from lung tumor, stroke, and most diseases of the heart. More than 90% of the world population lives in areas where the WHO open-air quality standard levels are not within the required standard, and about 33.33% of these exposures are mainly due to the burning of fossil fuels and utilization of petrochemical products, which is one of the major reasons driving climate change.[3,75] Efforts in managing the transmission of the SARS-CoV-2 virus have reduced most economic activities, leading to momentary improvements in air quality in several places, especially urban areas. In contrast, as CO_2 and other GHGs that initiate climate change remain for a lengthy period in the atmospheric environment, momentary emission reductions primarily have a restricted consequence on atmospheric concentrations. The level of CO_2 in most of the world's observation stations in the first period of 2020 has been reported to be higher than that in the later part of 2020 (which happens to be the peak for the SARS-CoV-2 pandemic).[68]

Environmental enhancements ensuing from the SARS-CoV-2 pandemic response could possibly be upturned by a swift expansion of adulterating economic events once the restrictions are removed, except that there is a clear emphasis to promote justice and environmental well-being around the what is known as "green economy".[73] Any of the reported short-term environmental benefits resulting from the SARS-CoV-2 pandemic come at an undesirable human and economic rate, and there are hardly any substitutes for strategic and sustained action for improving the quality of air and mitigating climate change. Even though some encouraging impacts of the SARS-CoV-2 pandemic on the environment have been reported, the interim effects were basically brought by the worldwide lockdown. Certainly, the SARS-CoV-2 pandemic has expectedly posed enduring adverse effects on the environment in the upcoming years. The utilization of chemicals/petrochemical/biochemical substances such as detergents, soaps, medicines, and plastics (such as masks, gloves, PPE, and syringes) and other chemicals/petrochemical/biochemical procedures of cleaning is expected to increase further, leading to an upsurge in environmental effluences. In summary, some of the reported key quantitative issues of the SARS-CoV-2 pandemic, especially as it relates to environmental issues *vis-à-vis* climate change drawn from existing publications, are as follows.

• The SARS-CoV-2 pandemic further highlights the interrelationships between natural and societal organizations since societal resilience relies on a resilient ecological support organization.

• The loss of biodiversity and the intensive food organizations make zoonotic diseases more prospective.

• Frequently interrelated to social differences, environmental features such as air quality seem to influence the consequences of the SARS-CoV-2 pandemic.

• Upsurged dependence on the sole use of plastics and fall in the prices of petroleum ensuing from the lockdowns have undesirable consequences.

• The lockdowns during the SARS-CoV-2 pandemic could possibly have some direct, temporary, and positive influences on the environment, specifically in terms of GHGs emissions as well as the improvement in the quality of air, even though these are expected to be short-lived.

It is, however, suggested and recommended that more research is needed or required to attribute the observed evidence and reported environmental changes *vis-à-vis* climate change due to the SARS-CoV-2 pandemic. The greatest emphasis of such research should be on the utilization of RSD in observing how the ecosystem is changing during the SARS-CoV-2 pandemic era and comparing the present RSD to pre-pandemic tendencies; this has presently been undertaken by researchers such as Newman.

3. Public health perspective of climate change owing to the SARS-CoV-2 pandemic

3.1 Mental stress

SARS-CoV-2 pandemic is the sixth public emergency worldwide and is now being considered as one of the most crucial global health calamities of the century, along with one of the greatest challenges that humankind has faced since the 2nd World War.[76] The pandemic has also benefitted the environment in quite a few ways. Due to global lockdown, fossil fuel emission has reduced, and the release of industrial pollutants into water bodies has been greatly reduced, which has led to a decrease in global warming, cleaner air, and blooming of under-water life. On the other hand, it has greatly affected the safety, welfare, and health of both communities and individuals.[77] A community suffers from economic loss, deficiency of necessities, insufficient resources, *etc.*, whereas an individual suffers from confusion, depression, stigma, emotional instability, and insecurity. These problems have led to a series of disturbing emotional behavior such as distress and destructive behavior, which lead to suffering and pain in the affected populations. Post-disaster can either make an individual resilient or make them sensitive and vulnerable, which makes Post Traumatic Stress Disorder (PTSD) one of the primary concerns in disaster management. Although the current pandemic does not come under the current criteria for diagnosing PTSD, other stress-causing factors, such as trauma, mental stress, and anxiety, may occur. The pandemic rules and regulations such as self-isolation, social distancing, and lockdown greatly affect the individual's personality as initially the students have to quit their daily routine of attending lectures and have to attend their lectures or classes online from home, and similarly, the working population has also been greatly affected by online work from home; therefore, these sudden changes in the lifestyles have made mental health challenges more formidable.[78] The sudden lifestyle change has caused much mental trauma as many were not in the habit of living a home-bound life because parks, gyms, offices, colleges, universities, schools, malls, cinema halls, *etc.*, were immediately shut down and social gatherings were strictly restricted. These restrictions have both pros and cons on mental health, as some people utilized this lockdown positively by considering this as a golden opportunity to get skilled and gained online learning experience, whereas, on the other hand, many people felt stuck inside and felt lonely, which led to the increase in the cases of suicides and also led to increasing domestic violence. Although social support plays an important role in decreasing the risks of mental health problems, the social distancing rules may greatly affect one's typical ways of obtaining such support.[78]

3.2 Cardiovascular diseases

People suffering from cardiovascular diseases possess a high risk of death when infected from SARS-CoV-2 because of their delicate and vulnerable myocardial condition.[79] Basically, the effect of SARS-CoV-2 is observed on microvascular function, leading to heart failure.[80] Moreover, it has also been observed that the drugs used in the treatment of SARS show their direct side effect on the heart, and heavy doses of these drugs will ultimately lead to cardiac arrest. Initially, it was assumed that SARS-CoV-2 causes lung embolism or cardiac failure, which spread the threat of infection in public and cardiology wards of hospitals but later, with the help of media platforms, the misconceptions were cleared. During the pandemic, the lockdown was observed globally, where people were strictly restricted from attending public meetings and social gatherings, and were forced to work and study from home. The threat of catching the infection made people scared of even consulting their doctors, making them even more affected by the disease. Moreover, the loneliness, anxiety, unemployment, and depression made things worse.[81] Rather, it was suggested that the risk of ischemic heart strokes and diseases were majorly caused due to loneliness and depression.

It has been reported that an increase in the atmospheric temperature can directly lead to an increase in diseases in humans; in particular, people with cardiac diseases are more vulnerable to an increase in the atmospheric temperature. As the heat exposure increases, the risk of developing ischemic heart disease also increases because as the thermal heat rises, it simultaneously increases the central body temperature, resulting in an increased rate of sweating, vasodilatation, and a rise in heart rate and coagulation. Therefore, these changes can cause imbalance in the heart's autonomic control, elevate arterial pressure, disturb clotting responses, and start systemic inflammation.[82] But worldwide lockdown initiated a decrease in global warming, which resulted in cleaner air and a reduction in atmospheric temperature. This great impact on the atmosphere was observed because the lockdown forced the industries to shut down, decreased public gathering and transportation, and reduced the burning of fossil fuels, which resulted in a decrease in water, air, and noise pollution. People suffering from diseases such as cardiovascular diseases observed a great improvement in their health as the pollution from air decreased; work or school burden decreased, and the body gained more time to rest and relax.[82]

3.3 Respiratory diseases

The diseases that affect and damage the respiratory system and its functions are known as respiratory diseases, which carry an immense worldwide health burden. The five most common respiratory diseases causing serious illness and mortality worldwide are chronic obstructive pulmonary disorders (COPD), asthma, acute lower respiratory tract infections, lethal neoplasm, and tuberculosis. COPD is regarded as one of the leading causes of death globally, causing 3 million deaths per year;[83,84] similarly, asthma and acute lower respiratory tract infections greatly affect children and cause 4 million deaths annually.[85] Tuberculosis and lung cancer are considered fatal respiratory disorders, which touch the highest fatalities worldwide as nearly 1.6 million people die from these diseases.[86] People suffering from respiratory diseases have more chances of getting seriously infected from SARS-CoV-2; therefore, they are advised to take extra care and protection.

Patients with respiratory disorders are more sensitive to pollution; therefore, the worldwide lockdown proved to be beneficial for them as they were inside their homes safe and secure, reducing their chances of transferring any infections. As the duration of lockdown increased, global warming decreased, which led to a decrease in the pollution from the air, water, and soil, resulting in cleaner and more fresh air to breathe; therefore, climate change played a great role during the pandemic times by reducing pollution as well as maintaining the atmospheric temperature. However, because of the strict lockdown, it was observed that many patients were not able to visit their regular checkups, and many of the drugs were unavailable due to lack of transportation, which caused many problems to the patients.

3.4 Diabetes during SARS-CoV-2

The threat of SARS-CoV-2 spread worldwide with the onset of December 2019 and was soon declared as a world pandemic in February 2020. Elderly people and people with underlying diseases such as high blood pressure and diabetes are more vulnerable to SARS-CoV-2. But it was revealed by the Centre for Disease Control (CDCs) that people with diabetes are more sensitive to SARS-CoV-2 infection and, if infected with this, possess a high risk of developing pneumonia or possess a 7% death risk.[87,88] A survey was conducted during the pandemic and how the lockdown affects healthcare services for diabetes care. The study revealed that most people with diabetes did not consult their doctors during the lockdown period, and those with regular checkups shifted themselves to private clinics or hospitals as public health facilities were engaged in the SARS-CoV-2 pandemic. However, it was also observed that 91% of patients took help from chemists. Telemedicine services were made available during the lockdown period to ease the patients' difficulties but due to a lack of awareness in people, telemedicine services were not efficiently utilized. However, after all the systematic diabetes care, a majority of people with diabetes still experienced high glucose level as due to the restriction of mobility, the depression and anxiety cases increased, which can be attributed to the increase in the glucose level and in some cases, the increase in the rate of mortality.[62]

It has been studied that climate change and diabetes are interconnected as the change in the temperature can effectively affect a person with diabetes in different ways. For example, at high temperature, a diabetic patient is likely to get affected by heatstroke or heat waves. Thus, both the extremes of temperature are reported to cause negative side effects on the body of the diabetic person. Therefore, climate change can also cause adverse effects on diabetic patients. However, due to the lockdown caused by the pandemic, cases of diabetes were also increased. However, here climate change did not affect many populations; the lockdown caused an increase in depression, anxiety, and stress, which became a primary cause for the rise in cases of diabetes.

4. Utility of various scientific domains for climate change studies during the SARS-CoV-2 pandemic

As the awareness regarding SARS-CoV-2 increased, various science domains were dedicated to gathering information on this dreaded virus to solve the problems caused by it. Fig. 4 illustrates various scientific domains, which are dedicated toward solving the problems pertaining to SARS-CoV-2.

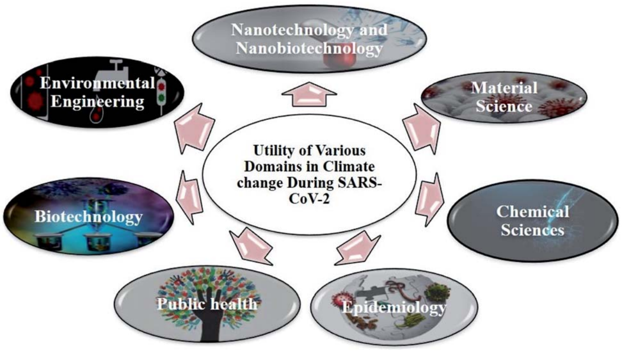

Fig. 4 Various science domains that were utilized to study climate change during the SARS-CoV-2.

4.1 Nanotechnology

The current pandemic has made us realize that ignorance of plenty of warning signals from epidemiological experts about infectious disease and their broad and borderless effect can lead to global vulnerability as microorganisms, which do not require a passport or geographic boundaries to travel, can affect all the living organisms equally. It has been reported that infectious diseases have always troubled the human race, which has caused a high number of morbidities and mortalities compared to other natural disasters, and they are still the leading cause of premature death worldwide. However, modernization and increasing awareness about sanitization, hygiene, antibiotics, vaccines, and sanity have decreased the threat and vulnerability of infectious diseases from people's mind.[89] As science and technology are developing and advancing, nanotechnology in the biomedical field is also increasing rapidly as nanomaterials exhibit unique and exciting physicochemical and biological properties, which make them grab the attention of researchers globally. Nanotechnology is dominating the biomedical field and is also being widely utilized in other domains such as pharmaceuticals, robotics, aeronautics, material science, chemistry, and physics. The nanoparticles chemical composition and small size give them the ability to exhibit biocompatibility and reduced toxicity, making them a suitable choice to be utilized in the biomedical domain.[90–93] Nanomaterials played a very important role in these pandemic times as they have been used in different healthcare utilities, such as anti-microbial sanitizers, anti-microbial coatings on PPE kits, implants, masks, diagnosis of the infectious virus, drug delivery, and bio-imaging.[94–96] During this pandemic time, various research studies and reviews have started focusing on the anti-microbial potential of different nanomaterials as they exhibit good anti-microbial activities against various bacteria, fungi, and viruses.[97–99] Moreover, it has been expected that the global consumption of healthcare-related nanotechnology products can reach more than 50 tons in 2021.[100]

Nano-enabled sensors/biosensors have gained much attention in the past by helping to combat various infectious and non-infectious diseases by diagnosing them;[101] these nano-enabled sensor/biosensors technologies have been very efficient in diagnosing infectious diseases, which makes them a potential candidate for helping to manage the SARS-CoV-2 pandemic by developing nano-enabled sensors/biosensors for the rapid, sensitive, and selective determination of early-stage SARS-CoV-2 virus protein.[102] Thus, to achieve these objectives, there is a need to determine the picomolar level of the SARS-CoV-2 protein in a way to avoid experiencing extensive labor and laboratory requirements as the human-to-human transmission of SARS-CoV-2 is getting worse. Hence, given the above situation, there is a need to research to link the diagnosis based on point-of-care (POC) sensing with artificial intelligence (AI) techniques and internet-of-things for the diagnosis the SARS-CoV-2 very efficiently and rapidly.[103] Further, A. Ahmadivand *et al.*[104] developed an approach to detect the SARS-CoV-2 virus protein at the femtomolar (fM) level using plasmonic metasensor technology, enhancing the clinical diagnostic and healthcare programs. However, detecting low-molecular weight biomolecules at low densities is a drawback of traditional metasensors, when studied using toroidal metasurface technology. Therefore, they aimed to fabricate miniaturized plasmonic immunosensors by utilizing toroidal electrodynamics, which can confine plasmonic modes with ultranarrow lineshapes in the terahertz (THz) frequencies, and the developed sensor works by exciting the toroidal dipole mode with the help of quasi-infinite metasurface along with carefully functionalized gold nanoparticles (AuNPs), which are blended with a specific monoclonal antibody to the spike protein (S1) of the SARS-CoV-2 virus onto the metasurface, and the resonance shift is monitored by the change in the concentration of the spike proteins. Thus, the fabricated sensor was rapid and precise in sensing the SARS-CoV-2 virus carriers, whether for symptomatic or asymptomatic patients.

Moreover, the chemical composition and size of nanomaterials can help them display antiviral activity as their extremely small size (lesser than virus) helps them communicate with the surface of the virus and alters their structural and surface proteins, making them suitable antiviral agents. The metal and metal oxide nanoparticles exhibit potential for combating viral diseases and hold a great future in antimicrobial applications. One example is selenium nanoparticles, which play a vital role in diagnosis and therapeutic applications against SARS-CoV-2 (Fig. 5).[97] Nanomaterials either show direct or indirect effects on the viruses; they do not directly inhibit the virus in the indirect method. Instead, they enhance the antiviral efficiency of the antiviral drug or induce an immune response.[105]

In contrast, some nanoparticles show a direct antiviral effect on the virus by inactivating its viral structure or altering its genetic makeup. However, nanoparticles are also utilized in different aspects such as increasing reactivity, biocompatibility, controlled diagnosis, and targeted drug delivery.[106] The various unique chemical, structural, and biological properties of nanomaterials make them have potential applications in combating SARS-CoV-2 or other viral diseases. They are widely used in textile and polymer industries, such as producing Personal Protective Equipment (PPE), sanitizers, medical packaging, textiles, and coating industries.[107] With the increase

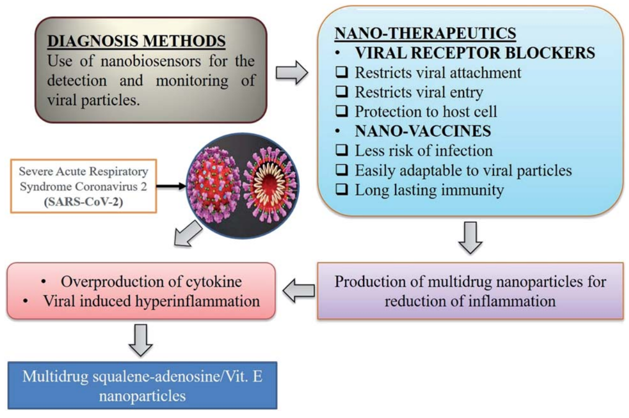

Fig. 5 The potential role of selenium nanoparticles in SARS-CoV-2 (reproduced with permission from V. Nayak *et al.*, 2021).[97]

in the use of nanomaterials in various safety equipment, it has become a major necessity to study the toxicity caused by nanomaterials on the environment. Recently, it has been reported that the use of safety equipment has increased solid waste pollution in both land and water, causing harmful effects on the environment and living beings. Good knowledge of the proper disposal of the used kits, samples, and other equipment is required to avoid environmental damage. Nanotechnology is also being utilized to study the negative impact of these solid wastes on the environment and the ways to decrease environmental pollution.[75]

4.2 Biotechnology

The fusion of biology with technology is known as biotechnology and is considered to be a multi-disciplinary field that majorly includes physics, chemistry, biology, statistics, and mathematics. With the spread of the pandemic, biotechnology's significance and importance increased, which led to an increase in the research and awareness about the subject.[108] The governments of many countries have started funding a number of projects and aligned their attention purely on the virus and vaccines' development. Similarly, many biotech companies have also started focusing on various biotechnological products that can be utilized during the pandemic, such as sanitizers, anti-microbial coatings on protective kits, masks, and disinfectants. Initially, the need of the hour was the detection of the virus and the development of the vaccine, along with the study of the virus and preventive measures to stop it from spreading. Various biotechnology fields such as medical biotechnology, molecular biotechnology, genomics, and plant biotechnology have played a distinct role in providing as many details about SARS-CoV-2.[29,109,110]

Biotechnology has been used in the study of SARS-CoV-2 but has been aligned with rapid climate change during the pandemic's worldwide lockdown. A great decrease in the temperature was observed due to the decrease in the burning of fossil fuels and the reduction in industrial waste. The current pandemic has made us realize that it is now the need of the hour to generate awareness about the increasing global temperature and its harms. The origin of SARS-CoV-2 is still unknown as many believe it to be artificial and some believe it to be of natural occurrence due to the melting of glaciers, which has made the release of several unknown microorganisms in the environment. In the past few decades, biotechnology has been utilized in the environmental aspects to detect and monitor pollutants, production of alternate resources, utilization of solar energy, *etc.* But, with the increase in PPE kits, masks, solvents, *etc.*, an increase in the biological waste has been observed, which has made the environment contaminated. The proper disposal of these biological wastes needs attention as these can cause the spread of other microbial infections, and here comes the requirement of climate change studies to be performed by biotechnologists to avoid the negative effect on the environment.[111]

4.3 Materials science

Materials science has found profound use in various domains and is currently the most trending subject in science after nanobiotechnology.[112] As the SARS-CoV-2 pandemic spread, the importance and significance of materials science in viral biology increased as it was utilized in detection, therapeutics, protection, and as well as in vaccination. Various detection techniques were developed, which are rapid, portable, accurate, and cost-effective using materials science and nanotechnology. The combination of nanotechnology, biotechnology, and materials science has increased the prospects in viral studies. Moreover, materials science also contributed to the design of suitable materials for producing anti-microbials and cost-effective personal protection equipment (PPE), namely, masks, PPE suits, gloves, and face shields.[113] Materials science has also been utilized in the production of disinfectant liquids, wipes, and sanitizers. The knowledge of materials science also enables the design and upgradation of sophisticated instruments used to study the structure and chemical composition of viral particles, such as cryo-electron microscopy, confocal microscopy, and electron microscopy. Further, in order to design portable and cost-effective super-resolution microscopy such as BiteOscope[114,115] and Octopi,[114] different nano-scaled materials have been utilized.[114,115]

Advanced materials are a fundamental block to build a clean, green, and viable energy innovation. As many countries' economies are highly affected by the SARS-CoV-2 pandemic and climate change, it is urgent to develop cost-effective and sustainable green materials that act as suitable alternatives for non-renewables or can be used to boost renewable energy sources. The pandemic has greatly affected climate change as there was a worldwide lockdown, which led to a decrease in the burning of fossil fuels, the release of harmful chemicals in rivers, and lesser carbon footprint generation; also, the depleted ozone layer started building up. However, many materials have been used to decrease and control the environment's pollutants, which were found to be successful. Moreover, the center for disease control and prevention (CDC) has stated that SARS-CoV-2 spreads mainly due to large respiratory droplets within the ~6 feet range of infected individuals but research on

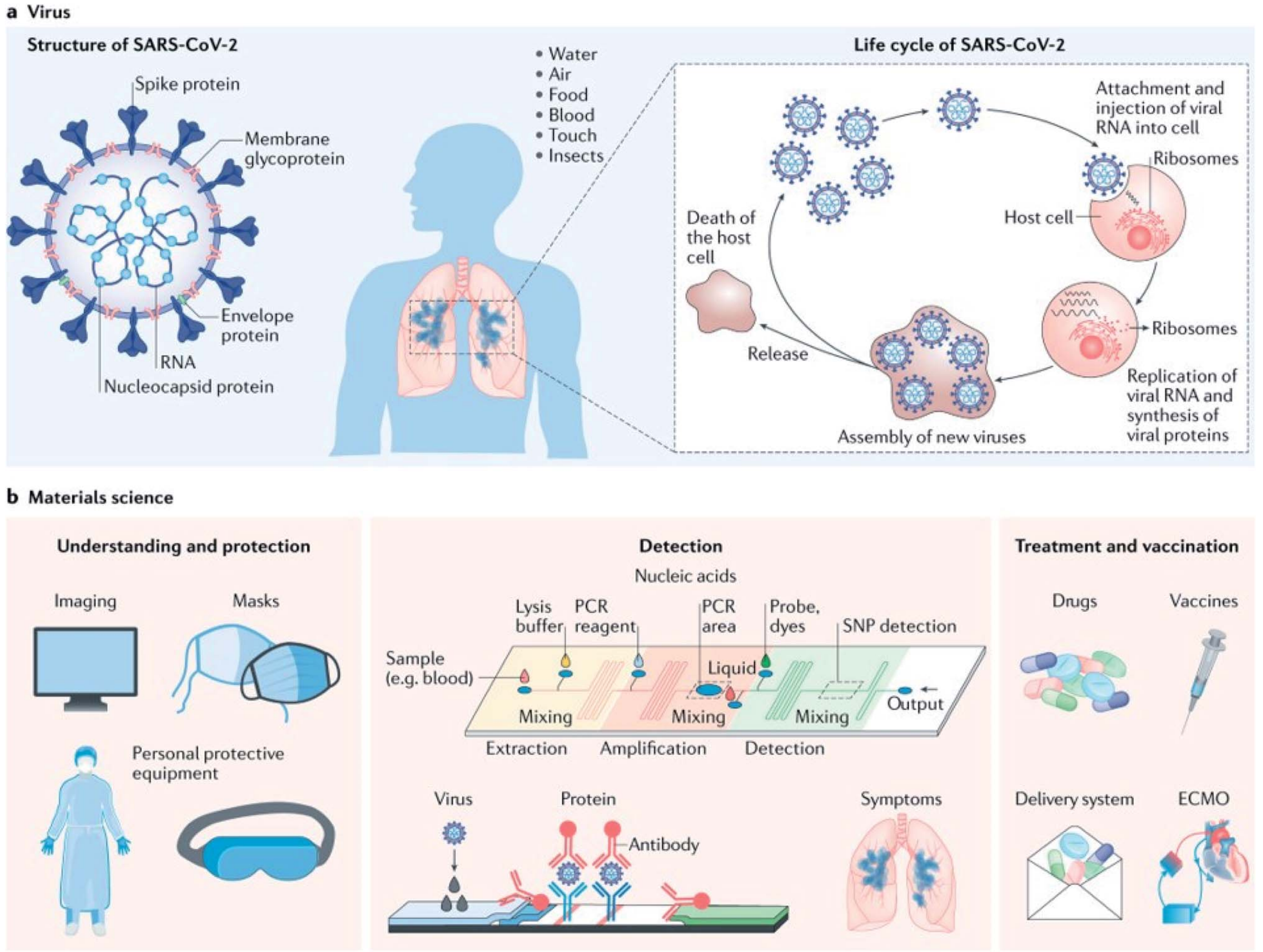

Fig. 6 Different roles of materials science during SARS-CoV-2 (reprinted by permission from Springer Nature: Nature Reviews Materials; a materials-science perspective on tackling COVID-19, Z. Tang *et al.*, 2020).[118]

transmission pathways is needed to restrict the SARS-CoV-2 spread. Materials science has proved to be a field that can help overcome this issue as in a study showed that in an indoor environment, particle control technology-based air filtration could help to reduce fine (<2.5 μm) and ultrafine (<0.25 μm) particles by 95%. Thus, it can be suggested that materials science also plays a vital role in combating SARS-CoV-2 by remediating it from the environment;[116,117] Fig. 6 illustrates the basic structure, different transmission routes, and the replication cycles of SARS-CoV-2 along with the utility of materials science in combating this pandemic situation.[118]

4.4 Public health

As the SARS-CoV-2 developed rapidly, public health awareness also increased as it was important to generate and spread the correct information among the public without any rumors and fright. The most valuable information that needed to be spread was the washing of hands, maintenance of social distancing, and regular wearing of masks, which helped reduce the spread of the disease. The current pandemic has put limelight on the gaps faced between the government and public health sectors. Public health refers to the science of preserving and enhancing the public's health and communities to promote healthy lifestyles, prevent injuries, and detect and treat certain infectious diseases. Generally, public health is to examine and prevent the population from various kinds of diseases. Public health diseases majorly include communicable diseases, cardiovascular diseases, urinogenital diseases, respiratory infections, mental stress, Alzheimer's disease, and Parkinson's disease. Public health sectors deal not only with the treatment of diseases but also in generating awareness and promoting healthcare quality, accessibility, and equality.

Apart from the spread of infection, the public has also been affected by the sudden change in climate, especially, the farmers, as they suffered a major loss in the harvest in 2020. A sudden change in the climate also developed the chances of seasonal infections, which at a certain point was misunderstood for the SARS-CoV-2 infection among many people. Not just under-developed and developing countries but also the developed countries such as France and Italy were questioned about the services provided by the public health sectors. At the beginning of the worldwide lockdown, a reduced carbon footprint was observed, which caused the lessening of pollutants in the environment but as the lockdown ended, carbon emissions increased rapidly as everyone was out of their houses. Although the clean air and water benefitted the public health, some places with severe low temperatures were reported at the end of December. The rise in the pandemic has taught the whole world that increase in public health literacy should be a major focus as the climate is changing very quickly and the temperature is rising at a very fast pace, which results in an increase in the melting of glaciers and puts the world at a major risk of future pandemics.[119]

4.5 Environmental engineering

The SARS-CoV-2 pandemic has greatly shaken all facets of life globally, including economy, health, biomedical, research, environment, transportation, stock markets, and supply chains. As the environment's temperature increases, the poles' glaciers are melting, which are assumed to be the possible cause of future pandemics, as many unknown and pathogenic microorganisms are still trapped in the glaciers, which, when released into the atmosphere, can be fatal to humans. The SARS-CoV-2 pandemic increased the impact of the medical research domains and simultaneously increased the impact of environment-based research. One of the promising areas of research in environmental engineering is the study of sewage to monitor the circulation of viruses in communities and also to detect outbreaks before clinical cases are identified. Environmental/climate engineering researchers have taken a broader, long-term, and more quantitative approach in studying viruses that majorly spread through the environment. One of the ways to understand the spread of the virus is to establish proper communication between the health worker and the environmental engineer. Currently, SARS-CoV-2 is not the last novel virus to occur and has seriously threatened global public health; therefore, the researchers and funding agencies should now start focusing not just on a specific virus during its outbreak but also focus on other topics when the outbreak subsides.[120]

5. Measures to avoid negative impacts on the climate owing to SARS-CoV-2

The climate change caused by the pandemic is temporary as when the lives will go back to normal again, the pollution will increase and the temperature will rise, resulting in the melting of the polar ice and an increase in global warming.[26] Therefore, it is very important to strategize sustainable environment management for long-lasting benefits.[28] To protect earth from destruction, it is very important to put united efforts into preparing sustainable strategies and eco-friendly products. Some of the possible sustainable strategies are discussed.

5.1 Increasing the use of public transport

There are many ways to reduce the excess emission of fossil fuels and one of the best agreed methods is the use of public transport. Many developed countries have increased their budgets to improve, enhance, and promote public transport systems in their countries, which have benefitted the environment and have also improved people's health and have leveled up the country's economy. The concept of public bike-sharing and carpooling is new and environment-friendly.

5.2 Industrialization and sustainability

Industrialization is considered a very important factor for economic growth but, at the same time, it is also blamed for the increase in global warming. As of now, sustainable industrialization is the need of the hour because it is important to transfer to less energy-consuming industries, and produce and utilize green fuels and technologies.[121] In addition, sustainability also includes setting up the industries in some specific zones where the population is less and the industry should be away from natural sources such as rivers and lakes. Also, certain methods and techniques should be developed to either reduce toxicity or recycle industrial waste.[122]

5.3 Use of renewable energy

Utilizing renewable energy in our daily life can reduce the demand for fossil fuels such as coal, oil, petrol, and natural gas, which help reduce the emission of different greenhouse gases.[123] The SARS-CoV-2 pandemic induced the worldwide lockdown, which restricted transportation and, therefore, reduced global energy demand, reduced fossil fuel emissions, and enhanced the air quality in different regions.[3,28] Sustainable industrialization seems to be easy but is difficult as it is impossible to meet the daily needs and simultaneously maintain the global economic growth at a cut-off energy demand in a pandemic situation. Therefore, it is suggested to use renewable energy sources such as solar, hydropower, wind, geothermal heat, and biomass, which can easily meet the energy demand and also decrease the emission of various greenhouse gases.[123]

5.4 Wastewater treatment and reuse

It is a global need to control water pollution as the freshwater bodies are decreasing at a high rate because both municipal and industrial wastewaters are being disposed in the water bodies.[16,124] To clean and maintain the water bodies, it is necessary to treat wastewater before discharging it in the water bodies properly. Moreover, the treated waters can be reused in non-production processes such as flushing of toilets and road cleaning, thus reducing the burden of excess wastage of water.

5.5 Waste recycling and reuse

Management of waste should now be considered important to decrease environmental pollution. Sustainable management includes the reuse and recycling of both municipal and industrial wastes in a way that provides benefit to the nation's economy and promotes a clean and hygienic environment. It has been suggested that circular economy or even circularity systems can be used to minimize the excessive use of raw materials and waste generation.[122] Also, bio-hazardous and infectious wastes generated from hospitals, research labs, *etc.*, should be properly managed by setting up guidelines. It is a well-known fact that most people lack proper knowledge regarding waste segregation and disposal issues.[56] Therefore, governments should take up the responsibility to implement extensive awareness campaigns using different mass media for proper waste segregation, handling, and disposal methods.

5.6 Ecological restoration and ecotourism

To maintain ecological restoration properly, a periodic shutdown of tourist spots should be implemented. The lockdown caused due to the SARS-CoV-2 pandemic has improved many tourists' spots as there were no tourists, which led to a decrease in pollution. Moreover, awareness about ecotourism practices should be promoted to generate sustainable livelihoods, cultural preservation, and biodiversity conservation.[125]

5.7 International cooperation

A combined international effort is required to maintain and meet the idea of sustainable environment protection to conserve the climate and biological diversity. Therefore, the United Nations Environment Programme (UN Environment) took up responsibility for effectively preparing time-oriented policies, arranging international conventions, and coordinating global leaders for the proper implementation of the plan.

6. Conclusion, challenges, and prospects

SARS-CoV-2 is starting to take an unpredictable shape, and most scientists are likely to miss the diagnosis. Even though there have been reports that the SARS-CoV-2 pandemic has caused significant adverse consequences, there is a great sigh of relief as there have been several reports at the moment on SARS-CoV-2 vaccines from some world-class countries such as China, Russia, US, and EU due to the advancement in scientific research. However, in the eyes of climate scientists, the global response to the crisis resulting from the SARS-CoV-2 pandemic has had little, limited, or no influence on the continuous upsurge in atmospheric concentrations of GHGs such as NO_2 and CO_2, which in turn is one of the foremost causes of climate change. The current carbon emissions have dropped dramatically due to the imposition of travel restrictions, closures of learning institutions and commercial activities, and the observance of the laid-down procedures; apparently, this has only slightly reduced the global rise in concentrations of NO_2 and CO_2.

All of these atmospheric environmental implications are allegedly temporary. Consequently, appropriate strategies for long-term advantages, together with sustainable ecological management, should be put in place. The SARS-CoV-2 pandemic has prompted a universal response to confront the dreaded virus.

Due to cautious evaluations of the developments and evolutions as specified in this study, it is observed and perceived that scientific domains such as nanotechnology and nanobiotechnology, materials science, public health, biotechnology, and environmental engineering for climate change studies during the pandemic have the possibility to function as well as play a critical part in combatting SARS-CoV-2 and its influences. However, there are some biological constraints or barriers; hence, these nanomaterials/bionanomaterials that are utilized for most of these aforementioned scientific domains require some level of biodegradation and the capability to deliver the chosen cell category and other parameters with increased drug delivery. These nanomaterials/bionanomaterials ought to be able to dodge the endocytic degradation mechanism once within the cells for the treatment and management of SARS-CoV-2. There is no doubt about the fact that these established nanomaterials/bionanomaterials utilized for most of these aforementioned scientific domains for the treatment and management of SARS-CoV-2 have demonstrated substantial as well as potential benefits but some recent investigations have conversely shown that these measures could instigate severe impairment to the respiratory settings and could also cause some form of impairments to the functioning ability of the lungs.

From the viewpoint of biomedical science (nanomedicine, to be specific), there are many established nanomaterials/bionanomaterials such as polymers, oligomers, dendrimers, liposomes, carbon nanotubes, as well as other nanoparticles/bionanoparticles. However, productive biomedical transformation has been hindered by the fact that during dilution, these nanomedicines could lose their efficiency as the SARS-CoV-2 composite-complex dissociates, making the SARS-CoV-2 virus somehow free to recommence its cycle of replication. However, from the viewpoint of climate science, there has been limited research reported on the nexus between climate change and SARS-CoV-2. However, from the reported and established studies on the influence of the SARS-CoV-2 pandemic on the environment, it is correct to infer a possible relationship between climate change and SARS-CoV-2, whose positive influences are more than the negative influences.

Correspondingly, to protect our world, a joint effort of the nations should be imperious. Therefore, it recommended that further innovative studies that would advance the conduct of scientific research in mitigating the impacts of the SARS-CoV-2 pandemic regarding climate change, biomedical, and environmental issues should be encouraged and conducted in various regions of the world to ascertain the influence of the SARS-CoV-2 pandemic on the biomedical and environmental domains and, in particular, the climate science domain (climate change) or *vice versa* so as to outline the ensuing consequences for prospects. Simultaneously, more prospects for imminent research and provision for theoretical and scientific direction as well as the organized basis for the utilization of various scientific domains such as nanotechnology and nanobiotechnology, materials science, public health, biotechnology, and environmental engineering for climate change studies during a pandemic such as the SARS-CoV-2 pandemic and measures to avoid the negative impacts on the climate change owing to it *vis-*

à-vis the public health perspective of climate change as well future occurrence of such pandemics should be reinvigorated.

Further, strategies and policies on the potential of artificial intelligence (AI), specifically the ones that are cost-effective and eco-friendly (known as green AI for tracking and manipulating machine-learning consumption of energy and carbon emissions), big data, and machine learning for evolving diagnostic devices and more resourceful systems, should be enhanced, as well as the transparent reporting of results and findings in publications.

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Conflicts of interest

The authors state that there are no personal, financial, or competing interests that could otherwise have appeared to influence this reported review study.

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