Report 22: Equity in response to the COVID-19 pandemic: an assessment of the direct and indirect impacts on disadvantaged and vulnerable populations in low- and lower middle-income countries

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Summary

The impact of the COVID-19 pandemic in low-income settings is likely to be more severe due to limited healthcare capacity. Within these settings, however, there exists unfair or avoidable differences in health among different groups in society – health inequities – that mean that some groups are particularly at risk from the negative direct and indirect consequences of COVID-19. The structural determinants of these are often reflected in differences by income strata, with the poorest populations having limited access to preventative measures such as handwashing. Their more fragile income status will also mean that they are likely to be employed in occupations that are not amenable to social-distancing measures, thereby further reducing their ability to protect themselves from infection. Furthermore, these populations may also lack access to timely healthcare on becoming ill.

We explore these relationships by using large-scale household surveys to quantify the differences in handwashing access, occupation and hospital access with respect to wealth status in low-income settings. We use a COVID-19 transmission model to demonstrate the impact of these differences. Our results demonstrate clear trends that the probability of death from COVID-19 increases with increasing poverty. On average, we estimate a 32.0% (2.5th-97.5th centile 8.0%-72.5%) increase in the probability of death in the poorest quintile compared to the wealthiest quintile from these three factors alone.

We further explore how risk mediators and the indirect impacts of COVID-19 may also hit these same disadvantaged and vulnerable the hardest. We find that larger, inter-generational households that may hamper efforts to protect the elderly if social distancing are associated with lower-income countries and, within LMICs, lower wealth status. Poorer populations are also more susceptible to food security issues - with these populations having the highest levels under-nourishment whilst also being most dependent on their own food production. We show that timing of the COVID-19 epidemic in low-resource settings has the potential to interrupt planting and harvesting seasons for staple crops, thereby accentuating this vulnerability.

These enhanced risks and key vulnerabilities – alongside the broader concerns surrounding displaced or conflict-affected populations - demonstrate the challenges that the most marginalised populations face during the ongoing COVID-19 pandemic.

1. Introduction

The COVID-19 pandemic has now spread globally, with nearly 4.2 million cases and 284,000 deaths reported as of 11th May 2020. At present the worst-affected countries are in Europe and North America, although trajectories of case numbers for countries across all continents suggest that it is expected that large-scale epidemics will emerge in other regions in the coming weeks. Experience in the most severely affected countries and regions to date has highlighted the potential for COVID-19 epidemics to rapidly exceed healthcare capacity, even in high-income countries (HICs) such as the US and Italy that are comparatively well-resourced. The impact of exceeding healthcare capacity may be even more severe in low- and lower middle-income countries (LICs and LMICs) where the availability and quality of healthcare relevant to the treatment of COVID-19 (e.g. mechanical ventilators and therapeutic oxygen) is typically more limited (1).

Health inequities – the presence of unfair or avoidable differences in health among different groups in society – arise via a cascade of determinants that create hierarchies within societies which directly shape an individual's circumstance and impact their health and well-being (Figure 1) (2,3). These determinants operate at a range of scales; structural determinants represent aspects of wider society such as the political governance and economics of a country or region and how they affect an individual's life experience. Such determinants are manifested, for example, in an individual's education, income, and occupation and may overlap with characteristics such as gender and ethnicity. Together, these factors shape the context in which intermediary determinants (e.g. material circumstance, behaviour etc.) play out, interacting with the health system to impact on an individual's health and well-being (2,3). As for other infectious diseases, the impact of COVID-19 is likely to be most acutely felt by the most disadvantaged populations – those who are burdened with a disproportionate number of these structural and hence intermediary determinants driving health inequity and who are therefore more likely to lack the capacity to effectively mitigate the direct and indirect consequences of the pandemic.

Within a social determinants of health framework, it is possible to map several different routes by which COVID-19 can impact these disadvantaged populations. For example, occupation and income may directly shape an individual's ability to social-distance, either through enhanced exposure in their employment or through their employment in a casual labour market that provides no safety net for periods of unemployment. Disadvantaged populations also typically lack many of the basic requirements for infection prevention and therefore, on becoming ill, face significant physical and financial barriers to accessing the health system. More broadly, in many LICs and LMICs the socio-economic and political context is often fragile and populations, including many affected by conflict or displacement, are particularly vulnerable. Each of these factors demonstrates one of the many routes by which the risk posed by a COVID-19 epidemic will differ between populations, leading to highly heterogeneous impact within countries and across different social hierarchies. Understanding these patterns of vulnerability and how they shape COVID-19 risk is critical both to identify those at highest personal risk and to understand and appropriately construct appropriate mitigation measures for these groups.

In this report, we draw on data from nationally representative population surveys to explore a subset of inequities, how they relate to wealth and the way in which they may drive variation in COVID-19 risk. Using a dynamical model of COVID-19 transmission, we illustrate the potential for these factors (using the examples of availability of handwashing facilities, healthcare accessibility and capacity to work from home), individually or in combination, to lead to substantial inequalities in health outcomes and significant excess COVID-19 mortality in the poorest and most disadvantaged populations. We then discuss the potential for COVID-19 and associated interventions to have considerable indirect effects that may further concentrate the impact of COVID-19 into the poorest and most marginalised groups.

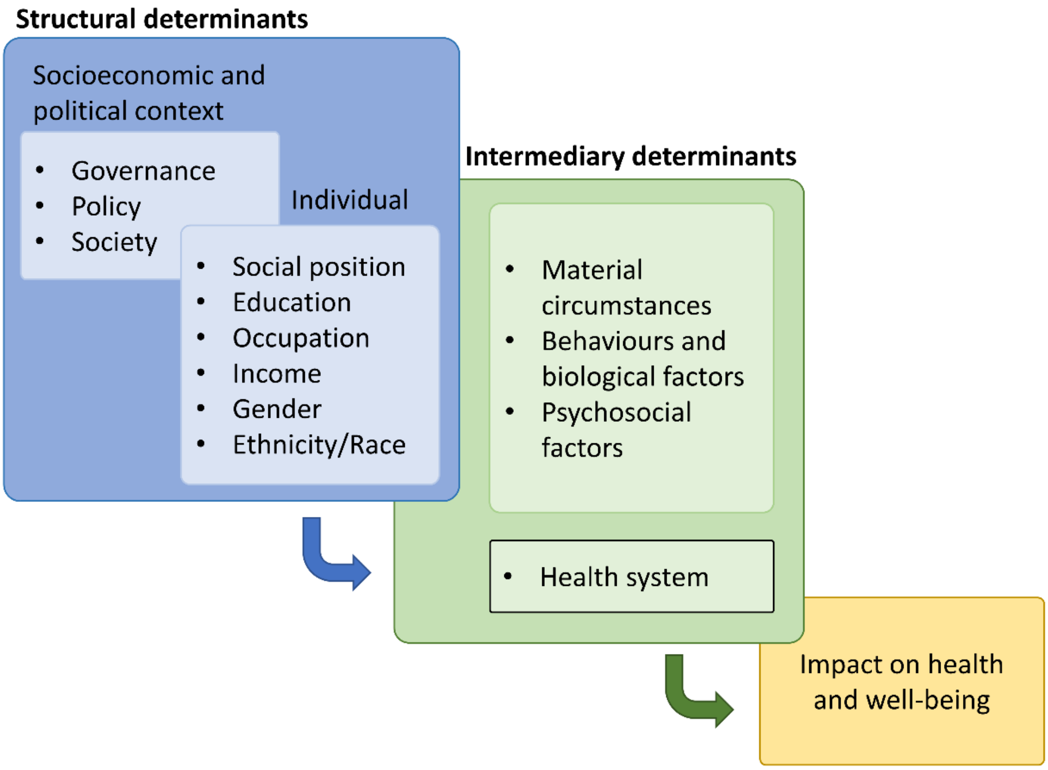

Figure 1. Social determinants of health in the context of COVID-19. Structural determinants (blue box) operate at different scales (socioeconomic, political, individual) and are the context in which social hierarchies are shaped. These structural determinants then drive intermediary determinants, which interact with the health system and impact an individual's health and well-being. Framework and figure adapted from (2,3).

2. Modelling the impact of COVID-19 with respect to wealth

Whilst there are a multitude of different determinants that will likely impact the risk from COVID-19 disease, here we illustrate the impact of three potential pathways. The first – handwashing – can be considered a basic preventative measure for infectious diseases. This intermediary determinant will arise due to structural determinants related to education, occupation and income – in turn determining the level of housing and hence access to clean water. The second – occupation – whilst acting as a structural determinant influencing many intermediary determinants (including handwashing), can also directly impact an individual's ability to protect themselves from infection through social distancing. Thirdly, access to the health system has a direct impact on an individual's health outcome if they become infected with the virus. For each of these pathways, we explore how they relate to household wealth as a measure of income inequity.

Having clean hands, washed with soap and water, remains a key component in the control of infection and transmission of SARS-CoV-2 (4) supported by recent data from the UK and elsewhere demonstrating that handwashing can reduce the carriage of coronaviruses (5). However, many people residing in LICs and LMICs do not have access to soap and clean water in their home, limiting their access to basic infection-prevention measures. This will be compounded if self-isolation or home quarantine interventions are in place. Recent work has estimated that 2.01 (1.89–2.13) billion people lack access to handwashing facilities globally (6). Within LICs and LMICs access to soap and water in the home is strongly correlated with wealth, with the poorest households consistently less likely to have access to soap and water than more wealthy households (Figure 2A) (7,8). In 22 out of 26 countries considered here (with data drawn from the Demographic and Health Surveys), less than 25% of households in the poorest wealth quintile had access to soap and water in the home.

An individual's occupation can influence their ability to adhere to social distancing policies depending on how amenable such employment is to remote-working. We quantified occupations amenable to working from home as those where the individual worked in non-manual occupations (professional, technical or managerial, clerical) and had access to either a phoneline, mobile phone or computer. The percentage of individuals with a home-work amenable occupation overall was low (country estimates ranged from 5%-33%, in line with other estimates for LICs and LMICs (9)) but also declined substantially with increasing poverty, a range of 14%-80% in the highest wealth category compared to just 0%-13% in the poorest wealth category (Figure 2B). These results suggest that the poorest individuals across these countries are not only the least likely to be able to access infection prevention and control measures (such as soap and regular hand-washing), but will also likely be disproportionately exposed to the virus, due to an occupation-related challenges to social-distancing measures.

Individuals from disadvantaged populations face significant barriers to the timely access of healthcare upon falling ill. Hospitalisation rates for COVID-19 are high (10) and in many LICs and LMICs large sections of the population live far away from the nearest hospital (Figure 2C) (11–13). Furthermore, access to a hospital decreases as poverty increases (Figure 2 C, D) (7), with the median distance to the nearest hospital 4km for the wealthiest category considered here and 30km for the poorest.

Even where healthcare is accessible, costs may prove prohibitive if public healthcare is not an option: health insurance of any kind is uncommon in LICs and LMICs (country-level mean % with health insurance ranged from 0.7%-58%) and additionally, decreases as poverty increases (health insurance rates are on average 23 times higher in the wealthiest compared to the poorest). We also observe gender stratification in the availability of health insurance - coverage is consistently lower for women than men (Figure S2) (7), increasing the risk of catastrophic healthcare expenditure (14) and concentrating this risk in women and the poorest populations.

Difficulties accessing healthcare for the poorest are further exacerbated by the capacity and quality of available healthcare in low-income settings, where many hospitals are chronically under-funded, under-equipped and/or under-staffed to deal with a COVID-19 epidemic (Figure S3) (15). The number of hospital beds available per 1,000 population declines with a country's wealth: LICs on average have 1.35 beds per 1,000 population, compared to 4.69 beds per 1,000 population in HICs. A similar pattern is present in the number of key healthcare personnel, although this disparity is even more marked - whilst the average HIC has 4.7 times more hospital beds per-capita than the average LIC, HICs have 13.0 times more doctors and 9.6 times more nurses per-capita compared to LICs (16).

To illustrate the role inequity is likely to play in amplifying both the spread and severity of COVID-19 within the poorest members of societies we incorporated these three exemplar inequities (handwashing, home-working and hospital access) within a transmission model of COVID-19. We parameterise this model using data from the Demographic Health Surveys (7) and a spatial database of hospitals (11) and explore the impact of disparities in handwashing access, ability to work from home and healthcare access across five levels of wealth (following the DHS wealth index). We then link these estimates to an epidemiological model of COVID-19 disease severity to assess the impact of these factors on mortality either individually or in combination (Figure 2E).

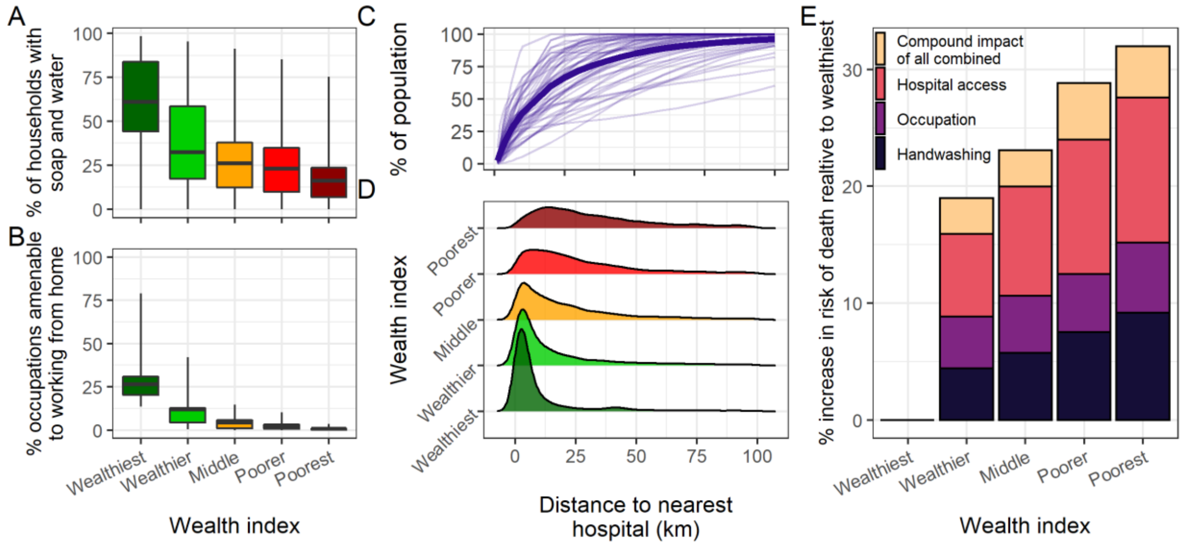

Figure 2. The relationship between wealth and access to handwashing, ability to work from home and hospital access and the impact of risk of death from COVID-19. A) the distribution of country-level average proportion of households with soap and water decreases with poverty, as does B) the proportion of people with occupations amenable to home-working. Hospital access is challenging in LICs and LMICs with C) a large proportion of the population in SSA live >25km from the nearest hospital and D) poorer subpopulations on average living further from a hospital. The E) modelled impact on the risk of death shows a clear increasing trend with respect to poverty for three factors considered (dark blue, purple and red bars segments) and the impact of all factors combined compounds (peach segments).

From this analysis, two important findings emerge. Firstly, the probability of death from COVID-19 consistently increases with increasing poverty, being highest in the poorest wealth quintile, and lowest in the wealthiest. Of the three factors considered, healthcare accessibility is predicted to be the most significant driver of differences in mortality risk between wealthiest and poorest quintiles (12.4% difference, 2.5^{th}-97.5^{th} centile: 0.7%-34.4%). Access to handwashing facilities results in an estimated 9.2% difference (2.5^{th}-97.5^{th} centile: 0.9%-18.8%) between the wealthiest and poorest quintiles whilst occupation as an indicator of the capacity to social distance results in a 6.0% difference (2.5^{th}-97.5^{th} centile: -5.2%-16.7%). Secondly, our results also highlight the compounding nature of these individual impacts – compared to models in which only individual factors were included, the model including all three factors consistently led to mortality that was higher than the sum of the individual impacts. Indeed, on average, we estimate a 32.0% (2.5^{th}-97.5^{th} centile: 8.0%-72.5%) increase in the probability of death in the poorest quintile compared to the wealthiest quintile, 4.5% (2.5^{th}-97.5^{th} centile: -4.6%-17%) of which is due to the compounding nature of the individual impacts considered here (full uncertainty shown in Figure S4).

3. Disadvantaged populations, mediators of risk and the indirect impacts of COVID-19

We have demonstrated that the direct impact of COVID-19 will be inequitably distributed and concentrated in the poorest populations. However, the damage from COVID-19 will extend beyond direct impacts and will have far-reaching implications for the social determinants of health in these populations. Such implications will manifest across time and space at both the social-economic/political level, as well as at the level of the individual. In the following section we present three data-driven examples to illustrate these issues, covering: i) age and household-structure, ii) food security and iii) vulnerable populations including displaced and conflict-affected people and domestic safety.

Age and Household Structure

Epidemics in China, Europe and North America have demonstrated a strong age-gradient in disease severity, rising sharply from age 50 years and above (17). In response, many countries have recommended that these at-risk groups protect themselves by social distancing. Given that suppression of COVID-19 might be challenging in some settings, this has been proposed as a method for reducing risk of infection for vulnerable individuals in countries which aim to mitigate the health impact of the epidemic (18). Previous modelling work (10) shows that such a strategy, focused on social distancing of the elderly modelled as a reduction in contact patterns between this group and younger populations, can significantly reduce mortality. However, the practicality of such a strategy, particularly in the most disadvantaged sectors of the population, is challenging. Average household size is higher in LICs (around 5 people) compared to high income countries (HICs) (around 2.5 people) (Figure 3A), with a far higher proportion of households in LICs that are inter-generational. Approximately 20% of households in LMICs include at least one younger (<20 years old) and one older (>60 years old) person (Figure 3B) compared to less than 5% in HICs. We see a similar trend within LICs and LMICs: there is a higher proportion of inter-generational households in the poorer wealth quintiles (Figure 3C). In both cases, this higher contact between younger individuals and the elderly (the most at risk from COVID-19) will limit the effectiveness of strategies aimed at shielding this vulnerable demographic in the home.

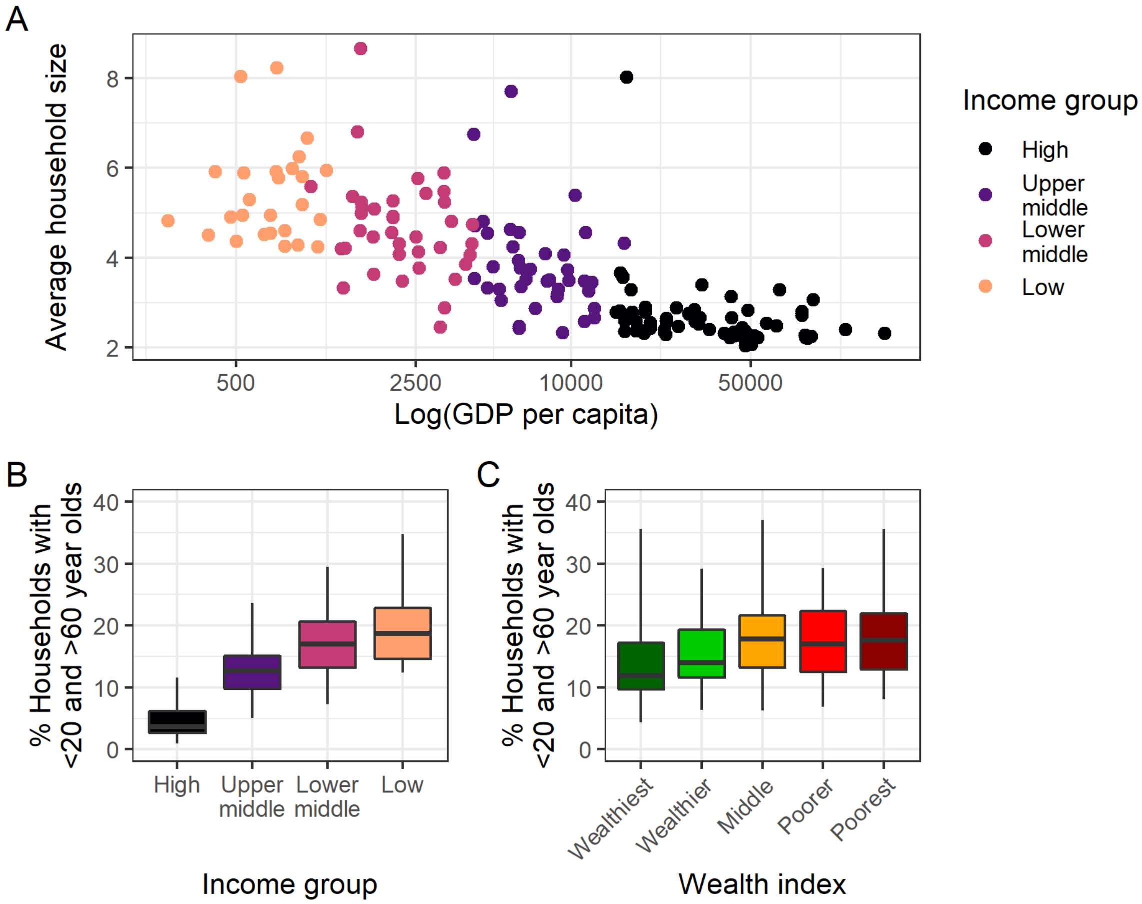

Figure 3. Household size and structure. Low-income countries on average A) have larger household sizes and B) are more likely to have both young (<20 years old) and old (>60 years old) residents. Within LICs and LMICs, poorer households are on average C) more likely to have young (<20 years old) and old (>60 years old) residents.

Food Security

The COVID-19 pandemic will have a marked impact on food security, impacting supply chains both downstream and upstream, affecting livelihoods and critically straining nations that already suffer from higher levels of undernourishment in the general population than wealthier countries (19). Figure 4A shows the prevalence of undernourishment by World Bank income group, demonstrating a clear trend across country income status (19). Notably, on average nearly one third of individuals residing in LICs experience undernourishment. LICs are also scored lower on a composite food security index that rates countries based upon food affordability, availability, quantity and safety and natural resources (median score for LICs was 45 out of 100 compared to 79 in HICs) (20). Given this baseline level of precarity with regards to food security, these countries will be particularly vulnerable to short-term food shortages that may result from widescale social distancing and lockdowns as well as other upstream impacts.

These vulnerabilities will likely be compounded further by the disruption COVID-19 epidemics could potentially cause to local food supplies – whether directly through illness or indirectly through the disruptive effects of epidemic control measures. Integrating our dynamical model of COVID-19 transmission (calibrated to deaths observed to date) alongside information on planting and harvesting times of staple crops, which typically share similar planting schedules (21,22), our results highlight the capacity for key agricultural products to be disrupted due to the epidemic trajectory of both controlled and uncontrolled COVID-19 epidemics (Figure 4 C-F, see Figure S5 for other areas).

Disruption to agricultural output will likely be particularly concerning given that within LICs and LMICs a large proportion of people subsist primarily on the food they produce themselves. This proportion is, on average, threefold higher in the poorest third of the population than the richest and fivefold higher in rural areas compared to urban (23). This leads to vulnerability to food supply disruption from a period of lockdown or other measures that restrict a person's ability to tend to crops.

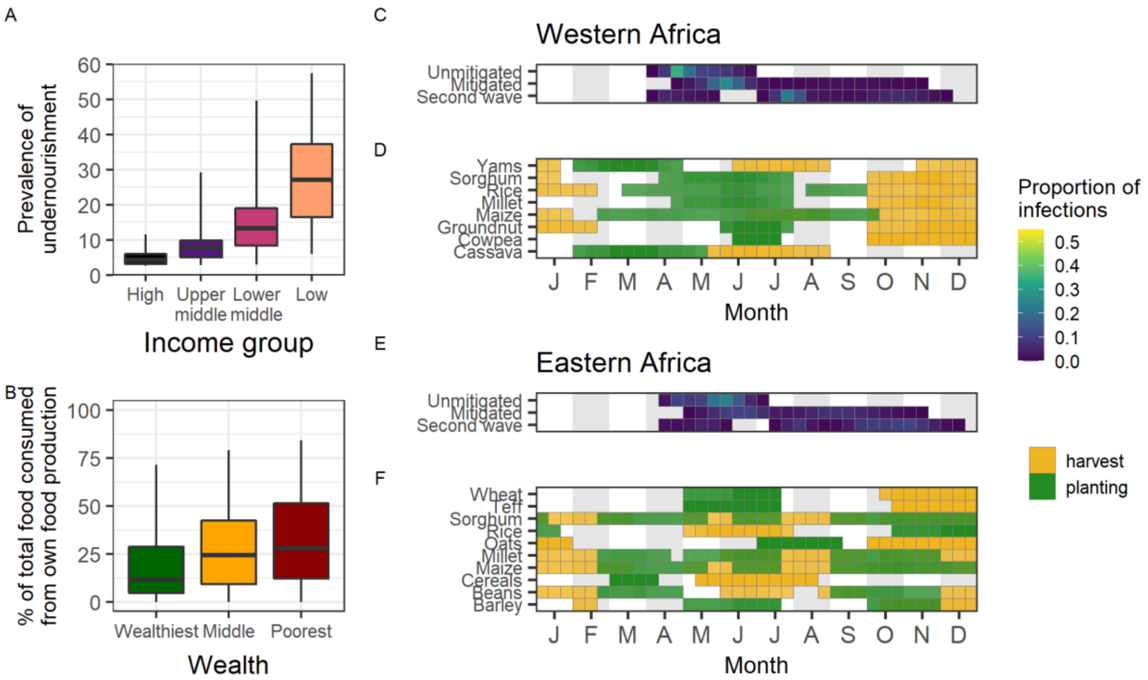

Figure 4. Food security. Distribution of country-level average A) prevalence of undernourishment that shows a strong trend of increasing undernourishment in LICs and LMICs. Within these countries the B) poorest populations rely the most on food produced themselves. Example key seasons for planting and harvesting of staple crops by region and exemplar unmitigated, mitigated and second wave COVID-19 epidemic trajectories for C, D) western African and E, F) Eastern Africa. We observe overlap between COVID-19 epidemics and control periods and planting and harvesting seasons for a wide range of staple crops. Harvest and planting shading indicates the proportion of countries reporting harvesting or planting in a given 10 day period (dekad) (and in some instances harvest and planting seasons may overlap).

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Vulnerable populations

The socio-economic and political situation within countries provides the context for all downstream social determinants of health. In some instances, this context is extremely fragile. Populations in these circumstances (such as refugees and internally displaced people) are especially vulnerable to the impacts of COVID-19 and associated non-pharmaceutical interventions (NPIs) that aim to reduce contact rates in the population. These include those who are displaced (24,25) and those who are affected by conflict. The median number of refuges per capita is 2 times higher and conflict fatalities per capita over 4 times higher in LICs and LMICs than in UMICs and HICs (1.09 refugees per 1,000 on average in LICs and LMICs versus 0.51 in UMICs and HICs. 0.40 conflict fatalities per 100,000 on average in LICs and LMICs compared to 0.096 in UMICs and HICs) (26)**.** People suffering from humanitarian crises face the additional challenges of fragile or non-existent health systems and poor infrastructure. In 2016, 7 of the 10 countries ranked as most vulnerable to infectious disease outbreaks were in active conflict zones (27).

Many of the NPIs against COVID-19 increase time spent at home with other family members, raising concerns with respect to domestic violence (28). While this is by no means a problem confined to LICs and LMICs, surveys of women from a number of LICs and LMICs show high reported rates of physical, emotional or sexual abuse (7). Country-level estimates of women reporting emotional, physical or sexual abuse from their spouse ranged from 9%-50%, 11%-53% and 3-28% respectively. Whilst statistics were not available in the representative surveys considered here, concerns for domestic safety also undoubtably extend to children in the household as well (29). This highlights the need to consider their safety with respect to any control measures that enforce prolonged stays within the home.

4. Conclusions

Vulnerable and disadvantaged populations are at significantly greater risk from COVID-19. This includes both direct impacts (such as morbidity and mortality) as well as indirect impacts stemming from the epidemic’s broader impact on society (such as food security and loss of livelihoods). The importance of equity in COVID-19 healthcare decisions must therefore be carefully considered in order to maximise health and well-being universally.

References

1. Nott D. Comment The COVID-19 response for vulnerable people in places affected by conflict and humanitarian crises. Lancet [Internet]. 2020;6736(20):19–20. Available from: http://dx.doi.org/10.1016/S0140-6736(20)31036-9

2. Solar O, Irwin A. A conceptual framework for action on the social determinants of health. Social Determinants of Health Discussion Paper 2 (Policy [Internet]. 2010. Available from: http://apps.who.int/iris/bitstream/10665/44489/1/9789241500852_eng.pdf?ua=1&ua=1

3. World Health Organization. Closing the gap in a generation: Health Equity Through Action on the Social Determinants of Health [Internet]. 2008. Available from: http://www.bvsde.paho.org/bvsacd/cd68/Marmot.pdf%5Cnpapers2://publication/uuid/E1779459-4655-4721-8531-CF82E8D47409

4. World Health Organization. Recommendation to Member States to improve hand hygiene practices widely to help prevent the transmission of the COVID-19 virus. 2020.

5. Jordan V. Cochrane Corner: Coronavirus (COVID-19): infection control and prevention measures. J Prim Health Care. 2020;12(1):96–7.

6. Brauer M, Zhao JT, Bennitt FB, Stanaway JD. Global access to handwashing : implications for COVID-19 control in low-income countries. medRxiv. 2020;

7. USAID. The DHS Program [Internet]. [cited 2016 Feb 17]. Available from: http://www.dhsprogram.com/

8. Kumar S, Loughnan L, Luyendijk R, Hernandez O, Weinger M, Arnold F, et al. Handwashing in 51 countries: Analysis of proxy measures of handwashing behavior in multiple indicator cluster surveys and demographic and health surveys, 2010-2013. Am J Trop Med Hyg. 2017;97(2):447–59.

9. Dingel J, Neiman B. How Many Jobs Can be Done at Home? [Internet]. Becker Friedman Institute White Paper. 2020. Available from: http://www.nber.org/papers/w26948Areplicationpackageisavailableathttps://github.com/jdingel/DingelNeiman-workathome/%0Ahttps://bfi.uchicago.edu/working-paper/how-many-jobs-can-be-done-at-home/

10. Walker P, Whittaker C, Watson O, Baguelin M, Ainslie KEC, Bhatia S, et al. The Global Impact of COVID-19 and Strategies for Mitigation and Suppression [Internet]. 2020. Available from: https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/report-12-global-impact-covid-19/

11. Maina J, Ouma PO, Macharia PM, Alegana VA, Mitto B, Fall IS, et al. A spatial database of health facilities managed by the public health sector in sub Saharan Africa. Sci data. 2019;6(1):134.

12. Lloyd CT, Sorichetta A, Tatem AJ. Data Descriptor: High resolution global gridded data for use in population studies. Nat Sci Data. 2017;XLII(July):1–17.

13. Porter G. Living in a walking world: Rural mobility and social equity issues in sub-Saharan Africa. World Dev. 2002;30(2):285–300.

14. McIntyre D, Thiede M, Dahlgren G, Whitehead M. What are the economic consequences for households of illness and of paying for health care in low- and middle-income country contexts? Soc Sci Med. 2006;62(4):858–65.

15. World Health Organization. A Universal Truth: No Health Without a Workforce. 2006;1–8.

16. The World Bank. Health system capacity [Internet]. [cited 2020 Apr 15]. Available from: https://data.worldbank.org/indicator?tab=all

17. Verity R, Okell LC, Dorigatti I, Winskill P, Whittaker C, Imai N, et al. Estimates of the severity of coronavirus disease 2019 : a model-based analysis. Lancet Infect Dis. 2020;3099(20):1–9.

18. Maysoon D, Kevin van Z, Stefan F, Abdihamid W, Paul B. S, Ronald W, et al. COVID-19 control in low-income settings and displaced populations: what can realistically be done? | LSHTM. London Sch Hyg Trop Med [Internet]. 2020;1–10. Available from: https://www.lshtm.ac.uk/newsevents/news/2020/covid-19-control-low-income-settings-and-displaced-populations-what-can

19. FAO, UN. Undernourishment [Internet]. [cited 2020 Apr 9]. Available from: https://unstats.un.org/sdgs/indicators/database/?indicator=2.1.2

20. The Economist Group. Global food security index [Internet]. [cited 2020 Apr 11]. Available from: https://foodsecurityindex.eiu.com/Downloads

21. FAO. GIEWS - Global Information and Early Warning System [Internet]. [cited 2020 Apr 16]. Available from: http://www.fao.org/giews/countrybrief

22. European Commission JRC (JRC). Crop calendar dataset compatible with satellite-derived land surface phenology [Internet]. [cited 2020 Apr 7]. Available from: https://data.europa.eu/euodp/en/data/dataset/jrc-10112-10003

23. FAO. FAOSTAT [Internet]. [cited 2020 Apr 7]. Available from: http://www.fao.org/faostat/en/#data/HS

24. The World Bank. Refugee population by country or territory of asylum [Internet]. [cited 2020 Apr 15]. Available from: https://data.worldbank.org/indicator/SM.POP.REFG

25. Truelove S, Abrahim O, Altare C, Azman A, Spiegel P. COVID-19: Projecting the impact in Rohingya refugee camps and beyond. medRxiv. 2020;

26. ACLED. Number of conflict related reported fatalities by country-year [Internet]. [cited 2020 Apr 9]. Available from: https://acleddata.com/curated-data-files/

27. Moore M, Gelfeld B, Okunogbe A, Paul C. Identifying Future Disease Hot Spots: Infectious Disease Vulnerability Index. 2016.

28. Salisbury H. Helen Salisbury: What might we learn from the covid-19 pandemic? BMJ [Internet]. 2020;368(March):2020. Available from: http://dx.doi.org/doi:10.1136/bmj.m1087

29. Usher K, Navjot B, Durkin J, Gyamfi N, Jackson D. Family violence and COVID-19: Increased vulnerability and reduced options for support. Int J Ment Health Nurs. 2020;140.

30. Watson OJ, Eaton J. rdhs: API Client and Dataset Management for the Demographic and Health

Survey (DHS) Data [Internet]. 2019. Available from: https://cran.r-project.org/package=rdhs

31. European Centre for Disease Prevention and Control: COVID-19 [Internet]. [cited 2020 Apr 27]. Available from: https://www.ecdc.europa.eu/en/covid-19-pandemic

32. GADM. Global Administrative Areas [Internet]. [cited 2018 May 10]. Available from: www.gadm.org

33. Thomas H, Webster S, Petherick A, Phillips T, Kira B. Oxford COVID-19 Government Response Tracker, Blavatnik School of Government. [Internet]. 2020 [cited 2020 Apr 27]. Available from: https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker

34. Watson OJ, Winskill P, Walker PG, Whittaker C. squire: SEIR transmission model of COVID-19 [Internet]. 2020. Available from: https://mrc-ide.github.io/squire/

35. Jefferson T, Del Mar CB, Dooley L, Ferroni E, Al-Ansary LA, Bawazeer GA, et al. Physical interventions to interrupt or reduce the spread of respiratory viruses. Cochrane database Syst Rev. 2011;(7).

36. Grant RL. Converting an odds ratio to a range of plausible relative risks for better communication of research findings. BMJ [Internet]. 2014;348(January):1–7. Available from: http://dx.doi.org/doi:10.1136/bmj.f7450

5. Appendix

Summary of data sources

ACLED
Conflict fatalities (26).

DHS
LIC and LMIC Household, Individual (Women and men) and cluster geo-references survey data sets were downloaded from the DHS website (7) using the rdhs R package (30). Surveys available were: Angola (2015), Bangladesh (2014), Benin (2017), Burkina Faso (2017), Burundi (2016), Cambodia (2014), Cameroon (2011), Chad (2014), Congo (2011), Congo Democratic Republic (2013), Cote d'Ivoire (2012), Ethiopia (2016), Gabon (2012), Gambia (2013), Ghana (2016), Guinea (2018), Haiti (2016), Kenya (2015), Lesotho (2014), Liberia (2016), Madagascar (2016), Malawi (2017), Mali (2018), Mozambique (2018), Myanmar (2016), Namibia (2013), Niger (2012), Nigeria (2018), Pakistan (2017), Papua New Guinea (2017), Philippines (2017), Rwanda (2017), Senegal (2017), Sierra Leone (2016), South Africa (2016), Tanzania (2017), Timor-Leste (2016), Togo (2017), Uganda (2016), Zambia (2018), Zimbabwe (2015).

ECDC
COVID-19 deaths (31).

EU JRC
Crop calendars (22).

FAO
FAO: Crop calendars (21), Subsistence farming indicators (23) and undernourishment (19).

GADM
GADM country boundaries (32).

Global food security index
Food security scores (20).

University of Oxford Blavatnik School of Government
Interventions (33).

World Bank
World Bank: Refugees (24), healthcare capacity (16).

WorldPop
Population raster (12).

Summary of methods

DHS data

DHS, Individual, household and geo-referencing of clusters were linked using the HH or cluster unique identifiers. Country level survey-weighted average (mean) estimates were calculated for i) availability of soap and water in the household (DHS variables: *hv230b* and *hv232*), ii) household wealth index (*hv270*), iii) domestic violence (*d105, d103*), iv) health insurance (*v481, mv481*). The (great-circle) distance between each DHS cluster and the nearest-neighbour public hospital was estimated.

The proportion of the population within a given distance of the nearest public hospital was estimated by taking the sum of the population within a given buffer-radius of all public hospital geo-locations, over the total population size.

Crop calendar

Epidemic trajectories for COVID-19 for countries with available data in 4 regions of Africa (Burundi, Djibouti, Ethiopia, Kenya, Mauritius, Malawi, Somalia, Tanzania, Zambia, Zimbabwe, Angola, Cameroon, Congo, DRC, Gabon, Botswana, Swaziland, South Africa, Benin, Burkina Faso, Côte d'Ivoire, Ghana, Guinea, Gambia, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal and Togo) as well as Southern Asia (Afghanistan, Bangladesh, India, Sri Lanka and Pakistan) were simulated using the squire R package (34). For each country, the epidemic was fitted using a particle filter to the observed deaths as reported on 26/04/2020 (31). Three scenarios were modelled 1) Unmitigated: No control measures modelled (R_0 fixed at estimated baseline for each country), 2) Mitigated: R_0 reduced to represent implemented intervention strategies in each country maintained indefinitely (33) and 3) Second-wave: R_0 reduced by 75% for a period of two months to represent a complete lockdown initiated when infections per day exceeds 1 per 1,000 people, before returning to baseline. To compare against crop calendars, we estimated the proportion of the total cases for each region occurring in each dekad (10 day period), for each scenario. Dekads with <1% of cases were not plotted to improve clarity of timings. Bimodal second-waves can be observed where timing of second waves differed between countries within the same region.

To summarise crop calendars by region country level data were grouped and, for each crop and dekad, the average number of countries in that region with either a planting or harvesting recorded for that time period, was estimated.

Healthcare capacity

The raw data available on number of physicians and nurses/midwives were extracted and for each country the most recent year's result used for calculation of summary statistics. For the number of hospital beds per 1,000 population, we used results from previous work that used a boosted-regression tree framework and a suite of socio-economic covariates to generate up-to-date estimates of hospital bed capacity in 153 countries (10).

Inequity simulator

We parametrised an equity simulator to allow us to model inequalities across wealth quintiles in relation to access to handwashing facilities, ability to work from home and hospital access. The general approach was to first fit an appropriate distribution to country level estimates of the proportion of households with handwashing facilities (beta distribution), the proportion with jobs amenable to working from home (beta distribution) and hospital access (log-normal distribution) in the wealthiest quintile. Secondly, we estimated the relative risk in other wealth quintiles from the data compared to the wealthiest and fitted log-normal distributions to each of these. This combination of fitted index (wealthiest) and relative risk distributions allowed us to simulate these factors across wealth quintiles. We then modelled each population split into 5 sub-populations based on DHS wealth index classification (Wealthiest, Wealthier, Middle, Poorer, Poorest) that were simulated independently. For each factor alone and for all three combined we ran 100 sensitivity draws that incorporated uncertainty in the impact of wealth on each factor (for the inequity simulator), the relationship between distance and hospital access and the estimated number of hospital and ICU beds per capita (see hospital access below) and the impact of handwashing on transmission (see handwashing below). The influence of these three factors on each sub-population was included in the transmission modelling in the following ways:

Handwashing

For each sub-population we simulated the proportion of households with available soap and water. To translate handwashing access to COVID-19 impact, we estimated the relative risk, RR, of transmission with respect to the availability of handwashing facilities given the measured impact of handwashing on the spread of respiratory viruses, $OR = 0.54$ (95% CI: 0.44, 0.67) (35) and the estimated baseline risk, $b_0 = 0.87$, of being infected in an unmitigated epidemic (10) using the following conversion (36) :

$$RR = \frac{I}{1 - b_0 + Ib_0}$$

Assuming an $R_0 = 3$ in the presence of good access to handwashing facilities (for example as observed in Europe and the USA) we then estimate increases in transmission, $\widehat{R_0}$, given a proportion of household with access to handwashing facilities, H, :

$$\widehat{R_0} = \frac{R_0}{RR + H(1 - RR)}$$

Such that, in this case, for 100% handwashing access $\widehat{R_0} = R_0 = 3$, and for 0% handwashing access $\widehat{R_0} = 3.45$. Sensitivity to the impact of handwashing (OR) was included by sampling from a log-normal distribution fitted to match the observed average and confidence bounds in the estimated OR.

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Occupation

We simulated the distribution of occupations in each wealth quintile, given occupation categories as well as household ownership of a landline, mobile phone or computer. We categorised those working in professional, technical, managerial or clerical position who also had access to a phone or computer as having an occupation amendable to home working and all others as not. We assumed that 75% of those with occupations amenable to home working and 10% of those with occupations not amenable would work from home. Working from home was assumed to reduce contact with other working age (16-65 year-olds) individuals by 75%. Household structure was not included in the model; we therefore did not model any increase in household contact for those able to social distance from the workplace.

Hospital access

We assume that the probability of being able to access a hospital or intensive care unit (ICU) bed is negatively associated with distance from a public hospital. We use the distribution of distances of households from the nearest public hospital in each wealth quintile to estimate the proportion of the total hospital and ICU beds available in a country that each sub-population can access. We conducted a sensitivity over five distance decay profiles with half-lives of 2, 5, 10, 20 and 50km, where the half-life indicates the distance at which the relative likelihood of accessing a hospital or ICU bed halves. We did not consider private hospitals or other treatment pathways which may vary by wealth quintile.

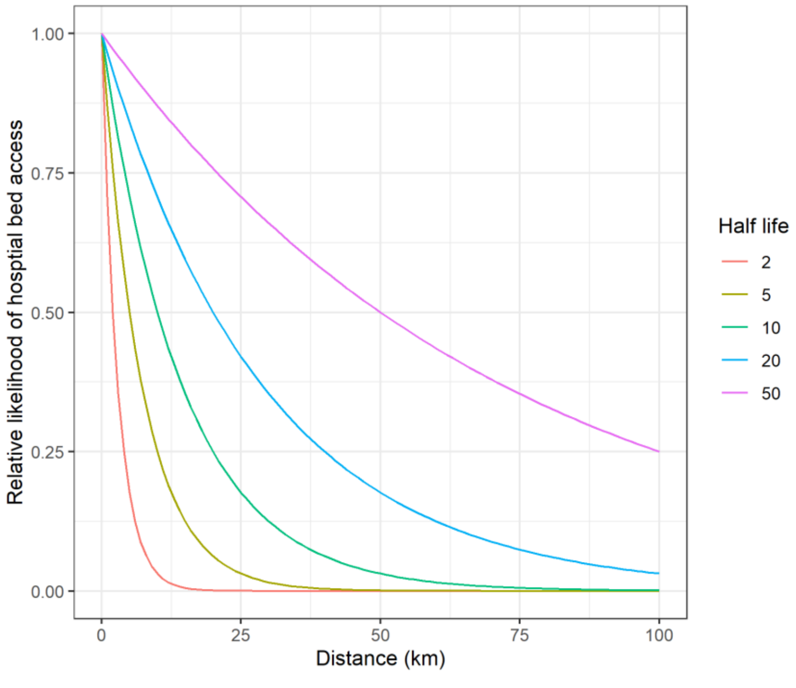

Figure S1. Relative likelihood of receiving a hospital bed with respect to distance. The analysis included 5 decay kernels with half-lives of increasing distance from 2-50km.

We also included uncertainty in the estimates of the number of hospital beds and ICU beds per person, drawing from a log-normal distribution fitted to estimates of hospital bed capacity and uniformly from the range of estimates for ICU bed capacity.

All simulations were run assuming a background mitigation strategy that halved R_0 60 days after the first infection which was maintained for the duration of the epidemic. For each simulation we took the median estimate over five stochastic model runs. We used an example age-structure for the population taken from Kenya. Sub-populations in each wealth quintile were run independently, resulting in the strong assumption of no mixing between the sub-populations, this assumption may be particularly influential for aspects impacting transmission (e.g. handwashing and occupation).

Supplementary figures

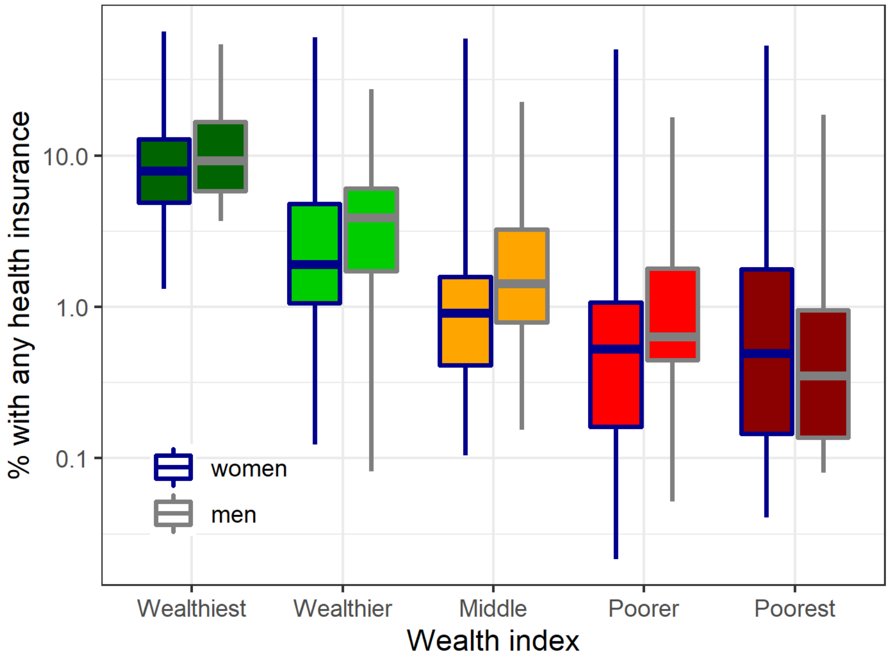

Figure S2. The distribution of country-level estimates of the proportion of individuals with health insurance. Health insurance coverage is low overall, falls with increasing poverty and is consistently lower for women than men (except in the poorest quintile).

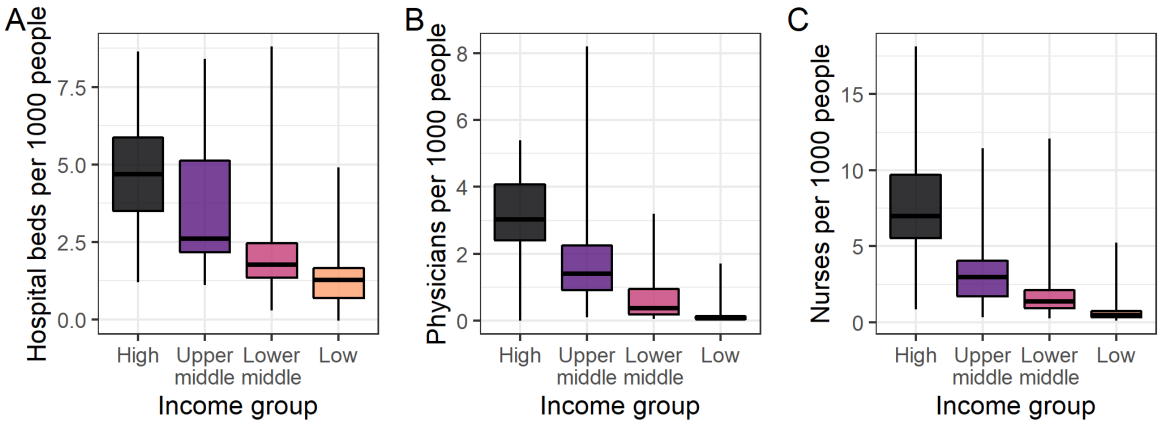

Figure S3. Healthcare capacity. The number of A) hospital beds, B) physicians and C) nurses per 1000 population is consistently lower in lower-middle- and low-income countries compared to high- and upper-middle-income countries.

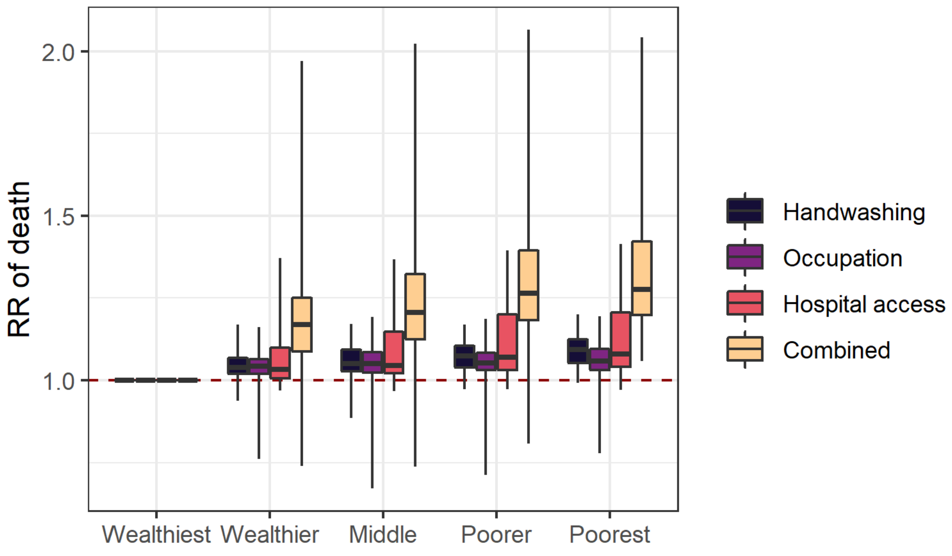

Figure S4. Uncertainty in modelled estimate of the impact of COVID-19 with respect to wealth quintile. The range of uncertainty in estimates of the relative risk of death with respect to wealth from 100 draws from the inequity simulator.

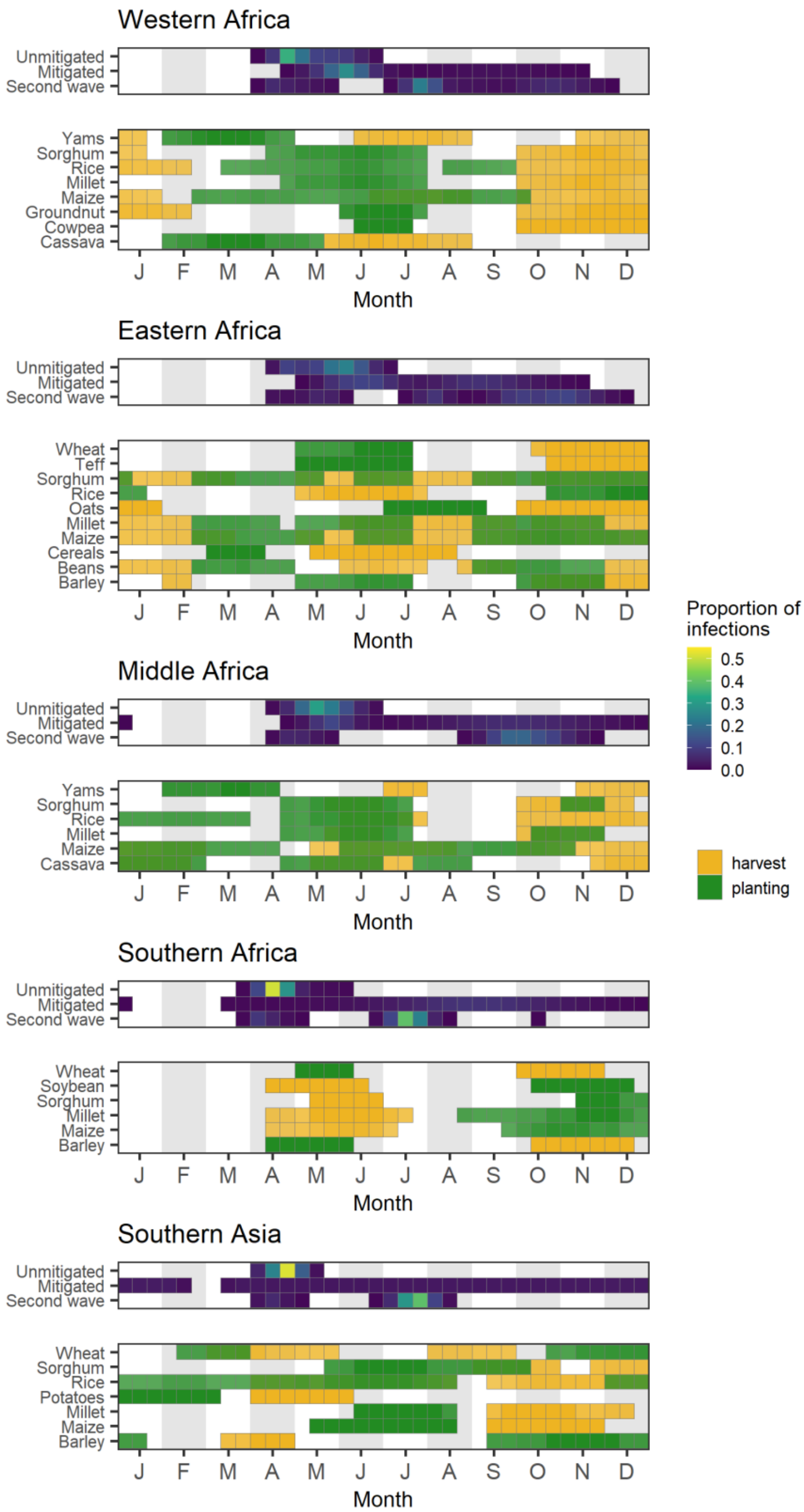

Figure S5. Key seasons for planting and harvesting of staple crops by region and exemplar unmitigated, mitigated and second wave COVID-19 epidemic trajectories. We observe overlap between COVID-19 epidemics and control periods and planting and harvesting seasons for a wide range of staple crops in areas of sub-Saharan Africa and Southern Asia. Harvest and planting shading indicates the proportion of countries reporting harvesting of planting in a dekad (and in some instances harvest and planting seasons may overlap).