CHAPTER SEVEN

Monetary quantification of COVID-19 impacts on sustainable development goals: Focus on air pollution and climate change

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1. Introduction

The presence and spread of the novel coronavirus have affected several regions throughout the world.[1,2] The epidemic began in Wuhan City in December 2019 and quickly spread to other regions of the world.[3,4] In light of the current crisis, the government agencies of the afflicted nations have devised initiatives to limit COVID-19 prevalence among their citizens. The Government of India implemented a series of curfews in this reference, which includes self-lockdown—"Janta Curfew" on 22nd March 2020, lockdown-1 that was declared from 24-03-2020 to 14-04-2020 and extended to lockdown-2 (15-04-2020 to 03-05-2020), lockdown-3 (04-05-2020 to 17-05-2020), and lockdown-4 (18-05-2020 to 31-05-2020). It is followed by Unlock 1 which started on 1-05-2020 and continues to Unlock 14 till 31-07-2021.[5] COVID-19 was lowered by these lockdowns and control measures, whose impacts can also be seen in social, economic, and environmental aspects with a positive drift associated with ambient air quality in national or state sectors.[6,7] Air quality is a crucial problem for residents' health as well as the economy.[6,8] An instantaneous strategic move of COVID-19-related lockdown may have helped to improve air quality; however, there are intensifying impacts associated with various sustainable development goals (SDGs).[5] During the pandemic, energy demands and production cycle drastically altered and became an insurmountable problem.

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Further the healthcare services got skewed towards COVID-19, resulting in the deterioration of other healthcare services. The pandemic has made hindrances in delivering essential services to the society by restricted capacity which it has formerly provided smoothly. Owing to disturbances in logistics and supplies of material and equipment, the services of the health system have been seriously affected due to this pandemic.[9] The Centre for Monitoring Indian Economy (CMIE) indicated an increase in poverty, unemployment, labor scarcity, and other information. The troubling state of economics and e-commerce hurt Indian citizens' livelihoods.[5]

According to recent research findings, the control strategies used during the COVID-19 outbreak had a significant influence on SDGs, particularly SDG-3 (Good Health and Wellbeing) and SDG-13 (Climate Action). The epidemic's social isolation, lockdown, and quarantine were all new to civilization, and they all harmed the society's equilibrium in every way. It did, however, provided some paybacks in terms of better air quality and reduced carbon footprint. Pandemic risk increases if accessibility to clean water for drinking and sanitation gets limited. However, the pandemic-triggered nationwide lockdown also delivered some benefits, such as decreased pollution rate in water resources. The longest freshwater lake in India (Vembanad lake) showed an approximate decrease in suspended particulate matter concentration by one-third in 2020 compared to 2019 which is a record lower rate of pollutants within the past 7 years.[10] Reduced industrial activities and consequent decrease in wastewater discharge during the lockdown period resulted in a 50% decline in the concentration of groundwater-borne cationic solutes, e.g., Se, As, Fe, and Pb, as well as NO_3, total and faecal coliform in the coastal city of Tuticorin. Approximately 50% of reduction in air pollution was evident in New York and Delhi from the previous year, with a considerable reduction in PM_{10}, $PM_{2.5}$, CO, and NO_2 which adds to the positive aspects of impacts of COVID-19.[3,10] According to data analyzed using statistical approaches, such as analysis of variance and regression models, air pollution in a specific place is increasing the risk factor of death due to COVID-19.[11] Particulate matter (PM) can play a prominent role in the spread of disease via the atmosphere, water, and touch due to its chemical characteristics, shape, and particle size, as well as its ubiquitous dispersion on virtually all objects.[12] An additional problem related to the outbreak is frontline staff's proper disposal of personal protective equipment (PPE), which can be a contaminant.[13] Decentralized incineration of PPEs have been proven to be environmentally and human health-friendly, with the purpose of safe waste disposal and illness prevention from such equipment.[14]

$PM_{2.5}$ is a primary source of respiratory sickness in individuals, which became a serious condition during the COVID-19 outbreak, among the different air pollutants. However, due to the entire cessation of human activities during the pandemic, there was a significant reduction in its level as well as CO_2 emissions, which became a blessing for addressing severe environmental concerns such as air pollution and climate change. The decrease in environmental pollution should be studied in light of forward-thinking initiatives and strategies aimed at achieving a truly sustainable community.[15] Analysts are now focusing their attention on the pandemic's mortality and economic implications. Assessing the economic impacts of ceasing human activities during such an outbreak shows a detailed picture of the changes in damage to the environment and public health. Such monetary evaluations can serve as a foundation for assessing the effects of a pandemic on various SDGs with a view that the efforts have taken now and in the future must be focused on creating a more fair, comprehensive, and resilient environment and communities that are more robust to epidemics, climate change, as well as many other worldwide problems that humankind addresses.[16] The valuation methodologies described in the subsequent sections can help policymakers comprehend the scale of COVID-19's implications on SDGs, as well as serve as a foundation for valuing other SDGs, allowing for adequate action to be taken to maintain a strong and sustainable community. Furthermore, it indicates the magnitude of losses the country incurs due to health and climate change burdens and underlines the bare minimum levels one can reach by using the example of COVID-19 lockdowns. This should convince policymakers about the cost of environmental deterioration to the country and should drive positive action for the betterment of the environment.

By using air pollution and human health as assessing metrics, the major objective of this chapter is to explain how to measure the effects of COVID-19-induced resource limits and lockdowns on SDGs. The study further determines the reduction in concentrations of $PM_{2.5}$ using advanced tools like geographic information system (GIS) and remote sensing (RS) data from moderate resolution imaging spectroradiometer (MODIS) along with CO_2 emissions statistics collected from various resources. Econometric tools and methods are used to calculate the monetary value of reduced morbidity and mortality linked with COVID-19 management efforts. The localized value of the social cost of carbon (SCC) is used to monetize CO_2 emission reductions.

2. Methodology for the assessment of $PM_{2.5}$ and CO_2 emissions

2.1 Assessment of $PM_{2.5}$

Annually, air pollution causes massive deaths and disabilities among the population, making it one of the leading sources of health concerns. It has ecological effects such as acid rain and poor vision, but it has a greater and much more substantial effect on public health. $PM_{2.5}$ is a key air pollutant that causes and worsens respiratory ailments in people. As a result, studying its prevalence in the environment is essential during a pandemic, because the virus harms people who have a respiratory illness. As explained earlier the control strategies adopted during the COVID-19 bought $PM_{2.5}$ levels in the environment to a lower figure. This reduction has a significant positive impact on a community's health. Recent research studies taking Delhi, Paris, London, and Wuhan as the study area show a substantial reduction in the concentration of various air pollutants from 2019 to 2020 related to COVID-19 control strategies. Accordingly, a total reduction of morbidity values from 167.29 to 102.97 Million \$ and mortality values from 12.83 to 6.50 Billion \$ has been reported for Delhi city.[3]

In this study, the assessment of $PM_{2.5}$ is done for a slot of two periods to understand its effect on the environment. The study period was from prelockdown phase (April–September 2019) to initial lockdown phase (April–September 2020) and from lockdown phase (April 2019–March 2020) to postlockdown phase (April 2020–March 2021). The lowered impacts of lockdown on $PM_{2.5}$ concentration are analyzed using GIS and remote sensing data from the MODIS, which is detailed later.

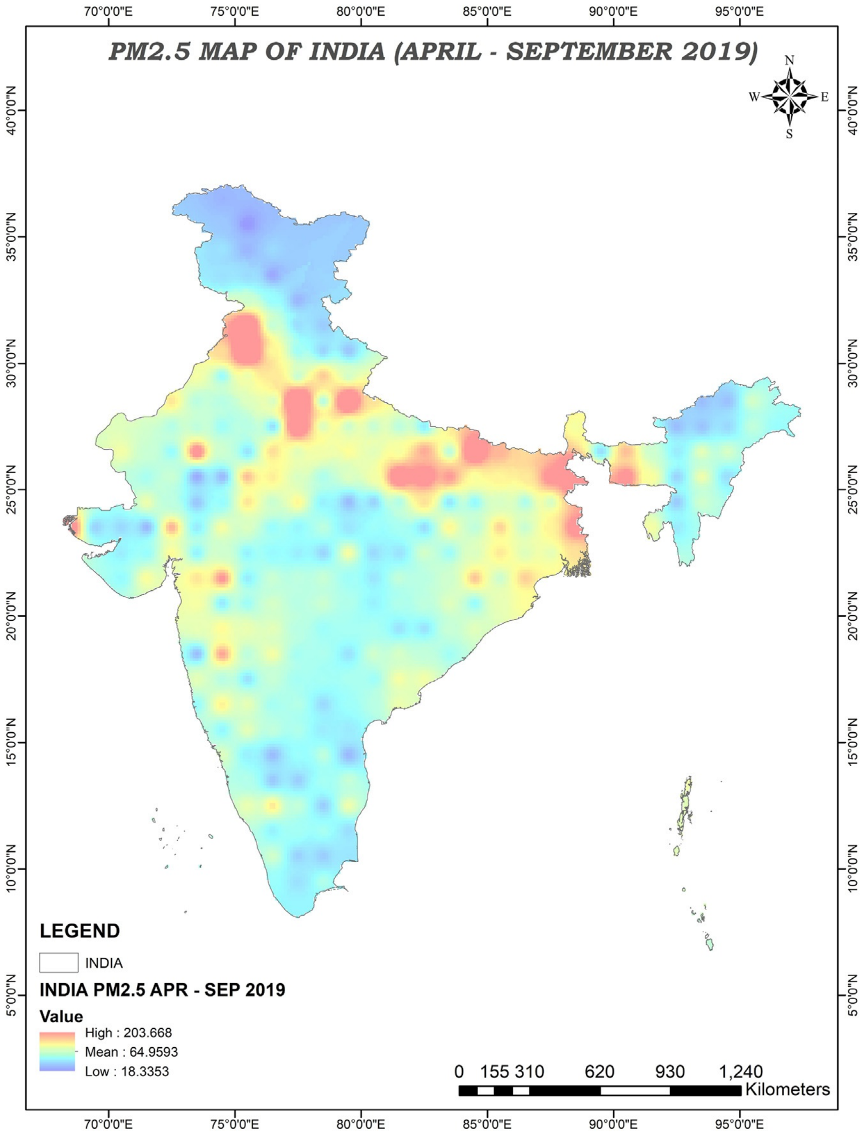
RS technology has a wide range of applications, but it can be particularly useful in predicting the environmental effects of a pandemic. The application of RS to extract aerosol optical depth (AOD) and $PM_{2.5}$ levels in India during the prelockdown, lockdown, and postlockdown periods is shown in this section. Ground-based monitoring stations that measure $PM_{2.5}$ levels in ambient air at higher frequencies have been established in most major cities across the world; however, these methods are insufficient to comprehend its spatial distribution.[17,18] In this study, a new approach for predicting $PM_{2.5}$ levels in the environment is applied by integrating AOD and meteorological data. Traditional $PM_{2.5}$ field measurements are hard to acquire spatial data, particularly at the accurate scale necessary to determine the volatility of high-density cities. Where ground estimations are not possible, RS technology can be used to estimate aerosols and aid in $PM_{2.5}$ evaluation.[18,19] The AOD has been the most often utilized technique in statistical models to forecast $PM_{2.5}$ levels in the environment since it is the easiest to generate.[20,21]

MODIS AOD data is extracted for the appropriate study period from Level 1 and Atmosphere Archive and Distribution System Distributed Active Archive Center (LAADS DAAC) for India, and AOD is computed accordingly. The Simplified Aerosol Retrieval Algorithm (SARA) binning model with the low surface pressure period equation [$PM_{2.5} = 110.5$ [SARA AOD] + 12.56] is used to convert AOD data to $PM_{2.5}$ measurements and the model has been verified.[22] The model relies on meteorological data and has a high degree of correlation between AOD and $PM_{2.5}$ observations. It also improves the regression coefficients of the $PM_{2.5}$ prediction model while incorporating meteorological dimensions. To accurately predict $PM_{2.5}$ data, several equations are established for each meteorological component in the binning approach.[23,24] Among these, the earlier mentioned approach equation predicts best. The model has a high correlation, a precise slope, a lower intercept, and a low error, and it can accurately reflect the spatial distribution of $PM_{2.5}$ in metropolitan areas at 500 m resolution. Fig. 1(A)–(D) represents the $PM_{2.5}$ estimated for India for the study period selected, respectively, as (April–September) 2019, (April–September) 2020, (April 2019–March 2020), and (April 2020–March 2021).

The analysis of the maps prepared for the prelockdown period (April–September 2019) and lockdown period (April–September 2020) reveals the mean concentration of $PM_{2.5}$ levels in the environment to be 64.95 and 62.55 $\mu g/m^3$, respectively. A reduction of a value of 2.40 $\mu g/m^3$ in $PM_{2.5}$ levels occurred during the lockdown period which is caused mainly due to cessation of all anthropogenic activities in the country resulting in an improvement in air quality. Moreover, the analysis of the maps prepared for the period of April–March in 2019–20 and April–March in 2020–21 shows values of $PM_{2.5}$ level to be on a higher side in 2020–21. This is because due to the unlock process numerous activities are carried out within a shorter duration and hence higher values of $PM_{2.5}$ for the period 2020–21.

2.2 Assessment of CO_2 emissions

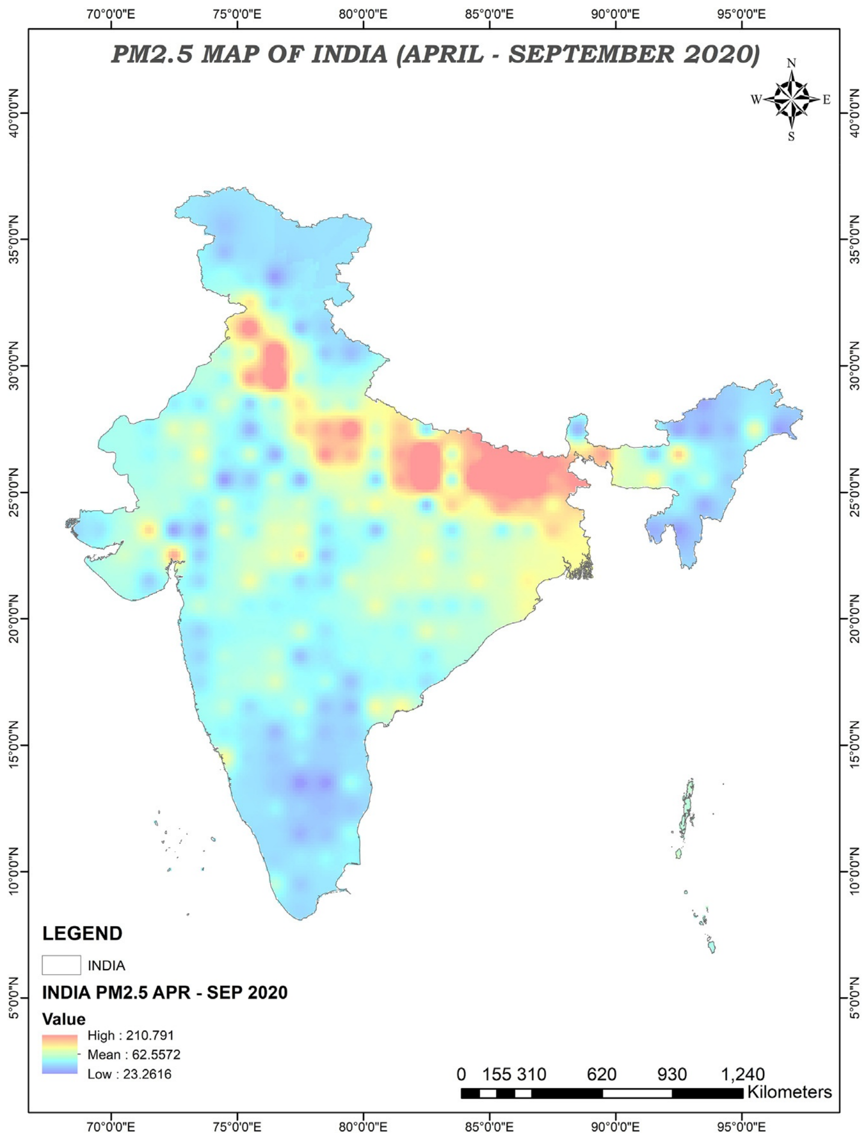
Carbon dioxide emissions are a primary cause of climatic change and global warming. It is emitted into the environment by numerous sectors of society



(a)

Fig. 1 $PM_{2.5}$ Maps of India for (A) (April—September) 2019,

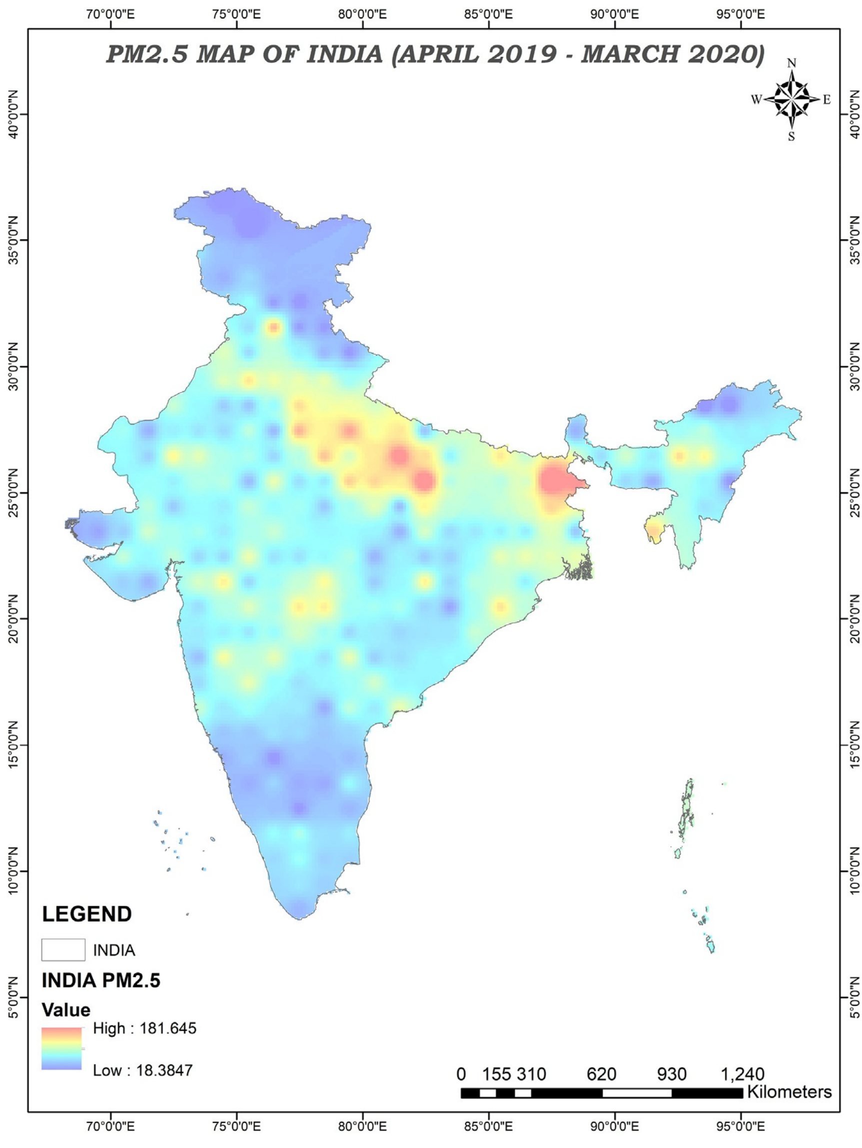
(Continued)



(b)

Fig. 1, cont'd (B) (April—September) 2020,

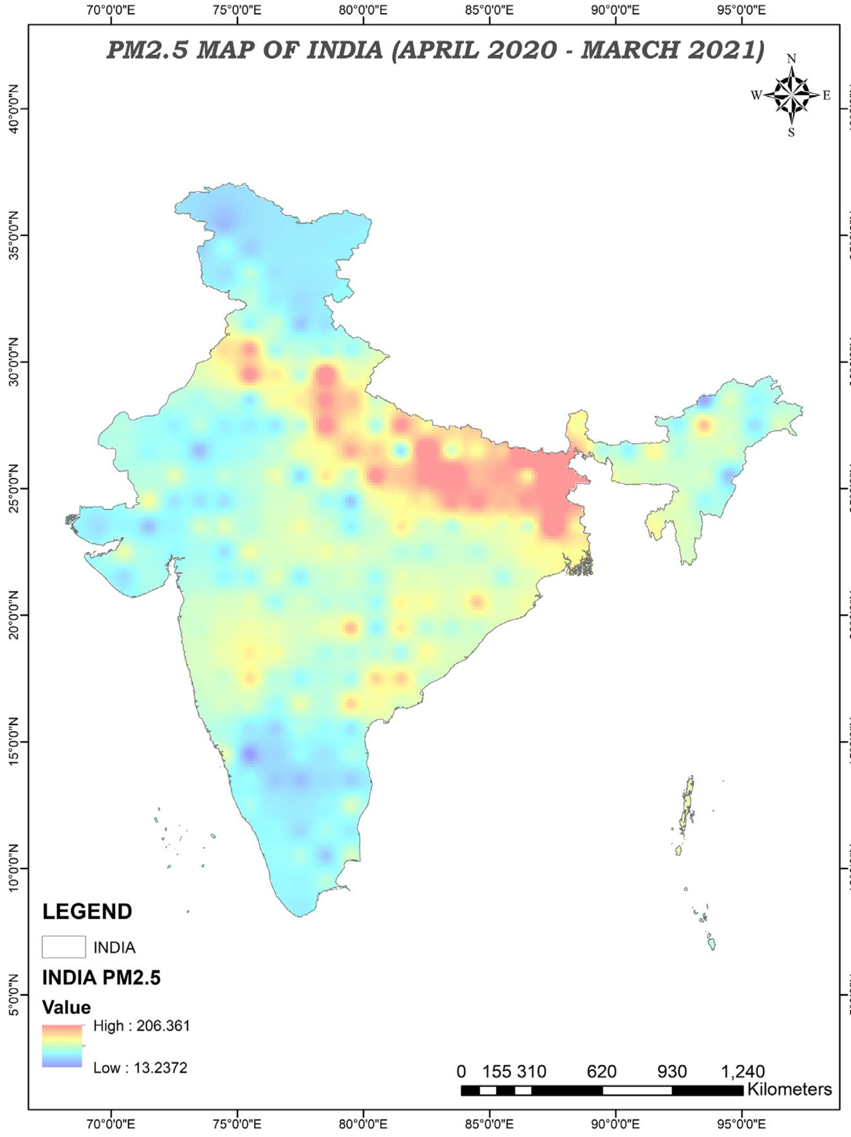
(Continued)



(c)

Fig. 1, cont'd (C) (April 2019—March 2020),

(Continued)



(d)

Fig. 1, cont'd and (D) (April 2020—March 2021).

and as a result of a country's economic operations. It was observed that due to the control techniques adopted during the COVID-19 epidemic, there was a significant reduction in these emissions due to the complete cessation of anthropogenic activities. According to a recent study outlining the impact of COVID-19 on SDGs, there was 26% reduction in CO_2 emissions during the lockdown period compared to 2019 levels.[5] As a result, there was an improvement in the weather conditions. For the assessment of improvement in these climatic conditions and their impact on the SDGs, the CO_2 emissions from fossil fuel use in India for the years 2019 and 2020 are considered and the annual changes in the emissions that occurred due to pandemic management strategies are evaluated.

3. Monetary valuation of $PM_{2.5}$ and CO_2 emissions

3.1 Valuation of $PM_{2.5}$

$PM_{2.5}$ is considered to be a major air pollutant that develops and aggravates respiratory illnesses in humans. Hence the study of its concentration in the environment is important during such a pandemic since the virus adversely affects the person already having the illness. The monetary value of reduced morbidity and mortality associated with COVID-19 management efforts is evaluated using the cost of illness (COI), disability-adjusted life years (DALY), and value of statistical life (VSL). The valuation methodologies are explained as follows.

The morbidity damages are assessed using COI and DALY. The data required for estimating the reduced monetary value of morbidity using the COI approach are taken from the National Sample Survey Office (NSSO) reports specifying the average cost of treatment involved for various diseases.

The DALY assessment of the morbidity loss estimation uses the DALY values determined from the statistics provided in the Global Burden of Diseases study in India in 2019. The COI and DALY assessment gives the total morbidity-related damages that are reduced due to improved air quality from 2019 to 2020.

The valuation of mortality damages cost saved due to the same scenario uses the reference value of VSL from previous studies conducted from labor wages. All the reference values are inflated using average inflation rates and 100 percent exposure is considered. The corresponding assessment equations used for the estimation are detailed as follows:

$$\text{Morbidity damages COI} = \text{COI} \times \text{I}_{\text{ne}} \times \text{IR} \tag{1}$$

$$\text{Morbidity loss DALY} = \text{DALY} \times I_{ne} \times \text{PCR} \times \text{IR} \quad (2)$$

$$\text{Mortality damages VSL} = \text{VSL} \times I_{ne} \times \text{IR} \quad (3)$$

The different attributes considered for the assessment are relative risk of pollutant (R_r), population attribute risk (PAR), rate attribute to exposure in the population (I_e), estimated no. of cases of mortality/morbidity (I_{ne}), and the total population of the city (N). The following attributes are calculated using the equations mentioned below:

$$R_r = 1 + (C_a - C_w) \times \frac{(R_r - 1)}{10} \quad (4)$$

$$\text{PAR} = \left(\frac{\sum([R_r(c) - 1] \times \rho(c))}{\sum([R_r(c) - 1] \times \rho(c) + 1)} \right. \quad (5)$$

$$I_{ne} = I_e \times \text{PAR} \times N \quad (6)$$

3.2 Valuation of CO_2 emissions

The cost of environmental harm caused by CO_2 emissions is calculated using the SCC. SCC, sometimes known as carbon emission shadow pricing, is the most widely used methodology for calculating economic losses caused by carbon dioxide. It illustrates the economic impact of increased CO_2 emissions as a result of climate change. The cost of damage is calculated as the difference between a baseline change in the climatic pathway and an additional rise in CO_2. The assessment method adopted for the current study also utilizes the same approach. For this purpose, the annual changes in the emissions of CO_2 from fossil fuels used in India are considered and it amounts to 30 million tonnes.[25]

The impact of these emission reductions on SDGs are monetarily quantified using the SCC equation provided as follows:

$$\text{SCC} = \text{Quantity of } CO_2 \text{ emitted } (t_{CO_2}) \times \text{Cost of } CO_2 \text{ per tonnes} \times \text{Purchase power parity (PPP)} \quad (7)$$

4. Results and discussions

The valuations of reduced morbidity and mortality damages due to COVID-19 lockdown are carried out and explained in this section based

Table 1 Input values.

Categories	Mean value (PPM)	Population (millions)[26]	Population (lakhs)	Per capita income (INR)[27]
India $PM_{2.5}$ from April to September 2019 (Prelockdown period)	64.9593	1367.6	13,676	92,085
India $PM_{2.5}$ from April to September 2020 (Lockdown period)	62.5572	1378.6	13,786	94,954

Table 2 Relative risk (R_r) and baseline incidence (I_e).[3]

Parameter	Mortality/morbidity	Relative risk (R_r)	Baseline incidence (I_e)
$PM_{2.5}$	Total mortality	1.015	543.5
	Respiratory diseases	1.022	550.9
	Cardiovascular diseases	1.013	546
	Asthma attack	1.021	940
	Chronic bronchitis	1.029	694

Table 3 Reference values.

Parameter	Reference value	References
COI	21,706	28
DALY	0.039	29
VSL	15 Million INR	30

Table 4 Mortality and morbidity damage cost.

Parameter	COI (morbidity damages cost) (Million INR)	DALY (morbidity loss cost) (Million INR)	VSL (mortality damage cost) (Million INR)
PM2.5	934.29	9.76	733,016

on the input values provided in Tables 1–3 and the damage cost estimated are given in Table 4.

4.1 Morbidity and mortality damages assessment

The mean concentration values of $PM_{2.5}$ for the prelockdown and postlockdown period are 64.95 and 62.55 $\mu g/m^3$ which is estimated from the AOD and $PM_{2.5}$ maps prepared. The various health-related problems caused by $PM_{2.5}$ include respiratory diseases, cardiovascular diseases, asthma attacks, and chronic bronchitis. Hence the baseline incidence values for these diseases and for mortality are taken from research studies and the relative risk of each illness is calculated according to Eq. (4) and are provided in Table 2. The study is carried out with the assumption of 100% exposure and hence the population statistics along with the per capita income is given in Table 1 is collected accordingly and the total damage cost of reduced morbidity and mortality using the reference values of COI, DALY, and VSL for India provided in Table 3 is estimated as per Eqs. (1)–(3). The monetary value assessed for the reduced morbidity damages and losses due to COVID-19 lockdown amounts to 943.76 million INR and the total reduced mortality damage cost amounts to 733,016 million INR which is a huge reduction when analyzed and accounts for about 0.5% of the GDP of the country. This is nothing but an improvement in SDGs relating to human health and well-being in the context of air pollution reduction due to COVID-19 lockdown.

4.2 SCC method

The values for the cost of CO_2 per tonne emitted to the atmosphere are taken as per USEPA for the year 2020. Monetary assessment is carried out for average discount rates of 3% and also considering the high impact scenarios. The values taken for the assessment are provided in Table 5.

The annual changes in the emission of CO_2 for the study period are collected from respective references, and the SCC for an average impact scenario yielded a value of 27,707 million INR and the high impact scenario is 81,143 million INR. This monetary quantification of reduced

Table 5 Estimated social cost of carbon (SCC).

Specifications	Values
Annual changes in the emissions of CO_2 (2019–20) (million tonnes)	30[25]
SCC for carbon for 2020 as per USEPA on 3% average discount rates ($)	42[31]
SCC for carbon for 2020 as per USEPA for high impact scenario ($)	123[31]
Purchase power parity (PPP) for 2020	21.99[32]
Estimated social cost of carbon (SCC) for 3% avg discount rates (million INR)	27,707
Estimated social cost of carbon (SCC) for high impact scenario (million INR)	81,143

CO_2 emission reveals the avoided damages to the environment and change in climatic conditions which would occur due to these reduced CO_2 emissions having huge worth.

5. Conclusion

The concept of sustainability is currently gaining a lot of traction all around the world. The SDGs are a major gateway for achieving a brighter future by addressing the world's problems. In the current situation, the goals relating to human health and well-being (SDG-3), as well as climate action (SDG-13), are some of the most important goals. SDG-3 aims to discover and validate all strategies to enhance health and well-being at all stages of life. Its goals encompass facilitating remote healthcare, promoting infection prevention and control through wearable monitoring systems, and tracking aspects that impact human life and well-being, such as air quality and traffic. Climate change is also affecting people and places all around the world today. It is harming lives and destabilizing global markets, injuring individuals, towns, and nations now and even more in the future. SDG-13 calls for action to fight this climate change and its consequences.

The COVID-19, which emerged unexpectedly and without warning, has created some positive impacts in various aspects recently. Due to the control techniques stated to bring the spread of illnesses to a lower value, the world nations that have been actively participating in economic operations and living a frenetic busy existence came to a halt. The continued lockdown strategies of COVID-19 thus became a portal for reduced carbon footprint and improved air quality which resulted due to the termination of anthropogenic activities. Improved air quality and climate conditions due to COVID-19 lockdown have a positive influence on human health which is quantified in monetary terms in this chapter. The quantified positive outcomes have thus impacted and enhanced the targets of SDGs relating the health and climate concerns.

COVID-19's monetary impact on air quality improvement and human health preservation in terms of lower CO_2, $PM_{2.5}$ emissions, mortality, and morbidity presents a clear picture of its influence as a turning point in the stages of growth that contributes to the goals of sustainable development. A reduction of 2.40 $\mu g/m^3$ of $PM_{2.5}$ from prelockdown to lockdown period yielded a total value of 943.76 million INR of reduced morbidity and 733,016 million INR of reduced mortality. The reduction of 30 million tonnes of CO_{2e} emission created a value of 27,707 million

INR for an average impact scenario and yielded 81,143 million INR for the high impact scenario as the reduced damage cost. Hence the current study estimating these reduction impacts reveals that it has a worth of 0.56% of the country's GDP at present. This research demonstrates that the quality of air should be considered as part of a comprehensive strategy for preventing infectious propagation, protecting human life, and achieving long-term environmental sustainability.[33–35] The monetary assessment carried out based on gross calculations and under certain assumptions gives a detailed picture of the kind of losses countries incur regularly due to high air pollution and carbon footprint.

6. Suggestions and future perspectives

These types of estimating methodologies can aid policymakers in developing and implementing programs that promote environmental and human harmony without jeopardizing natural resources. The COVID-19 lockdown-related impacts on SDG-3 and SDG-13 quantified in monetary terms establish the baseline which is achievable through the halt of economic activities. However, halting is not the solution that is being proposed here, rather, it is important to find ways in which the footprint of material and energy extraction and use can be reduced, using mechanisms such as the circular economy. The assessment carried out here, although under certain assumptions and grossing of values, should be improved with robust data for better communication to policymakers. Furthermore, to assess the exact implications of SDGs on COVID-19-related variations, it is necessary to examine local variables in the field, such as socioeconomic class, microclimatic conditions, health and community well-being, available resources, and so on.[35,36] Research and developments in these evaluation approaches may assist in extending these methodologies to evaluate the impact on other SDGs and act as a framework for developing innovative programs to achieve the targets.

References

1. World Health Organization. *Coronavirus disease (COVID-2019) situation reports*. Geneva: World Health Organization; 2020. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports. [Accessed 23 March 2020].
2. Gautam S, Hens L. SARS-CoV-2 pandemic in India: what might we expect? *Environ Dev Sustain* 2020;**22**:3867–9. https://doi.org/10.1007/s10668-020-00739-5.
3. Bherwani H, Nair M, Musugu K, Gautam S, Gupta A, Kapley A, et al. Valuation of air pollution externalities: comparative assessment of economic damage and emission

reduction under COVID-19 lockdown. *Air Qual Atmos Health* 2020;**13**:683–94. https://doi.org/10.1007/s11869-020-00845-3.
4. Gautam S. The influence of COVID-19 on air quality in India: a boon or inutile. *Bull Environ Contam Toxicol* 2020;**104**:724–6. https://doi.org/10.1007/s00128-020-02877-y.
5. Bherwani H, Gautam S, Gupta A. Qualitative and quantitative analyses of impact of COVID-19 on sustainable development goals (SDGs) in Indian subcontinent with a focus on air quality. *Int J Environ Sci Technol* 2021;**18**:1019–28. https://doi.org/10.1007/s13762-020-03122-z.
6. Gautam S. COVID-19: air pollution remains low as people stay at home. *Air Qual Atmos Health* 2020;**13**:853–7. https://doi.org/10.1007/s1186 9-020-00842-6.
7. Hamid MZSA, Karri RR. Overview of preventive measures and good governance policies to mitigate the COVID-19 outbreak curve in Brunei. In: *COVID-19: systemic risk and resilience*. Cham: Springer; 2021. p. 115–40.
8. Nair M, Bherwani H, Kumar S, Gulia S, Goyal S, Kumar R. Assessment of contribution of agricultural residue burning on air quality of Delhi using remote sensing and modelling tools. *Atmos Environ* 2020;**230**:117504. https://doi.org/10.1016/j.atmosenv.2020.117504.
9. Khetrapal S, Bhatia R. Impact of COVID-19 pandemic on health system & Sustainable Development Goal 3. *Indian J Med Res* 2020;**151**:395–9. https://doi.org/10.4103/ijmr.IJMR_1920_20.
10. Mukherjee A, Babu SS, Ghosh S. Thinking about water and air to attain Sustainable Development Goals during times of COVID-19 pandemic. *J Earth Syst Sci* 2020;**129**:180. https://doi.org/10.1007/s12040-020-01475-0.
11. Gupta A, Bherwani H, Gautam S, Anjum S, Musugu K, Kumar N, et al. Air pollution aggravating COVID-19 lethality? Exploration in Asian cities using statistical models. *Environ Dev Sustain* 2021;**23**:6408–17. https://doi.org/10.1007/s10668-020-00878-9.
12. Wathore R, Gupta A, Bherwani, Labhasetwar N. Understanding air and water borne transmission and survival of coronavirus: insights and way forward for SARS-CoV-2. *Sci Total Environ* 2020;**749**:141486. https://doi.org/10.1016/j.scitotenv.2020.141486.
13. Mousazadeh M, Naghdali Z, Rahimian N, Hashemi M, Paital B, Al-Qodah Z, et al. Management of environmental health to prevent an outbreak of COVID-19: a review. In: *Environmental and health management of novel coronavirus disease (COVID-19)*; 2021. p. 235–67.
14. Kumar H, Azad A, Gupta A, Sharma J, Bherwani H, Labhsetwar NK, et al. COVID-19 creating another problem? Sustainable solution for PPE disposal through LCA approach. *Environ Dev Sustain* 2021;**23**:9418–32. https://doi.org/10.1007/s10668-020-01033-0.
15. Filho WL, Azul AM, Wall T, Vasconcelos CRP, Salvia AL, et al. COVID-19: the impact of a global crisis on sustainable development research. *Sustain Sci* 2021;**16**:85–99. https://doi.org/10.1007/s11625-020-00866-y.
16. Frederick S. *Impact of COVID-19 on the sustainable development goals: pursuing the sustainable development goals (SDGs) in a world reshaped by COVID-19*. UNDP; 2020.
17. Gomiščček B, Hauck H, Stopper S, Preining O. Spatial and temporal variations of PM1, PM2. 5, PM10 and particle number concentration during the AUPHEP—project. *Atmos Environ* 2004;**38**(24):3917–34. https://doi.org/10.1016/j.atmosenv.2004.03.056.
18. Al-Saadi J, Szykman J, Pierce RB, Kittaka C, Neil D, Chu DA, et al. Improving national air quality forecasts with satellite aerosol observations. *Bull Am Meteorol Soc* 2005;**86**(9):1249–62. https://doi.org/10.1175/BAMS-86-9-1249.
19. Gupta P, Christopher SA, Wang J, Gehrig R, Lee Y, Kumar N. Satellite remote sensing of particulate matter and air quality assessment over global cities. *Atmos Environ* 2006;**40**(30):5880–92. https://doi.org/10.1016/j.atmosenv.2006.03.016.

20. Clarke AD, Collins WG, Rasch PJ, Kapustin VN, Moore K, Howell S, et al. Dust and pollution transport on global scales: aerosol measurements and model predictions. *J Geophys Res-Atmos* 2001;**106**(D23):32555–69. https://doi.org/10.1029/2000JD900842.
21. Holben BN, Tanre D, Smirnov A, Eck TF, Slutsker I, Abuhassan N, et al. An emerging ground-based aerosol climatology: aerosol optical depth from AERONET. *J Geophys Res-Atmos* 2001;**106**(D11):12067–97. https://doi.org/10.1029/2001JD900014.
22. Bherwani H, Kumar S, Musugu K, Nair M, Gautam S, Gupta A, et al. Assessment and valuation of health impacts of fine particulate matter during COVID-19 lockdown: a comprehensive study of tropical and sub tropical countries. *Environ Sci Pollut Res* 2021;**28**(32):44522–37. https://doi.org/10.1007/s11356-021-13813-w.
23. Bilal M, Nichol JE, Spak SN. A new approach for estimation of fine particulate concentrations using satellite aerosol optical depth and binning of meteorological variables. *Aerosol Air Qual Res* 2016;**17**(2):356–67. https://doi.org/10.4209/aaqr.2016.03.0097.
24. Bherwani H, Anjum S, Kumar S, Gautam S, Gupta A, Kumbhare H, et al. Understanding COVID-19 transmission through Bayesian probabilistic modeling and GIS-based Voronoi approach: a policy perspective. *Environ Dev Sustain* 2020;**23**:5846–64. https://doi.org/10.1007/s10668-020-00849-0.
25. *Annual change in carbon dioxide (CO_2) emissions in India*. https://www.statista.com/statistics/1119152/annual-carbon-dioxide-change-in-india/. [Accessed 13 July 2021].
26. *Estimated total population in India*. https://www.statista.com/statistics/263766/total-population-of-india/. [Accessed 13 July 2021].
27. *Value of per capita income across India*. https://www.statista.com/statistics/935754/india-per-capita-income-value/. [Accessed 13 July 2021].
28. *Health in India*. India: National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India; 2014.
29. Madheswaran S. Measuring the value of statistical life: estimating compensating wage differentials among workers in India. *Soc Indic Res* 2007;**84**(1):83–96. https://doi.org/10.1007/sll205-006-9076-0.
30. India State-level Disease Burden Initiative Air Pollution Collaborators. *Lancet planet health*; 2021. e25 – 38:5.
31. Bherwani H, Gupta A, Nair M, Sonwane H. *Framework for environmental damages cost assessment with examples. Special report on monetising damages*. Nagpur: CSIR-National Environmental Engineering Research Institute [NEERI]; 2019.
32. *Purchasing power parity values for India*. https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm. [Accessed 13 July 2021].
33. Chen H, Guo J, Wang C, Luo F, Yu X, Zhang W, et al. Clinical characteristics and intrauterine vertical transmission potential of COVID-19 infection in nine pregnant women: a retrospective review of medical records. *Lancet* 2020;**395**(10226):809–15. https://doi.org/10.1016/S0140-6736(20)30360-3.
34. Bherwani H, Gupta A, Anjum S, Anshul A, Kumar R. Exploring dependence of COVID-19 on environmental factors and spread prediction in India. *NPJ Clim Atmos Sci* 2020;**3**(38). https://doi.org/10.1038/s41612-020-00142-x.
35. Kaur S, Bherwani H, Gulia S, Vijay R, Kumar R. Understanding COVID-19 transmission, health impacts, and mitigation: timely social distancing is the key. *Environ Dev Sustain* 2020. https://doi.org/10.1007/s1066 8-020-00884-x.
36. Bherwani H, Singh A, Kumar R. Assessment methods of urban microclimate and its parameters: a critical review to take the research from lab to land. *Urban Clim* 2020;**34**(2):100690. https://doi.org/10.1016/j.uclim.2020.10069 0.