Interactions between climate and COVID-19

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In this Personal View, we explain the ways that climatic risks affect the transmission, perception, response, and lived experience of COVID-19. First, temperature, wind, and humidity influence the transmission of COVID-19 in ways not fully understood, although non-climatic factors appear more important than climatic factors in explaining disease transmission. Second, climatic extremes coinciding with COVID-19 have affected disease exposure, increased susceptibility of people to COVID-19, compromised emergency responses, and reduced health system resilience to multiple stresses. Third, long-term climate change and prepandemic vulnerabilities have increased COVID-19 risk for some populations (eg, marginalised communities). The ways climate and COVID-19 interact vary considerably between and within populations and regions, and are affected by dynamic and complex interactions with underlying socioeconomic, political, demographic, and cultural conditions. These conditions can lead to vulnerability, resilience, transformation, or collapse of health systems, communities, and livelihoods throughout varying timescales. It is important that COVID-19 response and recovery measures consider climatic risks, particularly in locations that are susceptible to climate extremes, through integrated planning that includes public health, disaster preparedness, emergency management, sustainable development, and humanitarian response.

Lancet Planet Health 2022; 6: e825–33

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Introduction

First reported to WHO in 2019 as a cluster of cases of pneumonia of unknown cause, COVID-19 (SARS-CoV-2) rapidly spread around the globe via highly connected global travel networks. It has now reached the most remote areas of the world, including Indigenous Amazonian communities and the polar regions,[1,2] with 599 071 265 confirmed cumulative cases and 6 467 023 cumulative deaths worldwide reported as of Aug 30, 2022.[3] COVID-19 is an unprecedented challenge to humanity, with widespread implications for health, economic development, and wellbeing that weaken progress made in achieving the UN Sustainable Development Goals.[4]

The COVID-19 pandemic is exacerbating existing inequalities, with marginalised and vulnerable groups experiencing higher numbers of infections and deaths, increased poverty, and growing deficits in education.[4–7] The reasons for this exacerbation of inequalities vary by context, but include the necessity of social contact for work, high population density, variable health-care provision and availability, and minimal or absent social protection. Unemployment as a result of COVID-19 has tended to affect individuals who work in the informal sector or in insecure jobs the most, as their livelihoods are at greatest risk of being made redundant due to government attempts to control the spread of the SARS-CoV-2 virus (eg, through lockdowns, and limits to transportation and mobility).[8] These individuals in precarious employment are more likely to be part of marginalised communities.[8] Diverse policies have been implemented to control the COVID-19 pandemic, including national and regional lockdowns, physical distancing measures, and compulsory face mask wearing in public spaces. Vaccines began to be administered to the public in 2020 in some, mostly high-income, countries. These policies have had varying degrees of success, but have also created new challenges to health, livelihoods, and wellbeing. At various stages of the pandemic, governments have been forced to develop and adjust policies to restrict the effects of COVID-19 response measures (eg, supplement lost wages or campaign to get people to return to restaurants). However, efforts to control other diseases (eg, tuberculosis, malaria, and dengue fever) have been affected by these policies, introducing difficulties for conditions that require chronic care.[9]

In a highly interconnected world, COVID-19 intersects with diverse regional and global challenges, such as inequality, conflict, nationalism, increasing commodity prices, and environmental change. Although the dynamics of the interactions between COVID-19 and these challenges are poorly understood, with little research taking a holistic look at how COVID-19 intersects with these diverse challenges, their co-occurrence can create effects that have consequences in areas other than the health domain and can weaken the resilience of multiple sectors of social–ecological systems.[4,10–12] The potential for compound risks or complex health emergencies could be counteracted by changes that have enhanced health and livelihoods, including technological developments, food sovereignty, improved communications technology, community empowerment, and lessons from previous pandemics.

The emergence of COVID-19 coincided with one of the hottest years on record globally (2020). 2020 and 2021 were characterised by notable climatic extremes, creating substantial interest in the intersection of the COVID-19 pandemic with climate risks. Research to date has investigated lessons learned from COVID-19 for climate policy,[10,13–15] disaster preparedness,[16,17] and support for climate action;[18,19] compared the politics of responding to COVID-19 with the politics of responding to climate

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***Panel:* Summary of case studies to show how COVID-19 and climate interact**

- The Sri Lanka case study shows the interactions between air quality and deaths, examining the climatic risks and responses of Coastal-Vedda communities to COVID-19 (appendix pp 2–4)
- The India case study reports the risks of cyclones and COVID-19 and how they are affecting the livelihoods of people and jeopardising physical distancing (appendix pp 4–5)
- The Russia case study focuses on wildfires that have affected remote Indigenous communities during the COVID-19 pandemic (appendix p 6)
- The Fiji case study reports on how COVID-19 restrictions delayed aid responding to tropical cyclones in a population with a high prevalence of non-communicable diseases (appendix pp 7–8)
- The Uganda case study shows how flooding and landslides before and during the COVID-19 pandemic lockdowns increased the risk to health, livelihoods, and wellbeing for Indigenous populations (appendix pp 9–10)
- The South Africa case study reports the long-term effects of climate change on food and water security, increasing vulnerability to water and food insecurity, and weakening community resilience to COVID-19 (appendix pp 11–13)
- The Peruvian case study shows how poorly prepared the health system in Peru was to respond to the COVID-19 pandemic, especially in the Amazon region, and how endemic climate-sensitive diseases (eg, dengue fever) increased the difficulty of identifying COVID-19 cases (appendix pp 14–15)

change;[20] examined implications of the pandemic for greenhouse gas emissions[21,22] and the environment as a whole;[23,24] and focused on how to improve the sustainability of recovery packages to fulfil the UN Build Back Better campaign goals.[25–27] Studies have also focused on the associations between weather and COVID-19 transmission and, to a lesser extent, the ways climatic factors affect lived experience of and response to COVID-19.[28–35] These studies have improved understanding of how environmental change and the pandemic interact, but typically only focus on particular regions, sectors, or geographical scales, and rarely focus on the interactions between multiple risks.[9,12,36,37]

In this Personal View, we explain the ways climatic risks can affect the transmission, perception, response, and lived experience of COVID-19. We also provide case studies that show ongoing work with Indigenous people and other marginalised communities as part of the COVID Observatories, an international research programme working in multiple nations of varying incomes to document lived experiences of, effects of, and policy responses to COVID-19 in the context of climate risks (panel; appendix pp 2–15). This Personal View is influenced by concepts from health geography,[38] sustainability science,[39] and planetary health.[40] These concepts bring attention to the complex interactions between natural and human systems that affect the emergence, spread, and effects of disease in the context of environmental risks. Research in these areas emphasises the importance of political, economic, social, and biomedical factors operating across local to global scales, and views health as encompassing not only the presence or absence of illness but also physical, mental, and sociocultural wellbeing.[41]

See **Online** for appendix

Climatic risks influencing the transmission of COVID-19

COVID-19 transmission mostly occurs through close contact between an infected person and an uninfected person through exposure to aerosols or droplets carrying the infectious SARS-CoV-2 virus. Contact with contaminated surfaces or objects can also transmit COVID-19, but the risk of infection is much lower.[42] This implies that the presence, survival, and infectivity of a virus in the air and on object surfaces could be affected by environmental conditions, such as temperature, humidity, precipitation, air quality, and type of surface.[29,43,44] As the SARS-CoV-2 virus has been isolated from stool and urine samples, other methods of transmission and the association with environmental factors, including water and food sources, are also being investigated.[45]

Studies examining the links between climatic factors and COVID-19 have drawn inconclusive results.[29,33,43,46–49] In Brazil, for example, some research has shown that COVID-19 infection rates are inversely correlated with temperature,[50] whereas other studies have documented that high mean temperatures were associated with increased COVID-19 transmission.[51,52] There is little understanding about the effects of humidity, wind, and solar radiation on COVID-19 transmission. Whether climatic factors affect SARS-CoV-2 itself or influence transmission by changing the behaviours, and therefore exposures, of people remains unclear. Some of the differences in results across studies reflect the wide range of statistical and modelling approaches used and the temporal scope of data analysed, and suggest that non-climatic factors are typically more important than climatic factors in disease transmission[53] as climatic factors alone are not large enough to control the COVID-19 pandemic.[28,33–35] As the pandemic has progressed and COVID-19 has become global, the robustness of early studies suggesting strong links between climate and COVID-19 have been questioned.[33,34,47,54,55] Reviewing these studies, Gutiérrez-Hernández and García[34] argue that evidence of climate influences on COVID-19 is not robust enough to be considered in public health policies.

There is negligible evidence that climate change will directly or substantively affect COVID-19 transmission in the long term. There is, however, evidence of links between air pollution and COVID-19 transmission. Multiple studies show strong correlations between particulate matter (PM) from fossil fuel combustion (eg, $PM_{2·5}$) and high rates of COVID-19 infection and mortality (appendix pp 2–4);[30,56–60] although the evidence remains merely associational.

Coinciding risks of climatic extremes and COVID-19

Globally, the beginning of the COVID-19 pandemic intersected with one of the hottest years on record (2020). 2020 and 2021 also had several extreme climatic events, including wildfires (eg, in Siberia, North America, and Türkiye); hurricanes and tropical storms (eg, in Fiji and the Bay of Bengal); floods (eg, in southern China, Pakistan, and Germany); droughts (eg, in west USA); and heatwaves (eg, in Canada). Although not all of these events are directly attributable to climate change, trends in the intensity and frequency of some climate and weather extremes have been detected. The World Meteorological Organization and Intergovernmental Panel on Climate Change note a clear effect of anthropogenic climate change on many of these extreme events.[61,62] The people and communities with the highest exposure to climatic extremes have also experienced more infections of and deaths from COVID-19,[63–66] creating a double burden to affected individuals. Evidence of the interaction between climatic extremes and COVID-19 has only just begun to emerge, with several discernible potential links (eg, direct effects on livelihoods or indirect effects on maternal health and nutrition). Different types of inequalities are increasingly known to interact to exacerbate vulnerability to a range of different health, social, and environmental hazards; COVID-19 has revealed how ubiquitous these interactions are.

Modified disease exposure

Extreme weather events result in mass displacement (eg, evacuation, migration, and mass sheltering), thereby introducing diseases into new regions, clustering survivors in temporary accommodation with little or no ventilation, increasing amounts of social contact, and making face masks difficult to use (eg, during temperature extremes).[30,31,67] In these situations, physical distancing is more challenging than in typical conditions, with guidelines for separation insufficient in enclosed spaces, such as shelters, and challenging to practise during evacuations (appendix pp 4–5).[64,68] Regular handwashing can also be difficult in these situations, in which hygiene facilities might be disrupted due to breakage or contamination of water and sanitation systems.[69,70] The COVID-19 pandemic could also amplify pre-existing inequalities in access to safe drinking water.[71] For example, in Namibia, movement restrictions and lockdowns hindered the ability of individuals to earn daily wages to pay for drinking and washing water, leading to an inability to observe all the COVID-19 protocols. Heavy rainfall events might potentially increase the risks of faecal-oral transmission of COVID-19 by causing sewage system overflows; the virus has been detected in human faeces and urine where it can remain viable for days.[72,73] Although research suggests COVID-19 transmission is largely airborne,[74] handwashing remains one of the most recommended preventive measures.

Increased susceptibility to COVID-19 through wildfire smoke inhalation

Previous exposure to smoke from wildfires has been linked to increased morbidity from influenza,[75] leading to concern about increased risk of COVID-19 infection associated with wildfires.[76–78] Wildfire smoke contains small particles ($PM_{2·5}$) that penetrate the lungs, causing irritation and inflammation and conceivably increasing the risk of COVID-19 infection. Individuals most at risk of enhanced susceptibility to respiratory infection due to wildfire smoke exposure are children and infants with small lung size and individuals with pre-existing lung or heart conditions.[78,79] Several large wildfires have coincided with the COVID-19 pandemic—notably in Siberia, California (USA), British Columbia (Canada), Türkiye, and the Brazilian Amazon—with studies documenting trends of increasing wildfire activity in some regions compared with previous years, driven partly by climate change and other anthropogenic factors, such as land management practices (appendix p 6).[77,80,81] Individuals with COVID-19-related pulmonary or cardiac impairment are at high risk of illness and death from wildfire-related smoke (and heatwaves).[30] Smoke from the 2020 California wildfire season also impacted people's lives during the pandemic by necessitating further restrictions on outdoor activities and exacerbating social isolation; with potential mental health implications.[76]

Compromised emergency response and reduced health system resilience

Climate-related disasters can challenge COVID-19 responses from governments and public health systems by disrupting supply chains, restricting access to humanitarian aid, and reducing the number of mobilisable health-care staff and resources (appendix pp 7–10).[30,82,83] Access to health-care services is an important factor in assessing the capacity of a health system to respond to risks and effects of climate-related disasters.[84,85] Extreme climatic events reduce patients' ability to seek treatment and access care for COVID-19. Climate hazards also cause problems in the delivery of public services (eg, disruption of power supplies and emergency services).[30,82] These events can also make contact tracing difficult as people move and intermingle (eg, in response to flooding).[73]

Actions taken to control COVID-19 could also increase the vulnerability of individuals and health-care services to climatic risks. Orders to stay at home and concerns about COVID-19 might result in people failing to heed evacuation orders, leading to preventable injury and death.[31,86] COVID-19 has also created challenges for managing extreme climatic events. For example, efforts to control wildfires in California were restricted by high heat, low humidity, high winds, and no people living in prison who are available to work (an integral part of fire control in the state) due to high infection rates within the prison population.[76] Measures for responding to climatic extremes can be incompatible with efforts to control COVID-19, leading to confusion, contradictory messaging, and uncertainty about whether to follow COVID-19 control efforts or not. These examples show how multiple risks can all affect health systems, leading to negative outcomes for people and locations with low capacities to respond to COVID-19.

Long-term climate change, community vulnerability, and increased COVID-19 risk

The effects of climate change have been observed globally in diverse regions,[87,88] with implications for community vulnerability to diverse threats, including COVID-19. In a modelling study, Ozkan and colleagues[89] showed that countries with high climatic risk also had a higher COVID-19 mortality rate than countries with low or no climatic risk. The apparent clustering of climate and COVID-19 vulnerabilty in particular regions and communities shows the potential for direct or indirect effects of the interaction between COVID-19 and climate, and that similar factors often drive both climate risk and COVID-19 risk, with climate risk also leading to specific conditions that result in increased COVID-19 risk.

Direct effects of climate change include damaging or undermining health and emergency response infrastructure. For example, in Peru, the 2017 El Niño Costero event severely damaged 934 health posts (primary care health centres) via flooding. Few of these posts had been rebuilt when COVID-19 happened, compromising pandemic planning and management.[37] Severe and long-lasting drought in some regions has negatively affected food systems, leading to malnourishment, poverty, increased sensitivity of individuals to COVID-19, and restricting access to clean water, which is essential for controlling the transmission of COVID-19 (appendix pp 11–13).[11,12,24,31] Heavy rainfall in south Namibia aggravated food insecurity by depleting household food stocks and increasing reliance on markets, which are costly and were difficult to reach due to flooding.

Indirect effects of climate change include long-term climate change interacting with social, economic, political, and cultural factors; undermining adaptive capacity to manage COVID-19; and increasing sensitivity of individuals and health-care systems to COVID-19. For example, Indigenous populations in South America are among some of the communities most affected by the COVID-19 pandemic.[90] Climate change has exacerbated pre-existing problems from structural inequalities, marginalisation, land dispossession, and government policy and has increased vulnerability to a diversity of threats (appendix pp 14–15).[91–94] In the Peruvian Amazon, changes to precipitation regimes, seasonality, hydrology, and temperatures have negatively affected Indigenous food systems by disrupting community fisheries, reducing access to and availability of highly valued forest animals, and reducing opportunities to develop and acquire traditional knowledge.[95] As some Indigenous communities in the Peruvian Amazon are currently encountering different forms of malnutrition,[95] climate-related food shortages risk affecting both the availability and the quality of food sources (eg, fresh vegetables and fish), suggesting that nutritional consequences will be observed in future generations.[96] Among reindeer herders in Siberia, Stammler and Ivanova[32] report how the cumulative effects of frequent climate-induced disasters (eg, large numbers of reindeer dying because of pasture icing events or an anthrax outbreak) have resulted in an increase in conspiracy theories, in which disasters such as COVID-19 are viewed as being caused by malevolent human forces that are beyond the control of herders. In this context, lockdowns imposed by regional or federal governments are seen as an attack on nomadic life, with implications for acceptance of control measures.

Discussion

In this Personal View, we explain the ways climatic risks might affect the transmission, perception, response, and lived experience of COVID-19, focusing on long-term climate change and sporadic extremes during the pandemic. The COVID-19 pandemic is ongoing, and therefore some interactions between climate and COVID-19 are probably not discernible at the time of writing and will emerge in the future. Understanding the links between the COVID-19 pandemic and climate change is essential to advance the field of planetary health, particularly in terms of the effects across daily life activities and professions. The potential interactions between COVID-19 and climate described in this Personal View offer a portent of how society might be affected by future compounding climatic risks as the COVID-19 pandemic continues to develop alongside an increase in severe and frequent climatic extremes.

In this Personal View we propose a conceptual model of how climate and COVID-19 risks interact (figure). The model places COVID-19 risk in specific locations and populations at the centre of analysis, emphasising both direct and indirect effects of COVID-19 on these populations. The model shows the complex societal, environmental, and health factors affecting how climatic risks and COVID-19 interact at different scales. These interactions could lead to vulnerability, resilience, transformation, or collapse of health systems, communites, and livelihoods throughout varying timescales, which changes depending on the phase of the COVID-19 pandemic a society is in. The model also shows important drivers and considerations for understanding the interaction between climate risks and COVID-19 using the published literature and research done as part of the COVID Observatories project.

Climate and other interacting factors affecting COVID-19 risk

Relationships between human society, the natural environment, and disease are affected by multiple, synchronous stressors.[39] Stressors come from rapidly developing threats, such as COVID-19 emergence and policy response, climate extremes, ecosystemic stress, changes to livelihood, food prices, protests, and market access. These threats, known as fast variables, interact with and are affected by long-term changes in society, human–environment interactions, and the natural environment. So-called slow variables include globalisation, conflict, development, colonisation, demographics, and environmental change. The interaction of fast and slow variables affects how climate and COVID-19 interact in specific locations, in which feedbacks, thresholds, and non-linear responses can result in rapid and immediate or slow and transitional outcomes. The complexities of these interactions are poorly understood and in some instances could lead to resilience to multiple interacting stressors (appendix pp 2–5, 11–13). In remote Indigenous communities in the Arctic, for example, a high amount of vigilance, travel restrictions, and rapid vaccinations have managed to keep infection rates low, despite the presence of underlying COVID-19 risk factors in Indigenous populations and climatic warming rates that are 3 times faster than the global average.[2] In Amazonia, some Indigenous communities have enforced strict measures regarding entry to their communities, showing self-determination and implementation of medical Indigenous strategies to control COVID-19.[92,97,98] For the Asháninka people in Peru, for example, the inability to travel to markets was an opportunity for people to revalue traditional knowledge of food sovereignty. Cities in South Africa have seen a rise in home gardens since the beginning of the COVID-19 pandemic to improve food security.[99]

Interaction between climate and COVID-19

The ways that climate and COVID-19 interact vary between and within populations and regions, intersecting with gender, ethnicity, culture, livelihoods, income, and access to health care to create differential risks. Evidence indicates that proactive responses to climatic risks and COVID-19 can moderate risks (eg, health, livelihoods, and wellbeing), emphasising the importance of planning and implementation of early and ongoing action, communication, flexible funding mechanisms, capacity building, and monitoring and evaluation of policies and responses.[37,100] Japan and South Korea had COVID-19 resurgences during the summer of 2020 after a category four typhoon, but were able to control the spread.[101] Responses to COVID-19 might only require minor alterations to existing hazard preparedness plans,[37] although substantial challenges, including an absence of tools for managing compound risks, unprecedented uncertainty, data scarcity, competing policy options, marginalisation, and inequality, have been identified as major constraints.[24,102,103] The effectiveness of a health system depends on its ability to help vulnerable populations; consider the intersections of gender, ethnicity, rights, and other influential factors; and consider the influence of these factors on differential health outcomes.[85] Integrated services and collaboration across sectors will be crucial in establishing effective and equitable health system prevention, detection, and responses to COVID-19.[84,85,104]

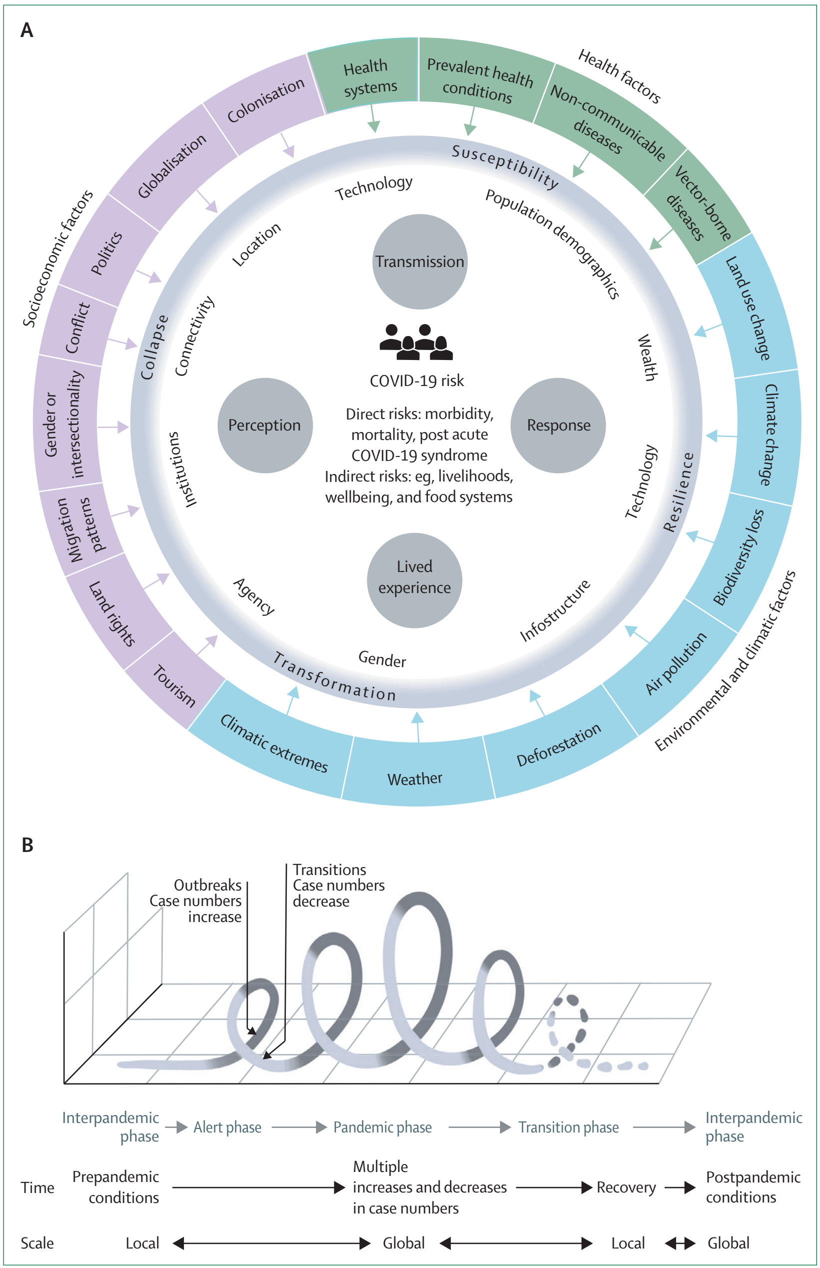

***Figure:* Conceptual model of the complex interactions between COVID-19 and climate risk**

(A) The multiple environmental, socioeconomic, and health factors affecting COVID-19 risk. (B) Different phases of the COVID-19 pandemic (eg, increasing and decreasing numbers of cases) across time and geographical scales.

The characteristics of individuals and their interaction with the pathological agent (SARS-Cov-2) modulate the severity of the effects of climate risk on COVID-19. Some of these characteristics have also been reported to be associated with adverse outcomes as a result of climatic extreme events (eg, fast variables),[105] suggesting that people with these characteristics would be more vulnerable to risks of COVID-19 and climate than people without these characteristics. For example, older adults and people living with particular non-communicable diseases are more likely to die during heatwaves.[106–108] The risk of developing severe forms of COVID-19 infection are higher in people with diabetes.[109] These two groups might therefore be vulnerable to compounding health risks from extreme heat and COVID-19 outbreaks. A high BMI is also associated with increased risk of severe COVID-19 disease.[110] The prevalence of overweight in many low-income and middle-income countries is increasing as food systems and food environments change (eg, slow variables), meaning that these populations could become more susceptible to severe health impacts from outbreaks of infectious diseases, such as COVID-19 (appendix p 7).[83]

COVID-19 measures, climate change, and increased climate variability

Policy responses to COVID-19 have prioritised controlling the spread of the SARS-CoV-2 virus.[111] While these public health measures were often necessary tools to confront the COVID-19 pandemic they have also increased poverty, reduced market access, and restricted mobility in many locations, and might consequently have increased vulnerability to climatic extremes and long-term climate change. As the COVID-19 pandemic continues to affect communities globally, it is important that planning and response considers these implications, as well as the complications from ongoing climate extremes.[10] Connecting research, practitioner, and policy-making communities within public health, disaster preparedness, emergency management, humanitarian response, and development planning sectors is imperative for informing more integrated responses across sectors and geographic scales. For example, responses to challenges affecting health, livelihoods, and wellbeing have had success in reducing disruption caused by COVID-19 and climate extremes (appendix pp 16–17).

The COVID-19 pandemic has shown the importance of challenging underlying inequalities and injustices that increase vulnerability to health emergencies and climate change. It also highlights deficits in existing efforts to adapt to climate change. For example, few climate adaptation actions integrate pandemic preparedness or have contingency plans for major or rare events, which might affect their implementation and effectiveness.[112] To fulfil the UN Build Back Better campaign goals, a comprehensive analysis of the multiple climatic risks that influence transmission, lived experiences, and responses to COVID-19 is required; as is an analysis of the underlying socioeconomic, political, and cultural factors that create pandemic vulnerability or provide opportunities to protect human health. Political incentives for focusing on short-term projects and results and nationalism motivate inadequate responses to both climate and pandemic risk. New political institutions and interventions that increase the focus on long-term projects and results and global cooperation will help with both climate change and future pandemic risk.

Contributors

JDF and CZ-C conceptualised the piece. JDF, CZ-C, DN, CS, LB-F, KH, JJM, and MN acquired funding. JDF, CZ-C, TA, CA-R, IA-R, JB, VC-Z, EKG, MH, CK, SL, DN, NN, RN, SO, MO, KP, and CS did investigations for the case studies. JDF, CZ-C, and LBF conducted the method. Project administration was done by CA-R. CZ-C, CA-R, EKG, KP, and CS created the figures. The original draft was written by JDF, CZ-C, LB-F, TA, CA-R, IA-R, JB, VC-Z, EKG, MH, CK, SL, DN, MN, NN, RN, SO, MO, KP, and CS. Reviewing and editing was done by JDF, CZ-C, TA, CA-R, IA-R, JB, VC-Z, EKG, MH, CK, SL, DN, NN, RN, SO, MO, KP, CS, LB-F, KH, JJM, AN, MN, and BvB.

Declaration of interests

The COVID-19 Observatory (project reference number: EP/V043102/1) is funded by a collective fund award from the UK Research and Innovation Global Challenges Research Fund and Newton Fund; the Foreign, Commonwealth & Development Office; and International Programme—Russia (Arctic Voices, 2021 006). CZ-C was supported by the National Institute for Health Research (NIHR) through the Official Development Assistance Funding of the UK and Wellcome (218743_Z_19_Z) under the NIHR-Wellcome Partnership for Global Health Research. The views expressed are those of the authors and not necessarily those of Wellcome, the NIHR, or the Department of Health and Social Care. All other authors declare no competing interests.

Acknowledgments

The COVID-19 Observatory would like to acknowledge the Indigenous Peoples and representatives from Uganda (Batwa), Namibia (Ovambo), Ghana (Dagaaba), South Africa (Xhosa), Peru (Asháninka, Shawi), Bolivia (Guarani, Amazónicos, Quechuas, and Aymaras), Sri Lanka (coastal-Vedda), India (Irula, Badaga, Toda, Kota, and Kurumba), Fiji (iTaukei), Russia (Even), Australia (Gubbi Gubbi), and Canada (Inuit), without whose collaboration this project would not be possible. In Peru, we would like to thank Ketty Marcelo Lopez and the Indigenous organisation she belongs to, Organización de Mujeres Indígenas Amazónicas Ashaninkas de la Selva Central (OMIAASEC). We are also grateful for the support in the visualisation of this Personal View prepared by Carlee Wright.

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