Synergies Between COVID-19 and Climate Change Impacts and Responses

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Abstract:
The COVID-19 pandemic and anthropogenic climate change are global crises. We show how strongly these crises are connected, including the underlying societal inequities and problems of poverty, substandard housing and infrastructure including clean water supplies. The origins of all these crises are related to modern consumptive industrialisation, including burning of fossil fuels, increasing human population density, and replacement of natural with human dominated ecosystems. Because business as usual is unsustainable on all three fronts, transformative responses are needed. We review the literature on risk management interventions, implications for COVID-19, for climate change risk and for equity associated with biodiversity, water and WaSH, health systems, food systems, urbanization and governance. This paper details the considerable evidence base of observed synergies between actions to reduce pandemic and climate change risks while enhancing social justice and biodiversity conservation. It also highlights constraints imposed by governance that can impede deployment of synergistic solutions. In contrast to the response to the COVID-19 pandemic, governance systems have procrastinated on addressing climate change and biodiversity loss as these are interconnected chronic crises. It is now time to address all three to avoid a multiplication of future crises across health, food, water, nature, and climate systems.

Keywords: climate adaptation, COVID-19 pandemic, sustainable development, biodiversity loss, co-benefits, urban systems

1. Introduction

The continuing COVID-19 pandemic has generated the deepest global recession since WWII (IMF 2021), with wide ranging additional social costs, including school closures affecting 1.6 billion students (World Bank 2020), and as early as May 2020, almost 150 million job losses (Lenzen et al. 2020a). Preventative measures, including reforms to ecological stewardship, health systems, and equal access to critical services, are costly but small in comparison to the costs of COVID-19 globally and were already agreed to by governments of the world and prioritised in the 2030 Agenda of the Sustainable Development Goals. A similar case is made for climate change mitigation and adaptation – costs of reorganising productive and social systems and humanity's underlying relationships with the natural world will require substantial investment, but the economic, human, and ecological costs of climate change far outweigh these. Here we bring together the causes, consequences, and potential responses to the pandemic, climate change, and biodiversity loss to show how interconnected these are.

The root causes of the COVID-19 pandemic, of climate change, and further global crises like biodiversity loss, are connected. They are products of a globalised economy built on generating and concentrating wealth through mass consumption and exploitation of socio-ecological systems (Sirkeci, 2021). Consumptive economies create wealth from the transformation of ecological and human assets into products, and from the marketing of services, experiences and ideas. They lead to the concentration of wealth and associated poverty, loss of biodiversity and anthropogenic climate change, and other crises like health pandemics. Their combined impacts only concentrate risk further on those already marginalized and result in increased inequalities and poverty.

There are three broad responses to this global failure of development to meet the needs of the many. First, that business as usual is desirable, and can be made resilient; second, that business as usual is part of the problem but can be reformed; third, that business as usual cannot continue and needs urgent and deep transformation (Pelling, 2011). The first course will likely generate additional risks, the second is preferable, but may not be sufficient. The third may have high social costs, especially for the poor and marginalised, and so needs careful evaluation before implementation. Here we consider how far reformist actions (the second option) following COVID-19 can add value to climate change risk reduction. We take a global view, commenting on the empirical literature from the global North and global South and drawing form this general lines for joined-up action. We ask if COVID-19 and responses to the pandemic open or close opportunities for a timely and sufficient reform, and if there are some openings for deep transformation. In either case - what are the lessons for transformation in climate change policy and action?

2. Pandemic risk and climate change are interlinked

The impacts of the COVID-19 pandemic and its managed responses have profound implications and lessons for policy and action on climate change risk, impacts, and adaptation. Similarly, adapting to climate change and strengthening the resilience of all systems can help to reduce future pandemic risks and moderate impact. There is a particular opportunity to bring together lessons from vulnerability reduction in climate change and pandemic experience to identify co-benefits for risk reduction that can also support the equity ambition of the Sustainable Development Goals. The rapidly expanding literature on the COVID-19 pandemic has also begun to consider linkages to climate justice. Afroki et al. (2021) show how COVID-19 and climate change share similarities in terms of the gender burdens they generate. They also outline how government measures taken to support women overcoming the care and livelihood crisis triggered by COVID-19 can benefit climate change adaptation. Manzanedo and Manning (2020) identify further similarities between the climate change and COVID-19 pandemic crises: (i) high momentum trends, (ii) irreversible changes, (iii) social and spatial inequality, (iv) weakening of international solidarity, and (v) less costly to prevent than to cure. These similarities bring confidence to any exchange of lessons learned from the pandemic to tackling anthropogenic climate change. Thus, the present more extensive assessment of the similarities, including link to the biodiversity crisis, is timely.

The case for considering and managing the pandemic and climate change in an integrated way, based on collaboration (see Figure 1), builds also from experience of preceding pandemics. SARS and Ebola brought a recognition of pandemics as socio-biological phenomena (MacGregor et al. 2020), building upon recognition of multiple and interacting determinants of disease, including those driven by climate change. Pandemics are an outcome not only of the arrival and spread of disease vectors but also of preceding and ongoing environmental and social conditions and behaviour that influence where infection of people with zoonotic pathogens occurs, where disease takes hold, and who benefits from recovery.

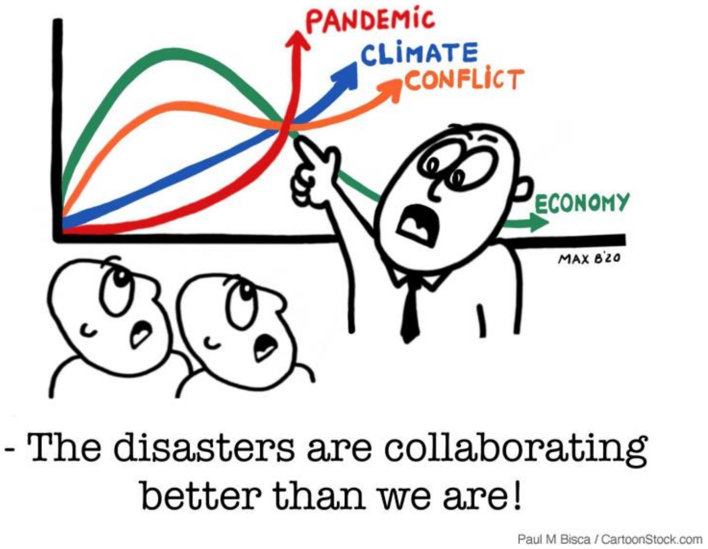

Figure 1: Interconnected crises and collaboration (image courtesy of Paul Bisca/ CartoonCollections).

The tools for reducing risk and loss from pandemics and climate change include options for reducing social vulnerability and exposure to hazards (root causes); early warning, monitoring and containment; and, enabling impact control through a response and recovery that can enhance wellbeing and sustainability for everyone. Framing this as "Build Back Better" points to the opportunity that COVID-19 recovery presents for synergies with enhancing resilience to climate change and other risks. In each stage – hazard propagation, exposure, vulnerability, and response – synergies exist between policy and action on climate change adaptation and pandemic risk management (Figure 2) and can be extended to intervening concerns, including biodiversity loss or a global crisis in social justice. Policy action must be multisectoral and coordinated across scales, given interactions between local, regional, national and global levels. Figure 2 illustrates the interconnectedness of the policy entry points for those seeking to manage hazard, vulnerability, exposure, and response.

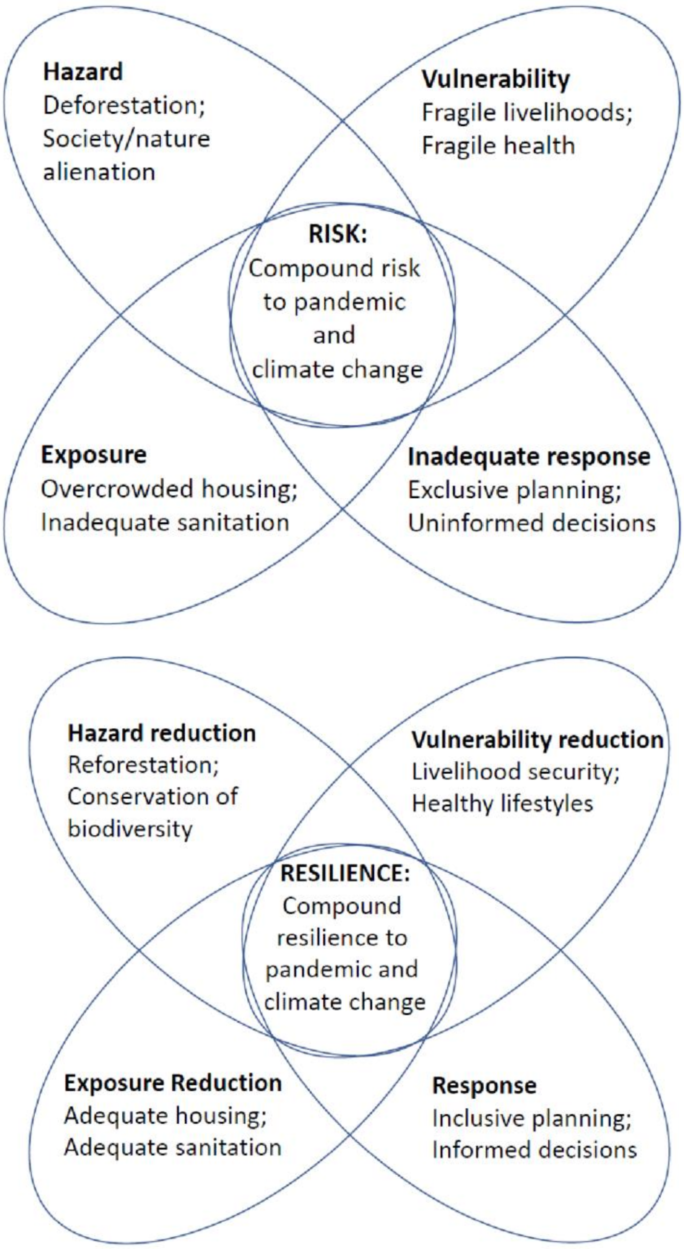

Figure 2: Interaction between COVID-19 and Climate Change risk and resilience using select determinants as examples. Based on Simpson et al. (2021)

This paper reviews the pandemic-climate change nexus from the perspective of climate change literature to identify linkages observed between COVID-19 impacts and responses and climate change actions undertaken or to be undertaken in pursuing climate resilient development pathways (Denton et al, 2014). The review is organised by selected policy sectors. Each section considers evidence for:

- Win-win synergies for healthy and climate resilient socio-ecological systems: opportunities, trade-offs, tensions and constraints;
- Power dynamics, including addressing inequity in decision-making and in the distribution of impacts and costs for pandemic and climate risk and resilience;

- Additional co-benefits with associated policy domains including biodiversity conservation and climate mitigation

The literature on COVID-19 is considerable, the linkages with climate change are multiple and even the focussed literature on COVID-19 and climate change is expanding rapidly. The Tables aim to summarise the breadth of evidence to date by sector, risk management interventions as well as, implications for COVID-19, climate change risk and equity. Not all fields have underlying data, but sufficient knowledge is available to inform the analysis.

3. Nature, Human Wellbeing and Conservation

The connection between biodiversity and human health has been brought again to the forefront of media attention because of the likely wildlife origins of the Coronavirus (COVID-19) epidemic caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) (Banerjee et al. 2021). According to Salyer, et al. (2017) 75% of new or emerging infectious diseases and 60% of the known infectious diseases are zoonotic in origin, and incidences of these have increased globally (Watts et al. 2019, 2021). Loss of biodiversity has accelerated for the past century and become a global crisis (Dobson et al. 2020). This loss has been primarily due to habitat loss associated with encroachment of farming and human infrastructure (including roads) into natural habitats, with some species driven to endangerment and extinction through hunting (Watson et al. 2018). Both of these activities increase exposure of people to pathogens from wildlife (Waitzkin 2021; Rivera-Ferre et al. 2021; Volpato 2020; IPBES 2020) (Figure 3). Industrial livestock production also raises concerns about increased viral contamination and mutations and antibiotic resistance (Waitzkin 2021; Rivera-Ferre et al. 2021). The COVID-19 pandemic, climate crisis and loss of biodiversity have some root causes in common, particularly the effects of industrialized food systems (Rivera-Ferre et al. 2021). This has provoked widespread reflection on how encroachment of humans into areas of natural biodiversity has increased the spread of zoonotics from wildlife to domesticated animals and people (Figure 3) (Everard et al. 2020; Volpato 2020; IPBES 2020).

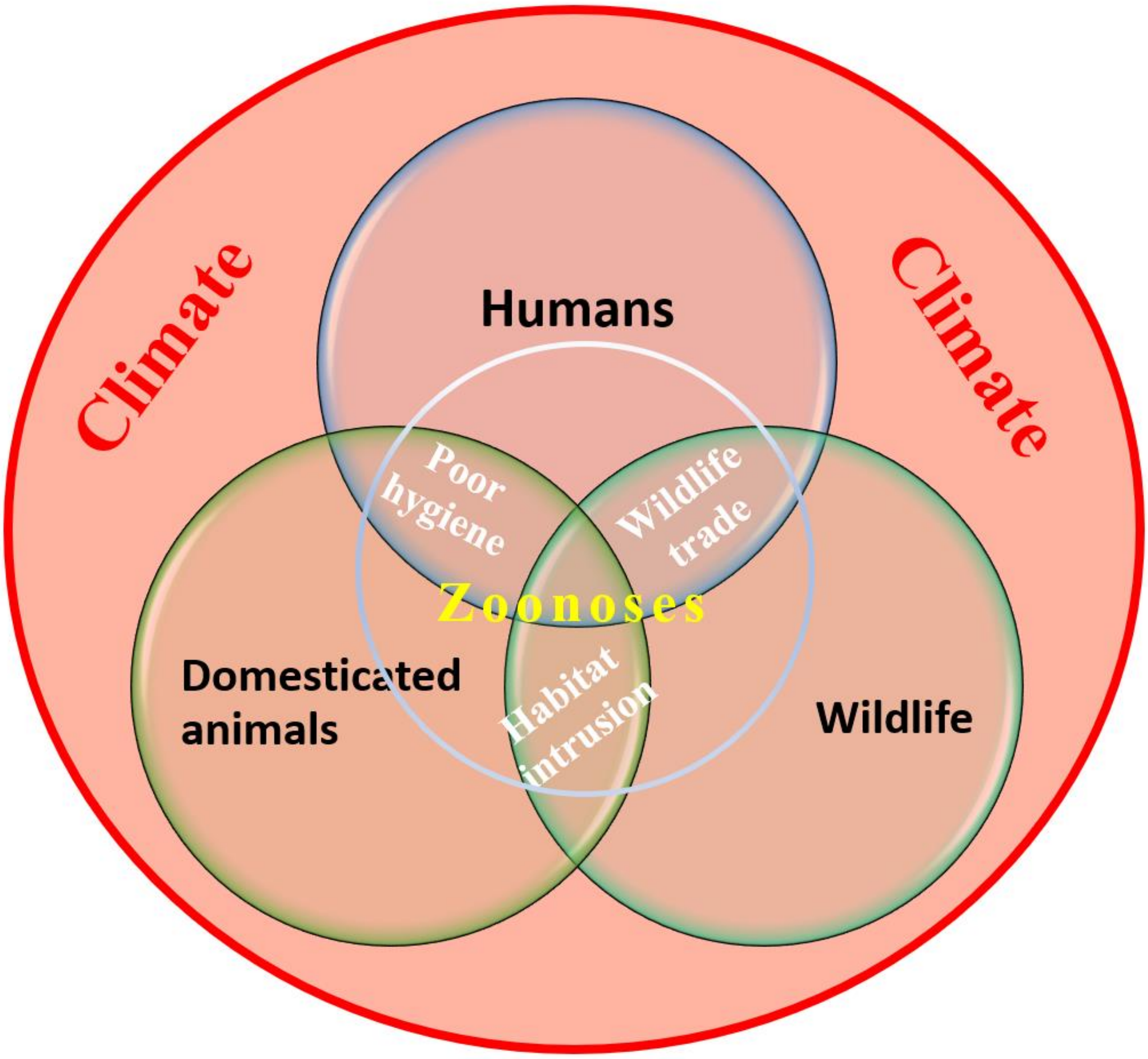

Figure 3. Illustration of how human incursion into natural habitats, wildlife trade, and poor hygiene intersect between human health, nature and food production that enable the spread of zoonoses, some of which become pandemics. All are affected by climate change.

Climate change influenced extreme weather events and chronic global warming are directly impacting public and wildlife health. These changes cause species to move, including bats and other vectors of disease and parasites, shifting geographic distributions, exposing hosts to new pathogens, and facilitating transfer of pathogens between humans, domesticated animals, and wildlife which aids zoonotic origin and spread (Jones et al. 2008, Parmesan and Hanley 2015; Dobson et al. 2020, Johnson et al. 2020, Beyer et al. 2021, Carlson et al. 2021). In addition, local climate warming may select for environmental fungi to evolve tolerance of warmer temperature and infect humans and other endotherms (Casadevall et al. 2009). Furthermore, humans may spread the virus back to domestic and wild animals and thus further aid its spread, mutation and recirculation in the biosphere (Mathavarajah et al. 2020). The COVID-19 pandemic has already caused greater economic cost than would have been involved in protecting biodiversity and ecosystems in the first instance. The prevention of biodiversity loss for 10 years has been estimated at 2% of the global cost of the COVID-19 up to mid-2020 (Dobson et al. 2020). Thus, protecting biodiversity through protected areas, restoring wildlife habitats, strictly controlling the wildlife trade and environmentally friendly farming practices benefit long-term human health and well-being (Table 1) (Ostfield and Keesing 2020; Rivera-Ferre et al. 2021).

A long-term One Health approach would help tackle the triple crises and global health (Jorwal et al, 2020, Emre et al, 2021). In particular nature-based solutions, which according to IUCN (2021) are defined as having a positive impact for biodiversity as well as for society, are a good base to build upon. Locke et al. (2019) offered concrete recommendations for the use of nature-based solutions to promote sustainability for both biodiversity and people. More than half the world's GDP - some US$44 trillion - is moderately or highly dependent on nature, and globally some 1.2 billion jobs depend on healthy ecosystems (ILO, 2020). Nature-based recommendations that help address the three crises are to: (i) halt degradation and loss of natural ecosystems; (ii) reform livestock production to reduce zoonotic pandemic risk, greenhouse gas emissions and loss of biodiversity; (iii) reduce zoonotic disease risk posed by commercial wildlife trade and markets; (iv) protect recent conservation investments in the face of COVID-19 pressures; and (iv) enact policies and strategies for a nature-positive COVID-19 economic recovery (Table 1).

The need to simultaneously address both biodiversity loss and climate change to minimise impacts on food production and ecosystem health, and aid adaptation to climate change has been widely recognised, including in a joint report by IPCC-IPBES (2021). The present pandemic overshadows these other crises in its urgency. However, it is highly inter-connected (Figure 3). Joined up approaches to addressing the biodiversity and climate crises (Table 1) will reduce the likelihood of novel zoonoses arising that may cause another pandemic (Dobson et al. 2020). Across the measures identified in Table 1, there is a need for timely data on trends in key variables that serve four audiences (Callaghan 2020), namely researchers to aid interpretation, citizens to make informed decisions, the private sector to implement environmentally sustainable business models, and policy makers and governments who can calibrate the evidence and regulate to support equitable societal change to address all three crises (Bouman et al. 2021).

Table 1: Biodiversity management synergies between COVID-19 and climate change risk reduction.

Risk management action	COVID-19 risk implications	Climate change risk implications	Equity implications
Risk root causes – prevent hazard and vulnerability creation			
Expand network of protected areas (Watson et al.2018, Locke et al.2019, Johnson et al. 2020)	Value of nature for human well-being (Pritchard et al.2020), scientific knowledge, evolution, and novel bioactive chemicals (drugs)	Biodiverse rich habitats (good status of natural capital) as resilient systems that sequester and store carbon	Access to green areas is a public good. Protection of habitats is the foundation of healthy ecosystems. Natural ecosystems are a gene bank and resource for future generations.
Improved regulation of bushmeat trade, particularly wet markets (Johnson et al. 2020, Volpato et al.2020).	Aims to prevent disease spread from wildlife to people (Wolfe et al. 2005, Daszak et al. 2020, Volpato et al.2020).	Species declines due to hunting are compounded by effects of changing climate on species abundance and habitat availability (Morton et al. 2021).	Bushmeat can be an important source of local protein in some regions (Challender and Hinsley 2020).
Reduce natural habitat fragmentation (Dobson et al. 2020, Johnson et al. 2020).	Reduce encroachment of people and domestic livestock into natural habitats (Faust et al. 2018, Morand 2020).	Loss of natural habitats leads to decreased biodiversity, decreased biological carbon capture, and release of greenhouse gases from land clearing and soil disturbances.	Habitat loss deprives Indigenous Peoples of ecosystem goods and services, and future generations everywhere of access to nature.
Reduce wildlife disturbance.	Human activity causes wildlife movement (Doherty et al. 2021).	Climate change also causes geographic change in species distributions (Parmesan & Hanley 2015, Pacifici et al.2017).	Tourism disturbance can be restricted.
Reduce large-scale deforestation (Daly 2020).	Loss of natural habitat may prompt dispersal of pathogen vectors into human living space, increasing exposure to pathogens (Allen et al. 2017, Volpato et al.2020)	Deforestation release greenhouse gas into atmosphere and reduces carbon capture by trees.	Deforestation deprives indigenous communities of ecosystem goods and services.
Risk early warning, monitoring and containment			
Monitoring data.	Daily counts of infection rates key to policy decisions regarding social distancing and mobility restrictions (Callaghan 2020, Daszak et al. 2020).	Timely quality assured data underpins IPCC assessments.	Data needs to be freely available online for citizens to be able to independently assess scientific advice and understand policy decisions.
Impact control, recovery and Building Back Better			
Ecosystem restoration (Seddon	Reduce spread of zoonotics from wildlife to domestic animals and	Restoration of natural ecosystems can increase carbon sequestration and	Future as well as present generations will benefit from restored ecosystems.

et al.2020, IPBES 2019).	livestock by separating domestic stock and wildlife (Allen et al. 2017, Pearson et al. 2020).	storage in soils and sediments (Heller and Zavaleta 2009).	
Document biodiversity knowledge.	Major gaps in knowledge remain about the distribution of hosts, diseases and their ecology in nature (Han et al. 2016, Daszak et al. 2020).	Species range shifts, declines and extinctions due to climate change may be undetected.	Indigenous Peoples food systems need to be safeguarded to support their knowledge and resilience to comparable future shocks (Zavaleta-Cortijo et al. 2020). Most biodiversity occurs in low income countries with least scientific research resources.
Effective biosecurity surveillance.	Increased monitoring of known and potential pathogens to provide early warning of future epidemics (Nunez et al. 2020).	Some species introduced by human activity become invasive and increase extinction risk of native species (Nunez et al. 2020).	

To date, government actions have not reversed either the biodiversity or climate change crises (Naidoo and Fisher 2020, McElwee et 2020). The consequences of similar inaction during the pandemic were increased deaths and pressures on health care, services, and business (Table 1). The slaughtering of intensively reared mink and poultry infected with viruses potentially transmissible to people raises issues of animal welfare and industrial livestock production. The pandemic prompted radical new regulations and public guidelines restricting social and business activity. The rapid spread of the pandemic showed how globally connected and interdependent modern societies are, regardless of nationalistic rhetoric. Thus, integrated approaches, such as One Health and EcoHealth, and coordinated global responses are necessary to address all three crises (Everard et al. 2020, Fakhruddin et al. 2020, McElwee et al. 2020, WHO 2020a, Zinsstag et al. 2018). In each crisis, delays in taking preventative action are leading to more extreme and costly emergencies, from the current pandemics and extreme weather events, to emerging extinctions of species (e.g., Frankel 2020, McElwee et al. 2020).

4. Water and WaSH

Access to adequate water supplies in association with appropriate sanitation and hygiene facilities (Water, Sanitation and Health, WaSH) provides win-win synergies for healthy and climate resilient socio-ecological systems while meeting SDG6 (water) and SDG3 (health). Universal access to reliable WaSH (i.e., everywhere for everyone) is essential for infection control, reduces undernutrition, and is an effective climate adaptation strategy to protect health, particularly from water-related and other infectious diseases, and especially post-disaster (e.g., Dodos et al., 2017; Jones et al., 2020; Nichols, 2018; Wolf et al., 2018; Brauer et al.2020). While evidence is limited, reliable and appropriate WaSH access may further help to prevent transmission of emerging zoonoses through prevention of interspecies transmission through water used by both people and animals (Figure 2). It is also an important component for increasing the resilience of health systems in face of climate change impacts (WHO, 2015 2020b). This underscores the need to meet SDGs 6 (water) and 13 (climate) while recognising how COVID has exacerbated challenges to meeting the SDGs (Neal 2020; Mukherjee et al.2020; Lambert et al.2020; Pramanik et al.2021).

WaSH infrastructure must be climate resilient, as it can be overwhelmed or damaged by water-related extreme events (Boholm and Prutzer, 2017; Sherpa et al., 2014) with compounding and cascading risks, such as for example, cyclones during COVID-19 (Baidya et al, 2020). Floods, heavy precipitation, droughts and wildfires have disrupted water availability and quality, WaSH provisioning, and supply chains (Cashman, 2014; Khan et al., 2015; Wanda et al., 2017). Events will become more frequent and intense under climate change. Compound climate risks such as hurricanes, cyclones, and droughts have exacerbated water and food insecurity and presented additional infection control challenges for undertaking emergency management and humanitarian response as well as evacuations in ways that prevent the spread of disease during the COVID-19 pandemic (Armitage and Nellums, 2020; Ebrahim et al., 2020; Phillips et al. 2020; Poole et al., 2020; Ashok et al. 2021; Shultz et al. 2020; Pei et al. 2020; Pramanik et al. 2021).

Existing inequities in water and WaSH access within and between countries have been highlighted by the current pandemic. Indigenous Peoples, migrants, refugees, the elderly, women and the urban poor are disproportionately affected by poor WaSH access, even in high-income countries. Unequal WaSH access creates a disadvantage in practicing infection control for COVID-19 prevention (Rodriguez-Lonebear et al.2020; Deitz and Meehan 2019;

Stoler et al.2021), particularly when the sick can require greater volumes of water per day (e.g., Stanley et al., 2018; Sivakumar 2020, Mukherjee et al., 2020). Universal access to adequate water supplies and WaSH can reduce gendered risks and water and caregiving roles exacerbated by the pandemic (Adams et al., 2021; Akseer et al., 2021; Neal, 2020). They can also resolve the need for difficult choices with respect to prioritising different domestic uses of water, including prioritising domestic over productive (agriculture) uses and allocation of scarce household finances (Hannah et al., 2020; Afroki et al.2021). During the pandemic, 771 million people did not have access to basic drinking water service (i.e., within 30 minutes round trip) in 2020 (WHO and UNICEF, 2021). This has implications for physical distancing and isolation protocols to prevent COVID-19 transmission (Staddon et al., 2020). Women, as caregivers in most societies, were the ones who bore the burden of COVID-19 and subsequent lockdowns who left them without childcare support, reduced employment opportunities, additional caregiving tasks and domestic violence risks (Wehman et al. 2020). Across continents, more women than men work in informal employment or work in health care facilities. These were all negatively affected by the COVID-19 pandemic, the first losing their income, the latter increasing their work burden and the risk of getting infected (Afroki et al.2021). For those who require advanced care as a result of COVID-19, one in four healthcare facilities do not have basic water services and one third do not have adequate point-of-care hygiene facilities (WHO and UNICEF, 2020). Social accountability is required to ensure that civil society has the capacity to hold authorities accountable for and responsive to progressive realisation towards their rights to water and sanitation.

Table 2: Water and WASH management synergies between COVID-19 and climate change risk reduction.

Risk management action	COVID-19 risk implications	Climate change risk implications	Equity implications
Risk root causes – prevent hazard and vulnerability creation			
Universal access to WaSH	Handwashing and cleaning are essential components of infection control and human dignity that are difficult to undertake with poor or lack of access to WaSH (e.g. Staddon et al., 2020; WHO 2021)	Improved access to water resources and WaSH are protective against climate change health impacts and represent a low regrets adaptation strategy (IPCC, 2012; Carlton et al., 2014; Jones et al., 2020)	Domestic water provisioning is highly gendered in many parts of the world; lack of access disproportionately affects women and girls and marginalised populations around the world (e.g., Yadav and Lal, 2018; Adams et al., 2020 Ivers and Walton 2020)
Elimination of inadequate and shared sanitation facilities	Inadequate / shared sanitation facilities may increase risk of COVID transmission (Ashraf et al.2020; Amoah et al., 2020; Caruso and Freeman, 2020; Sun and Han, 2020)	Improved access to sanitation reduces infectious disease risks resulting from extreme water-related events (Davies et al., 2015; Dickin et al., 2020 Nichols et al., 2016)	Prevention of disease in vulnerable populations without access to home-based sanitation facilities (Evans et al., 2017)
Wastewater management	Potential exposure through wastewater	Strengthening capacities in monitoring wastewater	Prevention of diseases in underprivileged areas

	(Bogler et al., 2020; WHO & UNICEF, 2020a).	systems in prevention of extreme weather events impacts on health (Widera et al., 2021)	where WaSH conditions are bad and wastewater flows are not treated (WHO&UNICEF, 2021a)
Natural infrastructure (blue and green) and green technologies	Blue and Green infrastructure, e.g., wetlands and rainwater harvesting to secure clean water and access to water supplies and make systems more resilient to extreme events (Tariq et al., 2017; Mercer and Hanrahan, 2017; White et al., 2017)	Reduced impact of climate-change-related regional increases in frequency and intensity of floods and droughts (Kapetas and Fenner, 2020)	Reduction of the impacts from water-related hazards in communities and households with compound social vulnerabilities that exacerbate costs of extreme events to health, livelihoods, and poverty status (Kher et al., 2015; Kohlitz et al., 2017)
Community-based and engaged WaSH strategies	Community cohesion reduces collective impact of COVID (Jewett et al., 2021; Lalot et al., 2021)	Build up of social capital which helps to reduce impacts of extreme events driven to increase through climate change in many regions by drawing on shared community resources and knowledge (Greene et al., 2015; Townshend et al., 2015; Cherng et al., 2019)	Reduces impacts of inequities through ensuring that “no-one is left behind” and “everyone is counted in” (e.g., Bisung et al., 2014)
Risk early warning, monitoring and containment			
Universal access to WaSH	Hand hygiene and cleaning of surfaces prevents transmission of infectious diseases, including COVID-19 (Wolf et al., 2018; Armitage and Nellums, 2020; Brauer et al., 2020; Jones et al., 2020)	Increased temperature and extreme events add to difficulties in responding to the pandemic (Ebrahim et al., 2020; Guo et al., 2020; Phillips et al., 2020)	Compound risks for vulnerable populations - more susceptible to COVID impacts and more likely to experience poor WaSH access (e.g. Blacks, Indigenous) (e.g., Wiemers et al, 2020; Deitz et al., 2019)
WaSH in healthcare facilities	Potential to create transmission hotspots in locations set up to care for the sick (McGriff and Denny, 2020)	Part of health system climate resilience strategy (WHO, 2020)	Healthcare providers in facilities with poor or no access to WaSH face greater risks of exposure at work (McGriff and Denny, 2020)
Wastewater-based epidemiology as an early warning system	Wastewater management and monitoring; tracking SARS-CoV-2 viral RNA in wastewater as an early warning for community infection levels (i.e., syndromic surveillance) (Bogler et al., 2020, Lorenzo and Pico, 2019; Widera et al.2021)	Wastewater efficacy, especially during extreme water-related events (e.g., Cashman et al., 2014; Kohlitz et al., 2017; Hughes et al., 2020); monitoring for achievement of SDG6 targets (UN Habitat and WHO, 2018)	

Appropriate risk communications	Risk communications (messaging, language, dissemination mechanisms) designed to reach the most vulnerable (Clark-Ginsberg and Petrun Sayers, 2020)	EWS mechanisms appropriate for climate-related hazards and extreme events (e.g., Paulik et al., 2020)	Marginalised populations often excluded from main EWS / risk communication messaging, reducing response times and increasing adverse impacts (e.g., Mustafa et. al., 2015; Acharya and Prakash, 2019)
Impact control, recovery and Building Back Better			
Investment into resilient integrated systems	Recognition of importance of universal WaSH access - prevention of transmission of infectious disease; improved overall health and nutrition; confers better immunity against infectious diseases (Khan et al., 2015; Nichols, 2018; Wolf et al., 2018; Jones et al., 2020)	Investment into climate resilient infrastructure; flood proofing facilities/locations (Cashman, 2014; Khan et al., 2015; Wanda et al., 2017; White et al., 2017; Boholm & Prutzer, 2017; Kirschen et al., 2018)	Target vulnerable populations, gender, elderly, youth, Indigenous (Howard et al., 2020)
Wastewater effluent monitoring	provide an early warning system for infectious disease outbreaks (Mao et al., 2020; Peccia et al., 2020) Widera et al., 2021)	provide notification of performance under climate extremes (e.g., Farkas et al., 2020)	Target vulnerable populations, gender, elderly, youth, Indigenous (Martuzzi et al. 2010)
Wastewater as a resource	Proper treatment and reuse of wastewater and wastewater byproducts can enhance local food security, provide energy for cooking and lighting, improving safety e.g for sanitation facilities (Schuster-Wallace, 2015; Silvestre et al., 2015; Mukherjee et al., 2016; Van der Hoek et al., 2016; Qadir et al., 2020)	climate change mitigation opportunities (e.g., Dickin et al., 2020); household/community resilience (Sovacool et al., 2015)	Target vulnerable populations, gender, elderly, youth, Indigenous

Co-benefits exist between inclusive WaSH strategies and public health strengthening. This includes through water for local food production and addressing questions of gender inequity. For instance, government programs geared towards women´s labor training and income subsidies implemented in response to the COVID-19 crisis can spur livelihood diversification which can facilitate climate adaptation (Afroki et al. 2021). Short term water quality improvements were also seen as a result of lockdowns and subsequent reductions in industrial activity. Several synergetic benefits of specific actions that were required to prevent the spread of pathogens during the COVID-19 pandemic and those expected to foster climate change adaptation exist in the WaSH sector (Table 2). There is merit in considering these from a One Health perspective (Zinsstag et al., 2018) given a predicted 250,000 additional deaths per year between 2030 and 2050, with 144,000 due to viral diarrhoea and malaria due to climate change (both linked to water and/or vector borne diseases) (WHO; 2018). For example, adequate access to WaSH in wet markets may help to prevent zoonotic spill over (Nadimpalli and Pickering, 2020).

During the COVID-19 crisis, wastewater flows have been quickly identified as a potential risky path for pathogen spread (WHO & UNICEF 2020). Although COVID-19 transmission has not been confirmed through virus-contaminated water (Adelodun et al., 2020), studies have found a direct correlation between the quantities of the COVID-19 virus in wastewaters and the number of persons infected in the corresponding area, demonstrating the utility of wastewater-based epidemiology to provide an early warning for and monitor variability in disease load (Widera et al.2021). Given that wastewater systems are particularly vulnerable to weather extreme events, strengthening capacities in monitoring wastewater flows could prove advantageous for ensuring wastewater treatment efficacy, particularly during, for example, heavy precipitation events (Hughes et al.2020). Wastewater is also a source of greenhouse gas emissions (Dickin et al., 2020) as well as a resource for fuel, lighting, and fertilizer (Schuster-Wallace, 2017). Harnessing these by-products can improve safety and local food security as part of community resilience strategies.

Nature-based solutions and green technologies offer multifunctional solutions that can help address a number of common climate-related household water security challenges simultaneously including storm surges through protection of mangroves or flooding through natural or hybrid infrastructure, e.g., raingardens or constructed wetlands which in many cases can also help to mitigate short dry periods and improve water quality while increasing green and blue spaces for health and wellbeing and helping to improve air quality (Chenoweth et al., 2018; Anim and Ofori-Asenso, 2020; Vndergert et al, 2021).

Finally, community engagement has been identified as an important part of implementation that improves sustainability, can empower women, and can provide a catalyst for social cohesion. Social cohesion - generally defined as voluntary participation in society, a sense of belonging, shared challenges, and tolerance for others (Fonseca et al., 2019) - is a broad resilience strategy (Patel and Gleason, 2018) that has also been demonstrated to reduce adverse impacts during extreme events and that would likely extend to all adverse events, including the COVID-19 pandemic (Bisung et al., 2014; Greene et al., 2015; Townshend et al., 2015; Cherng et al., 2019; Jewett et al., 2021; Lalot et al., 2021).

5. Health systems

Functional health systems are a key determinant of the numbers of cases of injuries, disabilities, diseases, and deaths in a population, whether these result from climate change or from pandemics. Health systems include policies, programs, and personnel that protect and promote human health and well-being, along with the associated institutions and infrastructure, including laboratories and healthcare facilities. The COVID-19 pandemic has severely tested health systems at all scales, highlighting long-standing under-investment, the critical need for continuous and inclusive access to healthcare, and weaknesses in policies and programs, particularly those needed d for further prioritizing environmental health (Lal et al. 2021; Cissé 2019; Knowlton, 2019). Building back better from COVID-19 requires better integration of robust local to regional and national health systems with sustainable human and financial resources that address the social and environmental determinants of health. In addition, as in other systems the COVID19 crisis has highlighted the important role that nature based solutions play in both physical and mental health and well-being (Bratman et al, 2019, Lovell and Maxwell, 2018).

The pandemic response shines a light on risks arising from health system management decisions, such as relying on just-in-time delivery of essential protective equipment, large-volume global supply chains, and lack of back-up facilities to manage surges in caseload (Skegg 2021). The COVID-19 pandemic has demonstrated the importance to resilience of long-term investment in capital works (e.g., safe isolation facilities), robust pan-sector information systems, and strategic redundancy in health care. All are relevant to health adaptation to great disruptions - including climate change (Folke 2002). Principles for decision-making include valuing flexibility alongside efficiency, protecting diverse response capacities, maintaining a high level of inter-connectedness within and beyond the health sector, and fostering system properties of self-organisation and learning (Woodward 2020).

Table 3: Health systems management synergies between COVID-19 and climate change risk reduction.

Risk management action	COVID-19 risk implications	Climate change risk implications	Equity implications
Risk root causes – prevent hazard and vulnerability creation			
Address underlying vulnerabilities	Support those who are poor, marginalized, and otherwise particularly vulnerable to COVID-19, including from the mental health impacts (Coker et al, 2020, Abrams and Szefler, 2020, Gupte and Mitlin, 2020, Lambert et al. 2020)	Support needed to reduce the health risks of climate change, including mental health, and to increase the capacity of health systems and health care to prepare for and manage the risks	Economically poorer and marginalized communities suffer disproportionately from pandemics and climate change (Lambert et al.2020). Underserved communities and health systems infrequently have the necessary human and financial resources, and the methods and tools, to protect the most vulnerable
Strengthen health system and health care disaster risk management	Improve surge capacity for hospitals	Address increasing risks to healthcare infrastructure and personnel from extreme weather and climate events delivery compromised s (Phillips et al. 2020)	Inadequate disaster risk management and unequal access to healthcare often has greater impacts on the poor and marginalized
Control the spread of infectious diseases	Sustain pandemic-related control measures, including vaccination (Lambert et al). Improve surveillance and research into zoonotic	Increase investment in surveillance and monitoring for climate-sensitive infectious diseases	Ensure research, policies, and programs protect marginalized populations

	diseases (Daszak et al. 2020)	Increase research into the interactions of climate, biodiversity loss, and health	
Improve indoor and outdoor air quality	Air pollution may increase prevalence and severity of respiratory diseases such as COVID-19 (Pozzer et al. 2020)	Wildfire smoke and dust storms increase the burden of respiratory and cardiovascular disease; climate change is projected to increase the numbers and intensity of these events (Johnston et al. 2021)	Women are often more heavily exposed to indoor air pollution. Outdoor air pollution affects those with respiratory illnesses, outdoor workers, and children
Boost health education	Education and support to reduce chronic poor health (e.g., diabetes, obesity) that may increase the likelihood of severe COVID-19. (Wilkinson, 2020). Expanded medical training to include potentially novel diseases.	Increase public understanding of the health risks of climate change. Expand training of health care professionals on climate change and health	Increased understanding can promote uptake of recommendations to protect health
Risk early warning, monitoring and containment			
Improve surveillance and monitoring	Improve community monitoring in terms of quantity, quality, and timeliness of data (Daszak et al. 2020). Expand understanding of trade flows and population movements	Co-develop and deploy early warning and response systems with vulnerable communities for climate-sensitive health outcomes. Increase understanding of cascading, compounding, and teleconnected risks.	Countries and communities with less science expertise and education have challenges with collecting and interpreting data, and with developing and deploying early warning and response systems
Recovery and Building Back Better			
Encourage necessary behavioural changes (Botzen et al, 2020)	Foster public willingness to undertake lifestyle changes to reduce COVID-19 risk	Conduct additional research on how to facilitate behavioral change to advance adaptation and mitigation	
Promote multidisciplinary, integrated risk management within the context of sustainable and resilient development. t	Ensure essential health systems and health care for emerging infectious diseases, linked with policies and programs to promote sustainable development	Promote achieving all the SDGs to ensure resilience and sustainable development that protects human health and well-being	Achieving the SDGs, including universal access to health care, will protect the most vulnerable and reduce inequities

Just prior to the COVID-19 pandemic, the Global Health Security Index[1] provided the first comprehensive assessment of national health security across 195 countries, focusing on prevention; detection and reporting; rapid response; health system; compliance with international norms; and risk environment (2019). These functions are needed at all levels of governance. Key conclusions that apply to both COVID-19 and climate change include that national health security is fundamentally weak worldwide; the same is true of preparedness for climate change. Few countries had tested health security capacities or shown they had functional capacity in a crisis. Most countries lacked health system capacity for effective epidemic and pandemic response, and coordination and training at all scales were inadequate. These weaknesses were determinants of the degree of success of each country with managing the COVID-19 pandemic. Similar conclusions have been reached in international reviews and assessments with respect to the health risks of climate change (Watts et al. 2021).

Equity is key for increasing resilience to pandemics and climate change, with the pandemic highlighting what could happen when social protections are limited (Table 3). The pandemic revealed to the general public a range of inequities that also drive vulnerabilities to weather, climate variability, and climate change and other environmental exposures. As well noted in the climate change adaptation literature, effectively addressing inequities is central to increasing resilience (UNDESA 2016).

Here is another lesson from the pandemic: building resilience requires community members and other stakeholders to be involved in planning and coordination of efforts to reduce hazardous exposures, reduce vulnerabilities to those exposures, and strengthening health system responses (Semenza 2011). Communities can pair monitoring of exposures, such as local temperatures, with information about particular individuals and locations to help protect the most vulnerable during a heatwave (Ebi and Semenza 2008). This helps to tackle mental health, where there is emerging evidence on the impacts being shared by both the pandemic and climate change (Ciaconi et al. 2020).

Developing and deploying early warning and response systems at scale reduce the burden of some infectious diseases, and can also prevent heat-related morbidity and mortality (Morin et al. 2018). These systems have the potential to identify where and when outbreaks of climate-sensitive infectious diseases could occur weeks to months in advance and can be used by decision-makers to allocate resources in a timely manner. This information could then be used by public health professionals and community partners to improve surveillance by targeting the most likely areas for threats, focusing on protecting the most vulnerable.

Globally, about 4.4 % of greenhouse gas emissions are from health care (Lenzen et al. 2020b). COVID-19 economic relief funds that both invest in building resilient health systems and in reducing the greenhouse gas emissions from health systems would significantly contribute to building back better.

6. Food systems

The impacts of the COVID-19 pandemic on food systems provides a window onto current levels of social adaptation, equity and linkages between food and health systems (Klassen and Murphy 2020; Patterson et al. 2020). In the short term the pandemic has doubled the number of acutely food insecure people and worsened malnutrition globally (FAO, 2020; Rippin,

[1] https://www.ghsindex.org/

2020). Lockdowns and mobility restrictions led to input supply and workforce shortages for producers, uncertain, shifting markets and increased food losses for perishable products (Klassen and Murphy 2020). Policies restricted wet meat-markets and some wholesale supply chains, threatening food security in many regions (Liverpool Tassie et al. 2020). These impacts reverberated throughout food systems, in turn affecting food prices and supply, with projected increases in medium to long term chronic food insecurity (WFP-FSIN 2020).

These pandemic impacts have reflected and reinforced inequity within the globalised food system. This has increased vulnerability to food insecurity of particular groups and sectors, including low-income households, smallholder farmers, farmworkers, informal food market sellers, and low-income countries dependent on food imports (HLPE, 2020; Erokhin and Gao 2020). Supply side disruptions due to labour shortages and COVID-19 outbreaks have exposed a reliance on and vulnerability of a mobile, marginalized and precarious labour force (Klassen and Murphy 2020). In some contexts large capital-intensive companies have been able to seize advantage during the pandemic, pivoting to digital infrastructure and home delivery systems (Reardon et al. 2021). This has increased the concentration and power of large vertically and horizontally integrated companies (HLPE 2020). New producer-consumer short food chain partnerships have also flourished (Blay-Palmer et al. 2020; Tittonell et al. 2021).

The food system can increase risk for pandemics and for climate change. Large-scale, intensive globalized food production contributes to zoonoses emergence, through weakening ecological barriers that prevent and regulate pathogen release, as well as increasing the risk of human exposure and susceptibility and increasing land use change (Plowright et al. 2017; Rivera Ferre et al. 2021) (Figure 3).

Table 4: Food systems management synergies between COVID-19 and climate change risk reduction.

Risk management action	COVID-19 risk implications	Climate change risk implications	Equity implications
Risk root causes – prevent hazard and vulnerability creation			
Sustainable agriculture and land use (Dobson et al. 2020; Rivera-Ferre et al. 2021).	Reduce spread of zoonotics to domestic animals and people	Large-scale intensified monoculture systems can increase vulnerability to drought, disease and pest outbreaks and other climate risks compared to diversified, agroecological farming systems (Snapp et al. 2021; HLPE 2019).	Agroecological practices, including increasing biodiversity, intercrops, crop rotation, agroforestry, integrated crop livestock systems can increase resilience of farm systems food security and nutrition (Bezner Kerr et al. 2021; Kremen and Merenlender 2018; Dainese et al. 2019).
Address social inequities in the food system at production and consumption level through rights-based approaches such as rights to green urban spaces, gender	Reduce risk of food insecurity in case of shocks such as pandemics.	Reduce risk of food insecurity and malnutrition in case of climate shocks such as floods, droughts and other extreme events.	On and off farm diversification strategies can also decrease gender inequality and promote gendered adaptive capacity (Afroki et al.2021).

transformative agriculture, food policy councils (Gumucio et al. 2020; Halvey et al. 2020; Horst et al. 2017; Lwasa et al. 2014).			
Risk early warning, monitoring and containment			
Inclusive early warning systems/ climate services and education for disaster preparedness (pandemic or climate related).	Infrastructure in place to allow for tracing, containment and rapid response.	Infrastructure for monitoring of algal blooms (Smith and Bernard 2020), droughts (Balehegn et al. 2019) and other climate risks can minimize losses and allow for responsive action.	Indigenous knowledge systems can be combined with scientific monitoring and citizen science to build trust, knowledge and awareness of risks (Balehegn et al. 2019).
Impact control, recovery and Building Back Better			
Promote local food production especially for low-income households, e.g., urban agriculture (Horst et al. 2017), public procurement from local farmers, farmers' markets community-based interventions (Ilboudo Nébié et al. 2021).	Preference for local food production to reduce food insecurity from interrupted supply chains and increase access to healthy, diversified food sources for at risk populations.	Reduce vulnerability to health impacts of climate change risk, while also reducing the carbon footprint of food production.	Local food production can increase local livelihoods and enhance the quality of food available for targeted vulnerable groups e.g., school children, hospital patients, low income neighbourhoods.
Coordinated social safety nets or social protection programs with inclusive governance processes for disadvantaged groups such as low-income households, smallholder farmers, farmworkers, informal food market sellers (Holsman et al. 2019; Ilboudo Nébié et al. 2021).	Reduce risk of food insecurity and malnutrition in case of shocks such as pandemics.	Reduce risk for food insecurity and malnutrition for disadvantaged groups in case of climate shocks such as floods, droughts and other extreme events.	Focus on marginalized, disadvantaged groups, including governance processes, helps to address systemic social inequities.

Climate change impacts are anticipated to compound vulnerabilities in the global food system (HLPE, 2020; WFP-FSIN 2020). Smallholders, for example, provide much of the diverse food supply in low- and middle- income countries, but often lack social safety nets, investments or savings and are often at higher risk to climate change impacts (Ingutia 2021). At the same time, experiences during the pandemic provides insights to address food system weaknesses made visible (Blay-Palmer et al. 2020; Liverpool Tassie et al. 2020). Strengthening local and regional food systems is one policy option that can avoid overreliance on uncertain import markets, build community, and be resilient to a range of shocks, both climate and health (Blay-Palmer et al. 2020; Capelli and Cini 2020; Tittonell et al. 2021).

Ensuring coordinated social safety nets, that are flexible enough to respond to multiple and compounding shocks, and address social inequities, is another lesson from COVID-19 (Table 4). Transitioning to agroecological systems which support diverse food production and biodiversity can address both a driver of zoonoses emergence and vulnerabilities within the food system to climate change impacts (Altieri and Nicholls 2020; Rivera Ferre et al. 2021). All three strategies point to the need for a One Health approach, that link health, water and food systems in governance, policy and programming in the face of uncertain and multiple risks.

7. Urbanization and cities

Urban places are diverse, characterised by high levels of internal and external connectivity, high density living conditions and very often by unequal access to basic infrastructure including water and sanitation, social fragmentation, economic inequality and cultural diversity. The balance in these characteristics shapes resilience and can generate compound risk to climate change and pandemic (Sharifi and Khavarian-Garmsir, 2021). For example, when homeless shelters (Richard et al.2021), evacuation centres (Shultz et al.2020) and refugee camps (Kamrujjaman et al.2021) designed to protect individuals from natural hazards increase COVID-19 transmissibility amongst those already affected by disaster. Where COVID-19 awareness brings greater sensitivity to the needs of diverse service users – women, children and the disabled, for example, this can bring cobenefits for climate change adaptation and risk management, especially for the safety of women and children (Alam and Rahman 2014). Lockdowns have had a disproportionate and compounding impact on the mental health and physical wellbeing of many climate exposed populations, including children, carers - many of whom are women – and some ethnic minorities (Proto 2021). For heatwaves, which have a disproportionate impact on cities, the global population exposed during the COVID-19 pandemic in 2020, was 432 million (Walton and van Aalst 2020).

Those exposed to the compound risks of COVID-19 and climate change can also be part of the solution. This is especially the case for community based action (Sverdlik 2020). In one slum, Kibera, Nairobi more some 58 unique community interventions were mapped, with 39% of these led by small scale organisations such as local NGOs and community groups to provide hand-washing facilities, organise food distribution and information points (Taylor et al 2021). The inclusion of local capacities into national programmes - from neighbours shopping for each other, to a resurgence in community-based action and local pharmacists administering vaccinations – is a key lesson from COVID-19 response that can help build longer-term urban resilience including to climate change.

Table 5: Urbanization and infrastructure systems management synergies between COVID-19 and climate change risk reduction

Risk management action	COVID-19 risk implications	Climate change risk implications	Equity implications
Risk root causes – prevent hazard and vulnerability creation			
Provision of adequate housing and basic services	Resolving high-density subserviced living conditions including access for all to clean water, electricity and	Better housing and access to clean and sufficient water and sanitation as human rights to reduce exposure and vulnerability	Economically poorer communities suffer disproportionally from pandemics and climate

	communication services. Good quality public transport	to flooding, drought and temperature shocks. This can also help address gender based inequity (Chant et al 2015). Improved public transport contributes to climate mitigation. Reliable communication systems especially critical during extreme weather events including floods, blizzards and wildfires. (Pelling et al.2021)	change. (Pelling et al.2021)
Air quality	Temporary improvement in air quality and greenhouse gas emissions due to reduction in traffic fossil fuel emissions (Le Quéré et al. 2020, Stoll and Mehling 2020)	Drop in greenhouse gas emissions is necessary to mitigate climate change. However, the temporary reduction in particulate emissions reduced their cooling effect on the planet (Gettelman et al. 2021)	Reduced air pollution a benefit to public health (Lambert et al, 2020).
Spread of COVID-19	Pandemic was spread and global due to high urban populations, flight connections (Coelho et al. 2020, Harbert et al. 2020) and land transport systems (Jia et al. 2020, Xiong et al. 2020)	Aviation transport is a significant contributor to greenhouse gas emissions.	Initial impact is on communities' wealthy enough to afford air travel.
Impact control, recovery and Building Back Better			
Promotion of a circular economy and regulation of extractive industries supplying urban construction booms driven by COVID-19 recovery finance (Ishiwatari et al, 2020).	Minimise degradation of natural resources during demand from construction boom (Pelling 2021)	Prevent loss of environmental assets and risk mitigation, e.g., river bank erosion caused by gravel extraction (Ishiwatari et al, 2020)	Prevent extraction and exploitation of local assets by predatory private interests. (Sirkeci 2021) and support for low carbon and low pollution urbanism (Girard and Nocca 2021)
Deployment of adequate infrastructure as part of future urban development to avoid overcrowding (Gupte and Mitlin 2021).	Contain future risk from communicable disease, and wider environmental health concerns. With a focus on the most vulnerable – infants, children, the aged and women (Satterthwaite et al 2019).	Reduce vulnerability and exposure for the most vulnerable to the cascading health impacts of flooding (Leichenko 2011).	Enhancing social justice within wider resilience building actions (Acuto 2020)
Community based action to support local service	Local action fills gaps in service provision during health emergencies, e.g. transporting the ill to	Social capital built during COVID-19 responses can be maintained to feed into longer term actions to	Enhanced local participation and leadership strengthens inclusion in decision-

delivery. (Sverdlik 2021)	hospital or shopping for neighbours (Taylor et al 2021).	reduce vulnerability to climate change risk (Taylor and McCarthy 2021).	making and action, including for women (Ventura Alfaro 2020).

The COVID-19 pandemic has exposed some of the limits of urban resilience thinking and action (Table 5). Urban connectivity and high density living without supporting infrastructure have been shown to be causes of risk. Connectivity brings resilience and can introduce harmful viruses, when relied upon connections fail impacts spread. The World Bank (2021) estimates the COVID-19 pandemic has caused a fall in global remittance flows to low and middle-income countries by 7 % in 2020 with a further decline of 7.5 % in 2021. Thus, COVID-19 impacts in urban centres have repercussions in distant places, including among many climate exposed populations. When high density living is not supported by associated infrastructure, including open public space, overcrowding can become a driver of pandemic risk. Where household and neighbourhood overcrowding coincides with precarious livelihoods and inadequate basic service provision, risk is further elevated (Wilkinson 2020). This includes unplanned, spontaneous and informal settlements, and Indigenous reserves. Designing adequate housing and open space into neighbourhoods is one specific action that can provide the flexibility needed during pandemic and climate change associated crises. For example, the importance of blue and green infrastructure in cities like, e.g., forests as critical natural infrastructure during COVID-19 with positive impacts for both physical and mental health (Derks et al, 2020, Nieuwenhuijsen, 2020) (Booth et al. 2020) including heatwave risk reduction (Campella et al. 2018). But even progressive interventions must be deployed with care to minimise the risk of capture and green gentrification (Anguelovski et al 2019).

Building resilience to multiple risks requires social and political as well as technological action. While local social action has burgeoned during COVID-19, climate change activism has been suppressed (Fisher and Nasrin 2020) through the use of surveillance and denying of mass gatherings (Honey-Roses et al. 2020). Building Back Better from COVID-19 is a rare opportunity to enhance the inclusivity of decision-making as well as encouraging more joined-up, coordinated but locally centred action that can have co benefits for climate change adaptation and resilience.

8. Governance and equity

The COVID-19 pandemic underscores the differentiated social vulnerability and importance of governance in managing crises in an equitable and just manner. Pre-existing, systemic inequalities, including economic, racial, gender, Global North vs Global South, and migration status, were exacerbated by the pandemic in the same way that climate change impacts are socially differentiated (Belsey-Priebe et al. 2021; Krieger 2021) (Table 6). Governance responses to both types of crises will need to take into account these historical, systemic inequities in order to ensure long term just and resilient societies (Krieger 2021).

Table 6: Governance and equity synergies between COVID-19 and climate change risk reduction.

Risk management action	COVID-19 risk implications	Climate change risk implications	Equity implications
Risk root causes – prevent hazard and vulnerability creation			

Security	Restrictions on size of social gatherings and movements. Increase in domestic violence.	Increased climate refugees from low income (Global South) countries.	Poorer communities must reach out to wealthier countries for food supplies and refugee status.
War	UN Security Council call for cease fires not heeded (Lambert et al.2020).	Environmental problems (e.g., drought, crop failure) arising from climate change can be underlying cause of regional conflicts.	Poor and refugees most vulnerable.
Social safety nets, fair pay, livelihood support	Prevent compounding risk through exposure to COVID-19 at work and though overcrowded living conditions (Lambert et al. 2020)	Enhances individual and household resilience and capacity to cope with climate change impacts	Raises basic living conditions allowing social mobility, can be especially important for women and minority groups (Lambert et al. 2020)
Risk early warning, monitoring and containment			
Risk (vulnerability and hazard) observation and tracking with inclusive monitoring systems.	Horizon scanning for risk to enable early action to prevent escalation.	Better understanding of teleconnected climate risk.	Improved tracking of relationships between inequality and risk emergence to direct public policy including for international development, and trust built with marginalized communities
Impact control, recovery and Building Back Better			
Public willingness to undertake lifestyle changes (Botzen et al, 2020)	Public support for lockdown, quarantine, travel restrictions etc	Indicates willingness of public to undertake action when presented with immediate threat, social cohesion and strong government leadership.	Can enhance local leadership and self-determination.
Strengthening geopolitical ties (Van Barneveld et al, 2020; Cheval et al, 2020; Dodds et al, 2020)	Collaboration through vaccine production, sharing data and joined-up responses increases the effectiveness of pandemic control and recovery. Increased pressure for international collaboration and support while addressing national demands for social and economic support.	International science and policy partnerships strengthened. Climate justice concerns align with social justice concerns related to covid-19 at global scale. International commitment to address systemic historical inequalities at the international scale is limited. Similar tension to address national interests while supporting allies and emerging climate-driven humanitarian crises in other countries. Hardens international contexts for collaborative action on climate change mitigation and adaptation.	Lessons sharing allows for innovation and enhancement of pro-poor policy and action.

Addressing economic impacts of COVID-19 (Gossling et al. 2020, Ahmed et al. 2020, De Paz et al. 2020)	Financial support for exposed sectors including aviation and construction, tourism and hospitality.	Conditionalities can be used to nudge private sector behaviour towards climate resilience	Conditionalities and targeted support, including for workers can enhance capacities of the lowest paid including women and migrants.
Addressing supply chain and remittance disruptions. (Oldekop et al. 2020; Sirkeci 2020).	Local production can withstand disruption to supply chains.	Renewed emphasis on local production chains can contribute to climate mitigation and prevent teleconnected risk	Prioritisation of renewed and reliable remittances can promote resilience of impoverished and vulnerable families.
Economic stimulus investment for recovery (Hepburn et al, 2020; Leal Filho et al.2020 ; Hanna et al. 2020)	Need to rebuild livelihoods and national economies to prevent and better manage health emergencies	Grant or loan conditionalities can support climate resilient businesses and behaviour Governments must reinvest and create economic incentives for businesses to reinvest in a society safer from pandemics and climate change (Hanna et al. 2020).	Grant or loan conditionalities can support fair employers and promote responsible business.
Addressing social impacts (Ahmed et al, 2020; De Paz et al.2020)	Extending social welfare	Scope for addressing both short-term and long-term gender, racial, economic, and other inequalities driving vulnerability to climate change associated hazards.	Government training programs directed at women can facilitate livelihood diversification both in and off farm which can be positive also for adaptation (Afroki et al.2021)
International financial flows and trade (Oldekop et al, 2020; Sirkeci, 2020).	Addressing supply chain and remittance disruptions. (Lambert et al. 2020)	Renewed emphasis on local production chains can contribute to climate mitigation. Prioritisation of renewed and reliable remittances can promote resilience of impoverished and vulnerable families.	Powerful multinational chains with Global North connections can prevent prioritization of local and regional supply chain strengthening.
Mainstreaming nature-based solutions as multifunctional solutions.	Protecting biodiversity to reduce risk of zoonotics (Figure 2).	Carbon is stored in biodiversity biomass and some is deposited in carbon sinks, thus mitigating climate change.	Significant biodiversity is in areas inhabited by Indigenous Peoples and in developing countries. Measures need to balance standard of living for all.

Here we highlight four key governance lessons with potential synergies and trade-offs between the COVID-19 pandemic and climate change impacts, adaptation and vulnerability.

Short term responses versus long term consequences: There is a potential for long-term positive outcomes of the COVID-19 pandemic to address long-term development challenges such as climate change and underlying social inequity and justice issues. Post-pandemic recovery programs are in some cases being aligned to support green transitions through economic stimulus packages, though to-date there is much less emphasis and little integration of climate change risk reduction and the addressing of systemic vulnerability (Engstrom et al.2020). There are a number of initiatives for a green recovery (Nature4climate, 2020) although skewed to the global North, with the fifty largest economies pledging USD14.6tn in fiscal spending in 2020, of which USD1.9tn (13.0%) was for long-term economic recovery (O'Callaghan, & Murdock, 2021). Present commitments have focused on green energy, green transport, green building upgrades & energy efficiency, green research and development, and natural capital aligned with the "Edinburgh Declaration on the Post-2020 Global Biodiversity Framework". This is important considering that natural infrastructure can provide environmental, social and economic benefits, which are particularly important for low-income countries in the Global South, where half their wealth is made up by natural capital, (World Bank, 2018) paying special attention to jobs (equity) (ILO, 2020b) and biodiversity (OECD, 2021) There is a danger that increased funding for COVID-19 recovery that does not take this wider view of wellbeing might come at the cost of other policy areas including climate change mitigation and adaptation (Maor, 2020; Obergassel et al. 2020). The economic consequences of the pandemic reduce national revenue and may mean there is less, not more, investment in public services and overseas development assistance. The UK decision to reduce ODA from 0.7 to 0.5 % of Gross National Income demonstrates the vulnerability of such funds with little impact on UK budget saving but considerable impact on the vulnerability of low-income groups whose support has been abruptly terminated. However, attention and actions in climate change mitigation and adaptation have increased in some cases, irrespective of the COVID19 pandemic, particularly amongst governments and civil society (von Homeyer et al.2021).

Science, trust and expert based leadership: As with debates on climate change, critical questions about the pandemic arose, particularly around how decisions are made and what knowledges are deemed legitimate and authoritative for intervening (Hulme et al., 2020; Klenert et al.2020). The COVID-19 pandemic demonstrated the importance of coordinated, publicly funded science with effective monitoring systems and strong linkages to stakeholder groups and governments for evidence informed decision making and rapid crisis response (Perkins et al. 2021). The risk of fake news and polarisation of views perpetuated by social media emphasise the importance of clear public health communication based on science. Studies on public and government decision-making in respect to climate change and the COVID-19 pandemic have confirmed that scientific knowledge by itself is not sufficient to ensure adequate and effective responses. For example, a One Health approach requires the collaboration across sectors to lessen the social and economic impact (Bonilla-Aldana et al, 2020; Mushi, 2020).

Political action in response to scientific information takes place within a given socio-cultural, political and economic context, requiring culture, inequities and political power struggles to be taken into account (Rosenbaum 2021). This opens up the value of Indigenous Knowledge and Local Knowledge as part of better understanding risk and its amelioration in ways that can enhance inclusion. Building linkages across governance scales - community, regional, national and international - was a clear priority with the pandemic and is equally relevant with climate change. While the shocks are global and local, effective response is at the community level. Community-based actions, that are able to coordinate with multiple levels of governance, may require explicit strategies to address inequities at multiple levels and incorporate plural perspectives, such as participatory scenario planning, citizen science, and anticipatory planning and adaptation (Butler et al. 2020; McNamara et al. 2020; McNamara and Buggy 2017) (see Plate 2). However, trust in the credibility and legitimacy of scientific expertise and institutions is critical for the public and governments to have a rapid and ongoing willingness to act based on scientific assessment (Bol et al. 2020, Manzanedo and Manning, 2020). That science brings diversity in views, not a simple dominant view and the distance between science advice and political decision have both been highlighted by COVID-19 and have consequences for the management of the science-policy relationships for climate change policy making, in adaptation and mitigation.

Figure 4: Anticipatory planning and adaptation (Image courtesy of Paul Bisca/CartoonCollections)

One size does not fit all: Studies show that although there are generic response options available to respond to climate change impacts and vulnerability (e.g., technical, social, institutional or economic measures) or COVID-19 (e.g., lockdowns, closing of schools, face masks, vaccinations) decisions on the timing of the responses and which measures are preferred depend on the solution space available. The solution space is largely shaped by dominant interests, which can be political (e.g., an ideology of rejecting science arguments for lockdown), economic (rapid procurement of sub-standard safety equipment) or cultural (a delay in recognition of the impacts of lockdown on women in abusive relationships or of children forced to stay away from school). Studies demonstrate a variety of responses in how governments have acted to date in both climate and COVID-19 crises (Hale et al. 2020; Berrang-Ford et al. 2015). Although there are many factors that drive this diversity, countries with dedicated ministries were found to be more effective in responding to the COVID-19 pandemic (Toshkov et al. 2021) which may transfer to responding to climate change (Biesbroek et al.2018).

Democratic dilemma in crises response: Democracies are under pressure across the globe. There is a tension between actions that require state observation of individual actions and the introduction of additional legal sanctions on behaviour and the emergence of the surveillance state (Engler et al. 2021). Wider democratic principles of inclusive and representative decision-making, transparency and accountability and an informed, consenting public have also been put under pressure during COVID-19. Governments have argued the need to make fast decisions against a growing threat with information uncertainty have justified some temporary reduction in these principles, for example in procuring equipment without usual public scrutiny (Kavanagh et al. 2020). These experiences are born out in the governance of disasters more generally and are a warning of the need to prepare the government and civil society in advance of the rising climate change threat. The implications of crisis responses for civil rights with the securitisation of issues (Waever, 2015), such as with climate change or pandemics, can pressure political leaders to turn to an ideological governing approach (to base decisions on politically dominant principles and core values) rather than the pragmatist approach (to base decisions on evidence) (Boin and Lodge 2021). The same is true for climate change – ideally this follows a pragmatist approach, but in practice an ideological approach has been adopted which tends to be more politicized.

9. Conclusions

We have identified key lessons from the pandemic, and interconnectedness with climate change through multiple policy agendas. In so doing associated global concerns, in particular biodiversity loss are also shown to interact and share possible solutions. The literature reviewed (Tables 1-6) suggests six mechanisms for revising dominant development approaches that can move past superficial adjustments to business as usual, but also avoid the disruption of transformation. There are some common opportunities for advancing more equitable, climate and pandemic resilient pathways – these centre on recognising and supporting community based action, nature based solutions and inclusive planning and action. The examples offered draw from existing action already being practiced in responding to COVID-19 and that have been recommended for achieving global sustainability. They are achievable. If maintained, there are also benefits for a more inclusive and accountable climate change adaptation and an agenda for wider risk reduction for both climate change and biodiversity (including mitigation).

1. Reform in administration and organisation to enhance risk prevention. Health and environmental policies must be integrated because events in one compound the costs in the other, and too often, emergencies may happen at the same time (e.g., wildfire smoke pollution, heatwaves, and floods during a respiratory pandemic).

2. Reform in policy to enable prevention-based policies in a number of areas, including public and ecosystem health, biodiversity conservation, and WaSH. It is important to support public and private investments based on the principle of avoided costs and with sufficient regulatory oversight based on open and independent knowledge and disaggregated data, coupled with innovative financing schemes.

3. Reform governance based on enhanced transparency in data, public science, and accountability for political interventions that deviate from best scientific advice. Timely and comprehensive data are a core element in building public support for policy decisions that might temporarily restrict individual freedoms. New institutions are needed to safeguard against a drift into the normalising of increased surveillance and the creation of new marginalities for those who are excluded (or chose not to participate in) collective risk reducing actions.

4. Reform in citizen-state relations. Both the COVID-19 pandemic, climate change and biodiversity crises emphasize the importance of community-based adaptation for local

resilience with state support. This is not limited to relying on empowered communities to help-themselves and fill gaps in basic services – but rather the observation that resilience comes from vital partnerships between active community leadership, local and central governments- and at times also the private sector. Embracing adaptive governance across sectors like WaSH, health, food, and nature conservation can help to prioritise enabling, strengthening, and empowering local communities to help themselves. Transparency of underlying data used in science and policy decisions educates and builds trust between citizens and governments.

5. Reform in management efficiency. Extreme events (fires, floods and heatwaves) are increasing in frequency and severity. A pandemic can be considered an additional extreme emergency. When extremes coincide, emergency and health services need to cope in synergy to maximise efficiency, share knowledge and prevent exacerbating existing inequities and vulnerabilities.

6. Reform the relationships between humans, society and the natural world so that the Sustainable Development Goals can be achieved.

These high-level lessons from COVID-19, and the more detailed examples presented in the Tables and the preceding discussion, are timely. Urgent, increased investment for climate change adaptation presents a one-off opportunity for reforming development to offset and confront the drivers and mediating powers that have led dominant development along a dangerous path. Making these changes requires consideration and action on governance and financing mechanisms. Not only for local government and line ministries but also for development donors. We have approached a crossroads. Surges in funding that enhance the resilience of existing dangerous and unequal development practices and structures will likely only transfer risk. COVID-19 has made visible the huge vulnerability gap that also underlies and in large part drives climate change risk. Focussed reform of the administrative structures and practices, governance mechanisms and management techniques of development have been identified by COVID-19 and shown through our analysis to tie closely to opportunities for reform that will also bring considerable co-benefits for climate change risks reduction. The combined analysis is one step in determining this proactive, scaled and joined-up agenda for reform.

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