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Scoping review of modelling studies assessing the impact of disruptions to essential health services during COVID-19

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ABSTRACT

Background Studies assessing the indirect impact of COVID-19 using mathematical models have increased in recent years. This scoping review aims to identify modelling studies assessing the potential impact of disruptions to essential health services caused by COVID-19 and to summarise the characteristics of disruption and the models used to assess the disruptions.

Methods Eligible studies were included if they used any models to assess the impact of COVID-19 disruptions on any health services. Articles published from January 2020 to December 2022 were identified from PubMed, Embase and CINAHL, using detailed searches with key concepts including COVID-19, modelling and healthcare disruptions. Two reviewers independently extracted the data in four domains. A descriptive analysis of the included studies was performed under the format of a narrative report.

Results This scoping review has identified a total of 52 modelling studies that employed several models (n=116) to assess the potential impact of disruptions to essential health services. The majority of the models were simulation models (n=86; 74.1%). Studies covered a wide range of health conditions from infectious diseases to non-communicable diseases. COVID-19 has been reported to disrupt supply of health services, demand for health services and social change affecting factors that influence health. The most common outcomes reported in the studies were clinical outcomes such as mortality and morbidity. Twenty-five studies modelled various mitigation strategies; maintaining critical services by ensuring resources and access to services are found to be a priority for reducing the overall impact.

Conclusion A number of models were used to assess the potential impact of disruptions to essential health services on various outcomes. There is a need for collaboration among stakeholders to enhance the usefulness of any modelling. Future studies should consider disparity issues for more comprehensive findings that could ultimately facilitate policy decision-making to maximise benefits to all.

STRENGTH AND LIMITATIONS OF THIS STUDY

⇒ This review will be the first review aimed to identify modelling studies assessing the potential impact of disruptions to essential health services caused by COVID-19 and to summarise the characteristics of disruption and the models used to assess the disruptions.
⇒ A thorough literature search of three major electronic databases and reporting as per the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols extension for scoping reviews guidelines.
⇒ A search of grey literature has not been performed, perhaps excluding significant contributions not published in commercial publications.
⇒ No comparisons of the findings of the studies were included in this review directly because of the large heterogeneity on which the models were built.

BACKGROUND

COVID-19 had a wide range of effects. The COVID-19 pandemic and actions taken in response to it have far-reaching indirect consequences on other diseases because of their substantial disruptions to healthcare services.[1] Disruptions include mitigation measures being undertaken in response to the COVID-19 pandemic, leading to the scaling back of certain actions and care-seeking; reduced capabilities of the healthcare system due to overwhelmingly high demand for the care of patients with COVID-19; and interruptions in commodity supply as a result of effects on both domestic and international supply chains.[2] It is critical to understand these consequences and how policies might eliminate, diminish or mitigate them.

Epidemiological or mathematical models have provided forecasts of the pandemic based on different policy scenarios; they have supported the planning of healthcare resources to meet the COVID-19 demand and have supported countries in understanding COVID-19 transmission mechanics.[3] Several models have been employed to assess the potential impact of disruptions to essential health services caused by COVID-19 pandemic on morbidity, mortality and other outcomes.[2 4–6] Modellers develop new models and review and improve existing ones in order to support decision-makers formulating policies to combat this devastating pandemic and to apply in future pandemics. Studies assessing the indirect impact of COVID-19 using mathematical models have increased in recent years.[7] Yet no scoping reviews summarising the description of such models assessed the effects of disruption to essential health services for several conditions other than COVID-19 in various settings exist in the literature. Since the field is rapidly developing, a review of the literature provides an overview, and description of existing models was considered important.

This scoping review aims to identify modelling studies assessing the potential impact of disruptions to essential health services caused by COVID-19 and to summarise the characteristics of disruption and the models used to assess the disruptions.

METHODS

This scoping review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols extension for scoping reviews (PRISMA-ScR)[8] and the protocol was registered with Open Science Framework (OSF) (https://osf.io/d5ymb). There are no competing interests for any author.

Data source and search strategy

A detailed literature search was carried out in PubMed, Embase and CINAHL from January 2020 to December 2022 for studies to include in the review. Searches were performed using index terms and phrases related to COVID-19, modelling and healthcare disruptions (online supplemental appendix 1, search strategy). No language restrictions were applied. References cited in identified sources were examined for additional studies meeting our eligibility criteria.

Study selection

Modelling studies that were published in peer-reviewed journals assessing any impacts of disruptions to health services caused by COVID-19 were included in this review. Detailed descriptions of categories of disruption[3 7] and models[3 7 9] are provided in online supplemental appendix tables 2 and 3, respectively. Reviews, commentaries, editorials, letters to the editor, documents, conference abstracts and case reports were excluded, unless they provided novel modelling analyses or outcomes. Studies that applied time-series and regression analyses to assess the impact of disruptions to health services during COVID-19 were not included in this review. Two reviewers (SKV and LS) independently screened the titles, abstracts and full texts identified in the literature search using predefined screening criteria as stated above. Any disagreements between the two reviewers were resolved by a third independent reviewer (NC).

Data charting process

A standardised data charting form was designed for the study. Two reviewers (LS and SKV) independently extracted the data. In case of any disagreement, a designated third reviewer (NC) cross-checked the data and the discrepancy was resolved through mutual consultation. The following characteristics were extracted in four domains: (1) general characteristics: author, year of publication, country, the population of interest, study setting, health condition, funding source and investigator group information; (2) nature of disruption: type of health service disrupted, category of disruption and possible reasons, effects on health services and other outcomes including clinical, economic, humanistic and public health goals; (3) model characteristics: specific name and type of model (classification provided in online supplemental appendix table 2) and its subclass as reported by the author, model application level, study and disruption time frames, time horizon, data sources, details on stakeholders involvement and assumptions employed; and (4) mitigation strategies: characteristics of mitigation strategies tested and its outcomes and overall recommendations.

Data synthesis

A qualitative analysis of the included studies was performed under the format of a narrative report. Findings were structured according to a primary description of the general characteristics of the included studies, followed by a comprehensive description of models and their findings. Effects of disruption were categorised as effects on demand for health services and clinical (eg, mortality and morbidity), humanistic, economic and public health goal (eg, delay in reaching disease elimination targets) outcomes. Demand for health services may change (increase or decrease) because of fear of seeking services, because of COVID-19 or difficulties in accessing them because of several reasons including disruptions to transportation or lack of funding for transportation. Mitigation strategies were conceptualised into three categories: (1) behavioural modifications including strategies to reduce social change affecting factors that influence health; (2) ensuring resources for services; and (3) ensuring access to services which are on demand. Appropriate data were presented in the form of summary tables. Because the purpose of this study is to summarise the characteristics of disruption and the models, quality assessment of included studies is least important; hence, it is not undertaken.

Patient and public involvement

Patients were not involved in this scoping review.

RESULTS

Study selection

A total of 4677 records, comprising 4077 unique articles after removal of duplicates, were identified. Title and

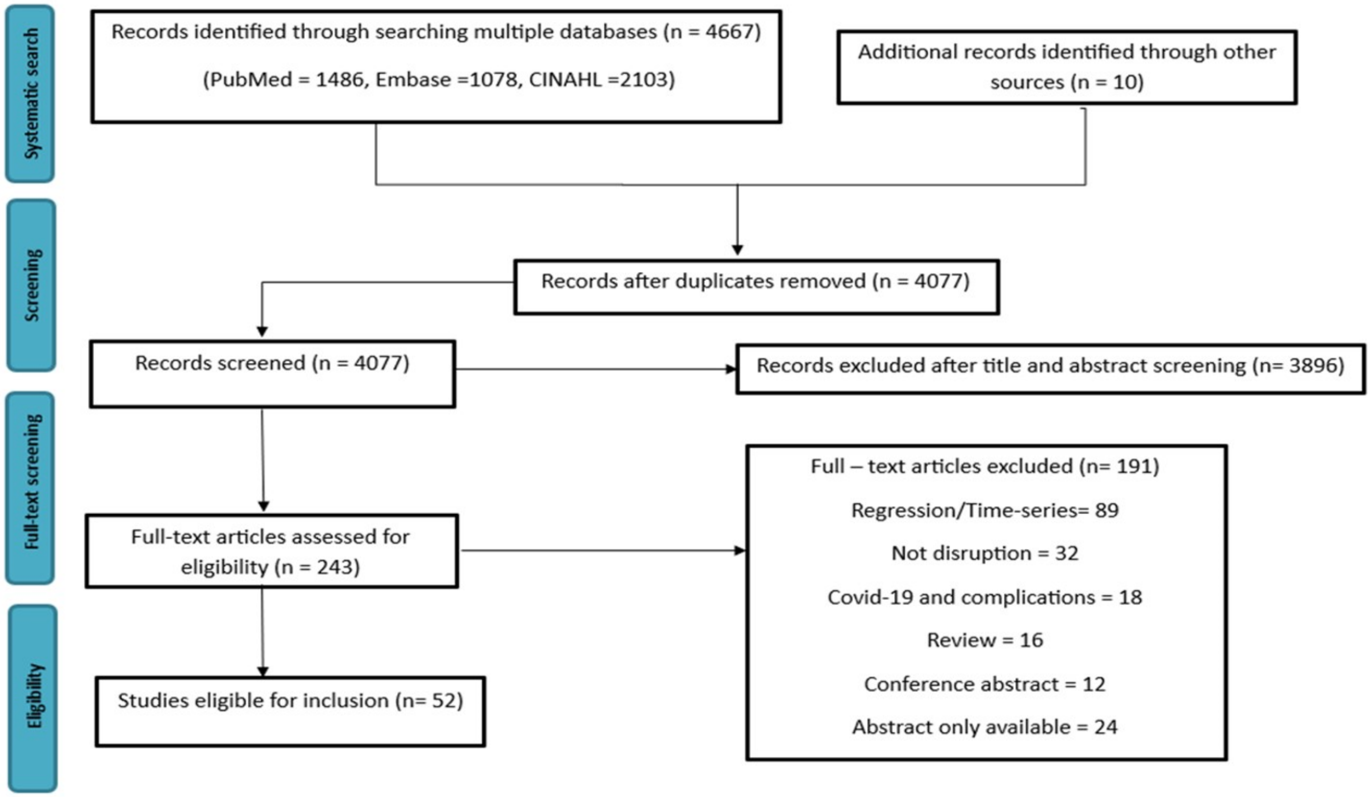

Figure 1

abstract screening removed 3896 articles, yielding 243 articles for review at full text. Another 191 were excluded due to other reasons listed in the PRISMA-ScR flow diagram (figure 1). Finally, 52 studies were included in this review.[2 4–6 10–57]

Study characteristics

All 52 studies were published between 2020 and 2022. Twenty-eight (53.8%) studies[10–23 25–38] analysed single countries and 24 (46.2%) analysed multiple countries (ranging from 2 to 190).[2 4–6 24 39–57] While four studies investigated settings with disease burden not specific to a certain country or a region.[11 18 19 53] Fourteen studies (26.9%) had models set for only low-income or middle-income countries (LMICs),[2 4–6 23 24 39 42–44 47 48 50 54] and 29 (55.8%) studies for only high-income countries (HICs).[10 12–17 20–22 25–38 40 45 46 52 55] Five (9.6%) studies focused on both HIC and LMICs.[41 49 51 56 57] There were 43 (82.7%) population-based studies[2 4–6 10–12 14–21 23 24 27 28 30 32 34–36 39–57] and 9 (17.3%) hospital-based studies.[13 22 25 26 29 31 33 37 38] Twenty-six (50%) studies considered the general population,[2 4 10 12 15 19 22 27–29 34–36 39–41 44 46 48–51 53 54 56 57] while the remaining studies included the population with or at risk for a disease condition, the older population, and women and children (online supplemental appendix table 4). Majority (45, 86.5%) of studies were funded. Among the 52 studies, 25 (48.1%) assessed the impact of both disruption and mitigation strategies on health services,[4–6 10–13 15 18 19 26 28 32 35 39–41 43 46–48 50 53 54 56] while the remaining assessed only the impact of disrupted services.

The main characteristics of all the included studies are provided in table 1. Additional information is provided in online supplemental appendix table 4.

The disruptions caused by COVID-19 have been studied for several health conditions (HIV infection (n=10),[2 5 12 16 20 24 41–43 52] tuberculosis (TB) (n=5),[2 27 49 50 54] and malaria (n=3)),[2 26 57] vaccine preventable (n=2)[39 44] and other infectious diseases (n=12),[11 15 18 19 21 26 29 47 48 51 53 56] cancers (n=11),[10 13 17 25 28 30 32 34 40 45 46] cardiovascular disease (n=2),[33 35] maternal and child health (n=2)[4 23] and many other disease conditions (n=7)[2 4 20 22 23 30 32 36 37 39 44 56] (table 1 and online supplemental appendix table 5). Twelve (23.1%) studies modelled multiple health conditions[2 4 20 22 23 30 32 36 37 39 44 56] while remaining focused on specific health condition or area. Disruption to the health service modelled in the studies fall into three categories[7]: (1) disruption to social change affecting factors that influence health (n=23; 44.2%)[2 4 5 12 16 20 21 23–25 27 29–31 33–35 41 43 49 50 52 55]; (2) disruption to supply of health services (n=51; 98.1%)[2 5 6 10–22 24–57]; and (3) disruption affecting demand for health services (n=28; 53.8%).[2 4 5 10 12–14 24 25 28–32 34–37 40 42 43 45 49 50 52 55–57] Shifts in behaviour (n=18;34.6%),[2 5 12 16 20 21 23–25 27 29 31 41 43 49 50 52 55] government-enforced lockdowns that limit health service provision (n=23 ;44.2%),[10–23 25–38] and shortage of income for households (n=2; 3.8%)[4 35] were the factors that affected social change. Lack of resources (n=50; 96.2 %)[2 4–6 10–22 24–28 30–57] and health personnel (n=46; 88.5%)[2 4–6 10–22 24–28 30–37 40–42 44–56] were the main reasons for the disruption to supply of health services

Table 1 Summary of characteristics of included studies

Characteristic	Studies (n)	References
Country		
HIC and LMIC	5	41 49 51 56 57
HIC only	29	10 12–17 20–22 25–38 40 45 46 52 55
LMIC only	14	2 4–6 23 24 39 42–44 47 48 50 54
Unspecified	4	11 18 19 53
Study setting		
Population based	43	2 4–6 10–12 14–21 23 24 27 28 30 32 34–36 39–57
Hospital based	9	13 22 25 26 29 31 33 37 38
Impact studied		
Impact of disruption	27	2 14 16 17 20–25 27 29–31 33 34 36–38 42 44 45 49 51 52 55 57
Impact of disruption and mitigation strategy	25	4–6 10–13 15 18 19 26 28 32 35 39–41 43 46–48 50 53 54 56
Health condition		
HIV	10	2 5 12 16 20 24 41–43 52
Tuberculosis	5	2 27 49 50 54
Malaria	3	2 6 57
Vaccine preventable diseases	2	39 44
Cancer	11	10 13 17 25 28 30 32 34 40 45 46
Cardiovascular diseases	2	33 35
Mother and child health	2	4 23
Other infectious diseases	12	11 15 18 19 21 26 29 47 48 51 53 56
Others*	7	2 4 20 22 23 30 32 36 37 39 44 56
Category of health service disruption†		
Social change	23	2 4 5 12 16 20 21 23–25 27 29–31 33–35 41 43 49 50 52 55
Supply of health services	51	2 5 6 10–22 24–57
Demand for health services	28	2 4 5 10 12–14 24 25 28–32 34–37 40 42 43 45 49 50 52 55–57
Types of models		
Microsimulation	45	5 10 11 13 17 26 28–30 32 34 35 38 40–42 44–48 53 56
Compartmental	30	2 5 6 12 15 16 18–22 24 27 40 41 43 44 52
Agent based	4	5 41 44
Discrete event	3	14 25 37
Markov	4	31 50 51 55
Other mathematical models§	30	4 23 30 33 36 39 49 50 54 56 57
Area of health service disruption		
Prevention	26	2 4–6 11 12 15 18–20 24 28 36 39 41–44 47 48 50 52–54 56 57
Diagnosis	26	2 5 6 10 13 16 17 21 25–27 32 36 37 40 41 45 46 49–52
Screening	16	12–14 17 20 26 30 34 40 45 46 51 52
Treatment	30	2 4–6 10 12 13 16 17 20 24–27 31 33 36 42 43 45 49–52 55 57
Hospital admission	1	22
Mass drug administration	5	11 18 19 47 48 56
Vaccination services	4	15 39 44 54
Surgery delay	2	10 33
Others¶	2	4 36 38
Model application level‡		
Global	28	2 4 11 18 39 41 44 45 51 53 54
Regional	37	5 19 24 40 42 46 47 55 56

Continued

Table 1 Continued

Characteristic	Studies (n)	References
National	45	6 10 12 13 15–17 20–23 25–27 30–36 38 48–50 52 57
Local	6	14 28 29 37 43
Stakeholder involvement		
Involvement	12	2 5 10 19 25 26 28 32 40 44 47 50
Engagement	3	10 28 32

*Others: Abdominal aortic aneurysm, stroke and transient ischaemic attack, dementia, cataract, psychiatric illness.
†Health service disruption: Disruption to the health service modelled in the studies fall into three categories[7]: (1) disruption to social change affecting factors that influence health; (2) disruption to supply of health services and (3) disruption affecting demand for health services.
‡Model application level: global: models applicable worldwide; regional: models applicable to a particular region (eg, African, Asian, Pacific, etc); national: models applicable to a nation; local: models applicable to an area within the country.
§Types of models: Others: for example, The Lives Saved Tool (LiST).
¶Service disruption: Others: availability of health workers and supplies of food, home care services.
HIC, high-income country; LMIC, low-income and middle-income country; STI, sexual transmitted infection; TB, tuberculosis.

modelled in the studies. Fear of seeking services (n=14; 26.9%),[2 4 5 10 12–14 24 28 36 37 45 49 50] or difficulties in accessing (eg, disruptions to transportation) (n=19; 36.5%),[2 4 10 12–14 25 28 30 32 34 35 40 42 43 50 52 56 57] were the main reasons for change in demand for health services. More details on the nature of COVID-19 disruptions are provided in online supplemental appendix table 5.

Description of models

The types of models used in the included studies were provided in table 1 and online supplemental appendix table 6. A total of 116 models were employed in the included 52 studies. Eighteen[2 5 6 13 17 30 32 40 41 43 44 46–48 53 55–57] studies employed more than one model (ranging from 2 to 7). The majority of the models were simulation models (n=86; 74.1%) including microsimulation (n=4538.8),[5 10 11 13 17 26 28–30 32 34 35 38 40–42 44–48 53 56] compartmental (n=30, 250.9%),[2 5 6 12 15 16 18–22 24 27 40 41 43 44 52] agent-based (n=4),[5 41 44] discrete-event (n=3),[14 25 37] Markov (n=4),[31 50 51 55] and a few other models (n=30)[4 23 30 33 36 39 49 50 54 56 57] such as models from Vaccine Impact Modelling Consortium (eg, Lives Saved Tool (LiST)[4 23]). Most models were applicable at the national level (38.8%),[6 10 12 13 15–17 20–23 25–27 30–36 38 48–50 52 57] followed by global (24.1%),[2 4 11 18 39 41 44 45 51 53 54] regional (31.9%),[5 19 24 40 42 46 47 55 56] and local (5.2%)[14 28 29 37 43] settings (table 1 and online supplemental appendix table 6). Two analytical study time frames were identified. First, the time frame of disruption itself applied in the models was from 2 months to a maximum of 1.5 years. Second, the time frame of the impact of disruption was measured from 4 months up to 50 years in these models. Among the 116 models, 54 and 108 models performed parameters sensitivity analyses (univariate,[2 6 10 12 13 15 16 18 21 22 24–26 34 35 39–43 46 48 51] multivariate[6 20 31] and probabilistic[28 52]) and scenario analyses,[2 6 11–20 22 24–38 41–48 51–53 55–57] respectively.

The impact of disruption during specific waves of the COVID-19 pandemic (ie, Omicron, Delta variants) was not considered in any models. Twelve studies considered stakeholder involvement.[2 5 10 19 25 26 28 32 40 44 47 50] Three studies engaged stakeholders to guide model parameters and project disruptions.[10 28 32] Stakeholders include clinical specialists[10 25 26 40 50] or advisory groups[2 5 10 19 28 44] and various agencies.[44 47] Three studies (gender[28 32 35] and ethnicity[35]) taken into account the equity considerations while assessing the impact of disruption. The impact of disruption during the pre-vaccination and post-vaccination era was not considered in any models.

Effects of COVID-19 disruptions modelled

Demand for health services was reported to change due to disruption in utilisation of health services. A total of 18 (34.6%) studies reported change in demand for health services.[2 4 5 10 12–14 22 24 25 28 30 40 42 43 45 49 50] Eight studies reported increase in demand[22 25 28 30 40 42 43 50] and 10 reported decreases in demand.[2 4 5 10 12–14 24 45 49] The impact of COVID-19 has been reported to disrupt several components of health services, including prevention,[2 4–6 11 12 15 18–20 24 28 36 39 41–44 47 48 50 52–54 56 57] screening,[12–14 17 20 26 30 34 40 45 46 51 52] diagnosis,[2 5 6 10 13 16 17 21 25–27 32 36 37 40 41 45 46 49–52] treatment,[2 4–6 10 12 13 16 17 20 24–27 31 33 36 42 43 45 49–52 55 57] vaccination services,[15 39 44 54] hospital admissions,[22] mass drug administrations,[11 18 19 47 48 56] and elective surgery,[10 33] and others.[4 36 38] Specific disruption effects reported by all 52 studies were categorised as clinical, humanistic, economic and public health goal outcomes (table 2 and online supplemental table 7). Forty-four studies reported clinical outcomes such as mortality and morbidity.[2 4–6 10 12–17 20 21 23–37 39–46 49–52 54–57] Fifteen studies reported public health goal outcomes (eg, delay in reaching disease elimination targets).[11 18 19 25 26 33 35 37 44 47 48 53 54 56 57] Seventeen articles reported humanistic outcomes (such as change in risky behaviour[2 5 12 14 16 20 21 23 24 29 35 41 43 49 50 52] and quality of life[28]) and four articles[22 29 35 38] reported economic outcome (eg, financial loss). Fourteen studies reported positive outcomes associated with COVID-19 disruptions such as decrease in risky behaviour,[2 5 12 16 20 21 24 27 29 41 43 49 50 52] reduction in morbidity[29] and financial saving.[29]

Table 2 Effects of disruption and mitigation strategies

Characteristic	Studies (n)	References
Effects of disruption		
Effects on demand	18	2 4 5 10 12–14 22 24 25 28 30 40 42 43 45 49 50
↑Demand	8	22 25 28 30 40 42 43 50
↓Demand	10	2 4 5 10 12–14 24 45 49
Clinical	44	2 4 6 10 12 17 20 21 23–37 39–46 49–52 54–57
Public health goal	15	11 18 19 25 26 33 35 37 44 47 48 53 54 56 57
Humanistic	17	2 5 12 14 16 20 21 23 24 29 35 41 43 49 50 52
Economic	4	22 29 35 38
Mitigation strategies		
Behavioural modifications	3	5 12 43
Resources for services	19	4 6 10 11 13 15 18 19 26 28 32 35 39 46–48 50 53 56
Access to services*	5	13 40 41 50 54
Outcomes of mitigation strategies		
Service	1	39
Clinical	20	4–6 10 12 13 15 26 28 32 35 39–41 43 46 47 50 54 56
Public health goal	6	11 18 19 48 53 56
Humanistic	1	35
Economic	1	28

*Ensuring access to services which are on demand; for example, reduce fear of seeking services, improve disruption to transport and prioritisation of population for health service.

Effects of mitigation strategies

Twenty-five (48.1%) studies assessed the effect of mitigation strategies that can reduce the impact of COVID-19 disruptions on health services.[4–6 10–13 15 18 19 26 28 32 35 39–41 43 46–48 50 53 54 56] Mitigation strategies were classified into three categories[7]: (1) behavioural modifications including strategies to reduce social change affecting factors that influence health (n=3),[5 12 43] (2) ensuring resources for services (n=19)[4 6 10 11 13 15 18 19 26 28 32 35 39 46–48 50 53 56]; (3) ensuring access to services which are on demand (eg, reduce fear of seeking services, improve disruption to transport and prioritisation of population for health service) (n=5).[13 40 41 50 54] Twenty studies reported improved clinical outcomes such as mortality and morbidity.[4–6 10 12 13 15 26 28 32 35 39–41 43 46 47 50 54 56] Six studies reported public health goal outcomes (eg, improvement in reaching elimination target and periodic intensification of routine immunisation).[11 18 19 48 53 56] One article reported a humanistic outcome (additional job creation)[35] and one article[28] reported economic outcome (eg, Maximise cost-effectiveness). One study[39] reported improved outcomes in health services such as fully vaccinated people.[39] Detailed description on the effects of mitigation strategies is provided in table 2 and online supplemental appendix table 8. Governments (n=16), policy makers (n=9), the health system (n=0.8), professional bodies (n=2), communities (n=1) and others (n=1) are among the audiences suggested by study authors for their findings (online supplemental appendix table 8).

DISCUSSION

The COVID-19 pandemic, and actions taken in response to it, will have far-reaching consequences on other diseases, poverty, food security and economic growth. Essential healthcare services are frequently interrupted across the world during the COVID-19 pandemic. This scoping review has identified a total of 52 modelling studies that assessed the potential impact of disruptions to essential health services including health promotion, preventive, diagnosis and treatment services. Studies employed several mathematical models including compartment, agent-based, discrete-event simulation, Markov, regression and time series models to assess the impact on various outcomes. Studies covered a wide range of health conditions from infectious diseases to non-communicable diseases. The impact of COVID-19 has been reported to disrupt the supply of health services, demand for health services and social change affecting factors that influence health. All studies showed that disruption in health services focusing on different health conditions and services during the pandemic generally caused a greater loss of life and an increase in the prevalence of disease conditions studied. Health system resilience is the ability to prepare, manage and learn from shocks such as the COVID-19 pandemic. Twenty-eight studies in this review modelled various mitigation strategies to manage the impact of COVID-19. The findings of these studies show that one way to lessen the indirect impacts of the COVID-19 pandemic is to maintain essential health services by ensuring resources and access to services (eg, reducing fear of seeking services, improving transport) and prioritising the population who are at risk (eg, cancer screening).

Healthcare delivery was impacted in several different ways. The demand for health services could be influenced by fear of contracting COVID-19 and/or difficulties accessing services,[7] while the supply of services especially operation of health services may be affected by shifting resources to fight the COVID-19 pandemic and/or by closing health services or healthcare facilities. It can be also due to the disruption to the supply of medicines and commodities. Additionally, social and public health measures due to the pandemic such as a stringent lockdown, may have an impact on people's socioeconomic status as well as their capacity to access the healthcare they require.[58] These included those for communicable diseases, non-communicable diseases, mental health, maternal and child health, routine immunisation services, and cancer diagnosis and treatment. It is important to understand which components of the health system as a whole were disrupted more severely and what the main contributing factors were. It is also important to track any changes in disruption that may be occurring as the outbreak progresses along its various stages. However, there was no attempt to assess the impact of disruption on the overall health system across all diseases and services in any of the included studies. It is important to have national or regional data on the impact of the pandemic from studies to improve understanding of the perceived extent of disruptions across all services, and the reasons for disruptions. This information can help to plan for mitigation strategies and policies and support decision-makers at various levels to advocate for resources and investment throughout the course of the pandemic for the most affected settings and populations.

Several studies in this review modelled various mitigation strategies to determine how they might affect COVID-19's impact on a specific healthcare setting. Based on a recent survey,[58] WHO suggested strategies to mitigate disruptions to services, such as triaging to identify priorities, shifting to online patient consultations, changes to prescribing practices and supply chain strategies, and refocusing public health information communications. However, focusing on only one area could have a detrimental effect on services provided in other contexts. It is crucial to carefully weigh the benefits and risks of pursuing mitigation strategies in an overall health system and recognise which strategies work best throughout different stages of the pandemic. RAPID (Rapid Assessment of Pandemic Indirect Impacts and Mitigating Interventions for Decision-making) for the State of California made such efforts, identifying and assessing the impact of mitigation strategies for six health conditions that severely deteriorated because of the COVID-19 pandemic and presenting a menu of alternatives for enhancing community health and generating cost savings.[59] The optimal trade-offs between safety (ie, reducing risk of exposure to COVID) and limiting disruption through various mitigation strategies should also be established using models.

Implementing evidence-based mitigation strategies should be a policy priority, especially given how the pandemic has exacerbated disparity across several socioeconomic circumstances. Compliance by the public with mitigation strategies is largely exogenous, especially in democratic societies. It is important to investigate how mitigation strategies and compliance might operate in parallel to improve the implementation process. A recent modelling study looked at how compliance tailored to the US conditions and mitigation strategies can work together to reduce the spread of COVID-19.[60] Further research on the short-term and long-term effects of these strategies, and approaches to address community acceptability and barriers to implementation is crucial. It is important to involve key stakeholders at local and national levels, including government and non-governmental agencies, to advocate for the proper allocation and regulation of available health resources while implementing mitigation strategies.

This review demonstrates the large heterogeneity on which the models were built, especially in the conceptualisation of disruption and mitigation, the structure of the models, and the underlying data used. It is difficult to compare the results of the models directly because the time periods of estimations, outcome measures, and underlying assumptions and model structures vary. In the context of a pandemic, models are often refined and updated in response to new information and data; therefore, allowing end-users to raise questions, comment and offer feedback to modellers can enhance future iterations. An appropriate stakeholder engagement manages to meet the expectations of both end-users, often policymakers, and modellers on what models can achieve and adherence of models to culturally relevant and socially acceptable policy options based on the local context.[61] In addition, stakeholders can advise on data gaps or assumptions; as it is particularly important in instances where models are not locally developed such as some of the models we have seen in this review. Recently, a framework was available to illustrate the collaborative process between modellers and stakeholders to address challenges including transparency, inclusive decision-making, and accountability that hinder successful policy implementation.[62] Of the studies examined in this review, only one has sufficiently engaged stakeholders.[10] We recognise that stakeholder engagement will be extremely difficult to employ in an emergency context due to capacity and resource constraints on the part of all stakeholders, not just researchers.

After living with the COVID-19 pandemic for almost 3 years, it has become evident that the pandemic had serious adverse health effects, especially on the vulnerable populations, such as children, the elderly, people living with chronic conditions or disabilities, and minority groups.[58] The effects of the COVID-19 pandemic on mortality and health disparities are underestimated when only deaths directly attributed to COVID-19 are considered. Vulnerable patient populations have faced greater challenges in accessing health services during the COVID-19 pandemic.[63] Of the studies included in this review, only a few studies incorporated focusing on vulnerable patient populations into the model. This is because of the unavailability of reliable data on indirect effects for different populations (eg, by geographic location, race/ethnicity and economic status) at the time of analysis. Future studies on pandemic, not limited to COVID-19, should consider the disparity issues in the modelling to estimate more comprehensive results that could ultimately facilitate policy decision-making to maximise benefits to all. Other considerations, such as the impact during specific waves of the COVID-19 pandemic (ie, Omicron, Delta variants) or before or after the vaccination era were not considered in any studies. Future models also should comprehend whether disruption's indirect impacts have any effects since the period of vaccination or during waves of the COVID-19 pandemic. A similar review may require to be carried out after some time when more data are available and more models incorporating these aspects are published.

To the best of our knowledge, this is the first scoping review that aims to identify modelling studies assessing and/or predicting the potential impact of disruptions to essential health services caused by COVID-19 and to summarise the characteristics of disruption and the models used to assess the disruptions. One limitation of our work is that a search of grey literature has not been performed, perhaps excluding significant contributions not published in commercial publications. We were unable to provide a precise categorisation of models in this review if the authors had not reported enough model descriptions. Another limitation is that we failed to include conference abstracts because there was insufficient data on key model characteristics required as per our objective. Finally, we did not compare the results of the studies included in this review directly because of the large heterogeneity on which the models were built, especially in the conceptualisation of disruption and mitigation, the model application level, the structure of the models and the underlying data used.

CONCLUSION

This scoping review summarised modelling studies assessing the potential impact of disruptions to essential health services published from January 2020 to August 2022. Regardless of what model is used, all studies show that disruption in health services focusing on a specific health condition or setting generally causes a greater loss of life and an increase in disease prevalence during the pandemic. It is important to assess the impact of disruption on the overall health system across all diseases and services because such information can help to plan mitigation strategies and policies and support decision-makers at various levels in advocating for resources and investment for the most affected settings and populations throughout the course of the pandemic. There is a need for collaboration among stakeholders to enhance the usefulness of any modelling; a process framework that articulates the roles and responsibilities of various stakeholders to enhance accountability needs to be developed. Implementing mitigation strategies should be a policy priority, particularly as the pandemic has exacerbated inequality in a wide range of socioeconomic conditions. For the next pandemic, future models should consider these aspects that could ultimately facilitate culturally relevant and socially acceptable policy options to maximise benefits to all.

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APPENDIX

A systematic review of modeling studies assessing the impact of disruptions to essential health services during COVID-19

June 21,2023

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Appendix Table 1 Search Strategy

Table 1a: EMBASE (Embase Classic + Embase 1947 to 2023 May 12)

Search: Jan 1, 2020, to 2022 Dec 31

Date of Search: 14/05/2023

Sl. No.	Searches	Results
1.	coronavirus.ti,ab.	132343
2.	covid-19.ti,ab.	365241
3.	covid$.ti,ab.	378495
4.	corona$.ti,ab.	875294
5.	sars-cov-2$.ti,ab.	127913
6.	exp statistical model/	695656
7.	exp epidemiological model/	828
8.	exp mathematical model/	893117
9.	Stochastic$.ti,ab.	53585
10.	Probabilistic$.ti,ab.	42826
11.	Deterministic$.ti,ab.	22785
12.	Discrete-event$.ti,ab.	2421
13.	(Transmission adj2model$).ti,ab.	4977
14.	Compartment$.ti,ab.	252013
15.	Simulation$.ti,ab.	466660
16.	Agent-based$.ti,ab.	6071
17.	Markov$.ti,ab.	39619
18.	Monte Carlo.ti,ab.	61234
19.	Time series$.ti,ab.	50151
20.	exp health impact assessment/	7816
21.	exp health care access/	100544
22.	Disrupt$.ti,ab.	461796
23.	Interruption$.ti,ab.	60497
24.	Public Health Consequences$.ti,ab.	1062
25.	Health care impact$.ti,ab.	159
26.	(indirect adj2 impact$).ti,ab.	2122
27.	(Direct adj2 impact$).ti,ab.	11125
28.	or/1-5	1171633
29.	or/6-19	1667306
30.	or/20-27	640103
31.	28 and 29 and 30	1481
32.	limit 31 to yr="2020 – 2022"	1078

Table 1b: PUBMED SEARCH

Search: Jan 1, 2020, to 2022 Dec 31; Date of Search: 15/05/2023

Sl.No.	Search strategy	No. of articles	Time of search	Filter
1	((((coronavirus[Title/Abstract]) OR (COVID-19[Title/Abstract])) OR (covid*[Title/Abstract])) OR (corona*[Title/Abstract])) OR (sars-cov-2[Title/Abstract])	858,055	05:27:50	01-01-2020 TO 31-12-2022
2	((((((((((((((Models, Statistical[MeSH Terms])) OR (Epidemiological Models[MeSH Terms])) OR (Mathematical Model[MeSH Terms])) OR Probabilistic*[Title/Abstract])) OR (Stochastic*[Title/Abstract])) OR (Deterministic*[Title/Abstract])) OR (Discrete-event*[Title/Abstract])) OR (Transmission model*[Title/Abstract])) OR (Compartment*[Title/Abstract])) OR (Simulation*[Title/Abstract])) OR (Agent-based*[Title/Abstract])) OR (Markov*[Title/Abstract])) OR (Monte Carlo*[Title/Abstract])) OR (Time Series*[Title/Abstract])	2,391,925	05:40:16	01-01-2020 TO 31-12-2022
3	((((((((Health Impact Assessment[MeSH Terms]) OR (Delivery of Health Care[MeSH Terms])) OR (Health Services Accessibility[MeSH Terms])) OR (Disrupt*[Title/Abstract])) OR (Interruption*[Title/Abstract])) OR (Public Health Consequences*[Title/Abstract])) OR (Health Care Impact*[Title/Abstract])) OR (Indirect Impact*[Title/Abstract])) OR (Direct Impact**[Title/Abstract]))	1,635,590	06:03:11	01-01-2020 TO 31-12-2022
4	1 AND 2 AND 3	1486	06:36:40	01-01-2020 TO 31-12-2022

Table 1c: CINAHL SEARCH

Date of Search: 16/05/2023

Sl.No.	Search strategy	No. of articles	Time of search	Filter
S1	AB (coronavirus or covid-19 or pandemic) OR AB sars-cov-2 OR AB COVID-19 OR AB corona* OR AB covid*	77,990	02:49:50	01-01-2020 TO 31-12-2022
S2	MH Models, Statistical OR MH Prediction Models OR AB Mathematical Model* OR AB Model* OR AB Probabilistic* OR AB Stochastic* OR AB Deterministic* OR AB Simulation* OR AB Transmission model* OR AB Compartmentf* OR AB Time Series*	249,768	02:52:16	01-01-2020 TO 31-12-2022
S3	MH Health Care Delivery OR MH Health Impact Assessment OR MH Health Services Accessibility OR AB Disrupt* OR AB Interruption* OR AB Public health Consequences* OR AB Health care impact* OR AB Indirect impact* OR AB direct effect* OR AB impact*	279,017	03:03:11	01-01-2020 TO 31-12-2022
S4	S1 AND S2 AND S3	2103	03:12:40	01-01-2020 TO 31-12-2022

Veettil SK, *et al. BMJ Open* 2023; 13:e071799. doi: 10.1136/bmjopen-2023-071799

Appendix Table 2 Categories of disruption

Disruptions and changes associated with COVID-19 that affect health have a broad range. Healthcare disruption fall into three main categories:[1]

1. Social change affecting factors that influence health
2. Supply of health services
3. Demand for health services

Category of disruption	Description
Social change affecting factors that influence health	Social changes include, for example, shortage of income for households, which may mean they do not have enough money to buy all the food they need, thereby leading to deficiencies in nutrition (e.g., impact mother and child health). These changes may also include shifts in behavior, such as changes in the number of marriages entered into, alcohol or drug use, sexual behavior or domestic violence. In addition, social changes may include government-enforced lockdowns that limit health service provision
Supply of health services	Availability of health services may decrease because lack of health personnel (health personnel fall ill or become fully engaged in treating COVID-19 patients), or because unavailability of critical resources, such as medicines or the government mandates that specific non-COVID-19 health services are not to be provided.
Demand for health services	Demand for health services may change because of fear of seeking services, because of COVID-19 or difficulties in accessing them because of several reasons including disruptions to transportation or lack of funding for transportation.

Reference: Modelling the health impacts of disruptions to essential health services during COVID-19. Module 1: understanding modelling approaches for sexual, reproductive, maternal, newborn, child and adolescent health, and nutrition. Geneva: World Health Organization; 2021. https://www.who.int/publications/i/item/9789240027695

Appendix Table 3 Types of models

Epidemiological/mathematical models of infectious diseases intend to model how infectious diseases progress in a given population depending on existing and counterfactual conditions or measures and a disease's characteristic. There are several variations in mathematical models whose use depends on the question being asked. Usually, epidemiological models that can perform scenario analysis of interventions can be broadly categorized into compartmental models, individual level microsimulation models including agent-based models.

Based on this, we conceptualize epidemiological models into two classes as shown in the table: [2,3]

No	Type of model	Examples
1	Simulation models	
1a	Compartment models	SIR; SEIR; SIRS; SEIRs; SIRD; SEIHARD; other simple State-transition models (e.g., Markov model); hybrid models (decision tree embedded with Markov models). Compartment models can either deterministic or stochastic.
1b	Individual level microsimulation model	Agent-based models, Monte Carlo simulation (individual sampling) of a Markov model with interaction, Discrete-event simulation models

Note: Statistical models such as Time-series, regression, and curve fitting are not included in this review.

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2. Kim SY, Goldie SJ. Cost-effectiveness analyses of vaccination programmes : a focused review of modelling approaches. Pharmacoeconomics. 2008;26(3):191-215. doi: 10.2165/00019053-200826030-00004. PMID: 18282

Appendix Table 4 General characteristics

Author	Year	Country Income Level	Single/Multiple Location	Population	Study Setting (population/hospital based)	Funding	Investigating Group
Hogan AB, et.al[4]	2020	LMIC	Multiple	General population	Population based	Bill & Melinda Gates Foundation, Wellcome Trust, UK Department for International Development, and Medical Research Council	Academicians
Jewell BL, et al[5]	2020	LMIC	Multiple	People living with HIV and those at risk	Population based	Bill & Melinda Gates Foundation	Academicians & Research Organization
Sherrard-Smith E et. al[6]	2020	LMIC	Multiple	People living with Malaria and those at risk	Population based	Bill & Melinda Gates Foundation, Wellcome Trust, UK Department for International Development, and Medical Research Council	Academicians
Roberton T, et.al[7]	2020	LMIC	Multiple	General population	Population based	Bill & Melinda Gates Foundation, Global Affairs Canada	Academicians
Toor J, et al. [8]	2022	LMIC	Multiple	General population	Population based	Gavi, the Vaccine Alliance and the Bill Melinda Gates Foundation	Academicians
Wifferen F, et al.[9]	2022	HIC	Multiple	Individuals at risk	Population based	Cancer Council New South Wales, Health Canada, and Dutch National Institute for Public Health and Environment	COVID-19 and Cancer Global Modeling Consortium (CCGMC) working group 2
Malagon T, et al. [10]	2021	HIC	Single	General population	Population based	Canadian Institutes of Health Research	McGill Task Force on the Impact of COVID-19 on Cancer Control and Care
Stover J, et al. [11]	2021	LMIC & HIC	Multiple	General population	Population based	Bill & Melinda Gates Foundation, NHMRC	Academicians
Flanagan C, et al. [12]	2022	LMIC	Multiple	Pregnant and breastfeeding women and children	Population based	Bill & Melinda Gates Foundation, US National Institutes of Health	Academicians
Borlase A, et al. [13]	2021	Trachoma-endemic settings	Single	Children at risk	Population based	NTD Modelling Consortium, funded by the Bill and Melinda Gates Foundation	Academicians
Silhol R, et al. [14]	2021	LMIC	Multiple	Population at risk	Population based	MRC Centre for Global Infectious Disease Analysis	Academicians
Mitchell K, et al. [15]	2021	HIC	Single	General population	Population based	NIH	Academicians
Gaythorpe K, et al. [16]	2021	LMIC	Multiple	General population	Population based	Bill and Melinda Gates Foundation and Gavi, the Vaccine Alliance	Academicians
Alagoz O, et al[17]	2021	HIC	Single	Women	Hospital based	NIH	Academicians, CISNET Breast Working Group
Kim L, et al. [18]	2021	HIC	Single	Eligible men	Population based	UK Medical Research Council, British Heart Foundation, NIHR Cambridge Biomedical Research Centre	Academicians
Smith M, et al. [19]	2021	HIC	Multiple	Women	Population based	National Health and Medical Research Council, Cancer Council NSW, Cancer Research UK, Cancer Institute NSW, National Institutes of Health, Norwegian Cancer Society	Academicians
Kitano T, et al. [20]	2021	HIC	Single	General population	Population based	None	Academicians
Booton R, et al. [21]	2021	HIC	Single	Men at risk	Population based	Global Public Health strand of the Elizabeth Blackwell Institute for Health Research, funded under the University of Bristol's QR GCRF strategy, US NIH, NIHR Health Protection Research Unit in	Academicians

Author	Year	Country Income Level	Single/Multiple Location	Population	Study Setting (population/hospital based)	Funding	Investigating Group
						Behavioral Science and Evaluation at the University of Bristol, Health Data Research UK, UK Medical Research Council, Engineering and Physical Sciences Research Council, Economic and Social Research Council, National Institute for Health Research, Chief Scientist Office of the Scottish Government Health and Social Care Directorates, Health and Social Care Research and Development Division, Public Health Agency, British Heart Foundation and Wellcome	
Burger E, et al. [22]	2021	HIC	Single	Women	Population based	U.S. National Cancer Institute	Academicians
De Jonge L, et al. [23]	2021	HIC	Multiple	General population	Population based	Cancer Council New South Wales, Health Canada, and Dutch National Institute for Public Health and Environment	COVID-19 and Cancer Global Modelling
Blumberg S, et al. [24]	2021	Critical mass drug administration settings	Single	Children	Population based	NTD Modelling Consortium by the Bill and Melinda Gates Foundation	Academicians
Hamley J, et al.[25]	2021	LMIC	Multiple	Children	Population based	Bill and Melinda Gates Foundation via the NTD Modelling Consortium, the UK Medical Research Council, MRC and the UK Department for International Development (DFID) Joint Centre Funding	Academicians
Prada J, et al. [26]	2021	LMIC	Multiple	General population	Population based	Bill and Melinda Gates Foundation through the NTD Modelling Consortium	Academicians
Kura K, et al. [27]	2021	Burdened locations	Single	General population	Population based	The Bill and Melinda Gates Foundation through the NTD Modelling Consortium	Academicians
Jenness S, et al. [28]	2021	HIC	Single	Men at risk	Population based	National Institutes of Health and the MAC AIDS Fund	Academicians
Xiridou M, et al. [29]	2022	HIC	Single	Men at risk	Population based	None	Academicians
McQuaid CF, et.al [30]	2020	LMIC & HIC	Multiple	General population	Population based	Bill and Melinda Gates Foundation, UK Medical Research Council, UK Department for International Development	Academicians and Centre for Mathematical Modelling of Infectious Diseases (CMMID) COVID-19 Working Group
Martin B, et al.[31]	2021	HIC	Single	General population	Hospital based	AHRQ Funded R01	Academicians
Cilloni L, et al[32]	2020	LMIC	Multiple	General population	Population based	Stop TB Partnership, United States Agency for International Development (USAID),Bill and Melinda Gates Foundation, and the UK Medical Research Council.	Academicians and Stop TB Partnership
Jacome A, et al[33]	2020	LMIC	Single	Children below 5 years of age	Population based	None	Academicians and INLAMA Network
Jewell BL, et al[34]	2020	LMIC	Multiple	People living with HIV and those at risk	Population based	Bill & Melinda Gates Foundation, MRC Centre for Global Infectious Disease Analysis, UK Medical Research Council (MRC) and the UK Department for International Development (DFID)	Academicians
Blach S, et al[35]	2020	LMIC & HIC	Multiple	General population	Population based	John C. Martin Foundation, United States of America	Academicians

Author	Year	Country Income Level	Single/Multiple Location	Population	Study Setting (population/hospital based)	Funding	Investigating Group
Bardet A, et al[36]	2021	HIC	Single	Cancer patients without COVID 19	Hospital based	La Ligue contre le Cancer	Academicians
Barocas J A, et al[37]	2021	HIC	Single	population at risk for or infected with HCV	Hospital based	National Institutes of Health: The National Institute on Drug Abuse, National Institute of General Medical Sciences, Burroughs Wellcome Fund/American Society for Tropical Medicine and Hygiene, the Charles A. King Trust, and Gilead Focus	Academicians
Fojo A, et al[38]	2022	HIC	Multiple	People living with HIV and those at risk	Population based	National Institutes of Health	Academicians
Malizia V, et al[39]	2020	Tropical regions	Multiple	General population	Population based	Bill and Melinda Gates Foundation, Task Force for Global Health- NTD Modelling Consortium, Dutch Society for Scientific Research, European Marie Skłodowska-Curie fellowship	Academicians and WHO
Kim B, et al[40]	2022	HIC	Single	General population	Population based	Government-wide R&D Fund project through GFID and funded by seven ministries	Academicians
Shaikh N, et al[41]	2021	LMIC	Multiple	General population	Population based	TB Modelling Group, Wellcome Trust, NIH, EDTCP, UK MRC, ESRC, BMGF and WHO	Academicians
Mandrik O, et al[42]	2022	HIC	Single	General population	Population based	National Institute for Health Research UK	Academicians
You, et al.[43]	2021	HIC	Single	General population	Hospital based	None	Academicians
Yong J HE, et al.[44]	2021	HIC	Single	General population	Population based	Canadian Partnership Against Cancer, Statistics Canada and Health Canada.	Academicians
Yanev I, et al.[45]	2021	HIC	Single	ESKD patients	Hospital based	Fonds de recherche du Quebec—Santé chercheur boursier clinician award	Academicians
Ward ZJ, et al.[46]	2021	HIC	Single	Cancer patients	Population based	Harvard TH Chan School of Public Health	Academicians
Tan EX, et al.[47]	2021	HIC	Multiple	Patients ≥18 years of age on the national LT waitlists	Population based	None	Academicians
Rodriguez R, et al.[48]	2021	HIC	Single	Patients who underwent surgery and recovered at the cardiovascular recovery unit	Hospital based	None	Academicians
Poelhekken K, et al.[49]	2022	HIC	Single	General population	Population based	W.J. Kolff Institute (WJKI)	Academicians
Nghiem N, et al.[50]	2021	HIC	Single	General population	Population based	Health Research Council of New Zealand	Academicians
Borlase A, et al.[51]	2022	HIC & LMIC	Multiple	General population	Population based	Bill & Melinda Gates Foundation, Medical Research Council, and the UK Foreign, Commonwealth & Development Office	Academicians & members of TD Modelling Consortium
Weiss D J, et al.[52]	2020	HIC & LMIC	Multiple	General population	Population based	Bill and Melinda Gates Foundation; Channel 7 Telethon Trust, Western Australia	Academicians

Author	Year	Country Income Level	Single/Multiple Location	Population	Study Setting (population/hospital based)	Funding	Investigating Group
Shukla P, et al.[53]	2022	HIC	Single	General population	Population based	None	Academicians
Sethi K, et al.[54]	2021	HIC	Single	Patients visited retina clinic	Hospital based	Harry N. Lee Family Chair in Innovation at the Lahey Hospital & Medical Center, Beth Israel Lahey Health	Academicians
Sawicki G S, et al.[55]	2021	HIC	Single	Cystic Fibrosis program directors	Hospital based	Aricca D. Van Citters and Kathryn A. Sabadosa	Academicians & Cystic Fibrosis Foundation

[#]Abbreviations: LMIC (Low- and middle-income countries), HIC (High-income country), HIV (Human immunodeficiency virus), HCV (Hepatitis C), TIA (Transient ischemic attack), ED (Emergency department), UMIC (Upper middle-income country), ESKD (End stage kidney disease), LT (Liver Transplantation)

Appendix Table 5 Nature disruption

Author	Health Condition	Health Service	Category of Disruption	Reasons for Disruption
Hogan AB, et.al.[4]	HIV, Tuberculosis and Malaria	Diagnosis/Prevention/treatment services	1,2,3	SB, LD, LHP, LR, LT, FS, DA
Jewell BL, et al.[5]	HIV	Diagnosis/Prevention/treatment services	1,2,3	SB, LD, LHP, LR, FS
Sherrard-Smith E et. Al.[6]	Malaria	Prevention/treatment services	2	LHP, LR
Roberton T, et.al.[7]	Maternal & child health	Availability of health workers and supplies of food	1,2,3	SI, LHP, LR, LT, FS, DA
Toor J, et al.[8]	Vaccine preventable diseases	Vaccination programmes	2	LR
Wifferen F, et al[9]	Colorectal cancer	Screening service	2,3	LHP, LR,DA
Malagon T, et al.[10]	Cancer	Diagnosis/treatment services, Surgery delay	2,3	LHP, LR,GM, FS, DA, LT
Stover J, et al.[11]	HIV	Prevention/ diagnosis services	1,2	SB,LD, LHP, LR, GM
Flanagan C, et al.[12]	HIV	Prevention/treatment services	2,3	LHP, LR, DA, LT
Borlase A, et al.[13]	Trachoma	Mass drug administration	2	LHR, LR,GM
Silhol R, et al.[14]	HIV	Prevention/treatment services	1,2,3	SB, LD, LR, DA, LT
Mitchell K, et al.[15]	HIV	Prevention/treatment services, Screening service	1,2,3	SB,LD,LHP,LR,FS, DA,LT
Gaythorpe K, et al.[16]	Vaccine preventable diseases (measles,meningococcal A and yellow fever disease)	Vaccination programmes	2	LHP,LR,GM
Alagoz O, et al.[17]	Breast cancer	Diagnosis/treatment services, Screening service	2,3	LHP,LR, FS, DA,LT
Kim L, et al. [18]	Abdominal aortic aneurysm	Screening service	2,3	LHP,LR,GM,FS,DA,LT
Smith M, et al.[19]	Cervical cancer	Diagnosis/treatment services, Screening service	2,3	LHP,LR,GM,FS
Kitano T, et al.[20]	Invasive pneumococcal disease	Vaccination programmes	2	LHP,LR,GM
Booton R, et al.[21]	HIV	Diagnosis/treatment services	1,2	SB, LD, LHP,LR
Burger E, et al.[22]	Cervical cancer	Diagnosis/treatment services, Screening service	2	LHP,LR
de Jonge L, et al.[23]	Colorectal cancer	Diagnosis, screening services	2	LHP,LR
Blumberg S, et al.[24]	Trachoma	Mass drug administration	2	LHP, LR,GM
Hamley J, et al.[25]	Onchocerciasis	Mass drug administration	2	LHP, LR,GM
Prada J, et al.[26]	Lymphatic filariasis	Mass drug administration	2	LHP, LR,GM
Kura K, et al.[27]	Schistosomiasis	Mass drug administration	2	LHP, LR,GM
Jenness S, et al.[28]	HIV/STIs	Prevention/treatment services, Screening service	1,2	SB,LD,LHP, LR
Xiridou M, et al.[29]	STIs	Prevention/diagnosis services	1,2	SB,LD,LHP,LR
McQuaid CF, et.al.[30]	TB	Diagnosis/treatment services	1,2,3	SB,LD,LHP,LR,FS

Author	Health Condition	Health Service	Category of Disruption	Reasons for Disruption
Martin B, et al.[31]	Any disease	Hospital elective admissions	2	LHP,LR,GM
Cilloni L, et al.[32]	TB	Diagnosis/Prevention/treatment services	1,2,3	SB,LD,LHP,LR,FS, DA
Jacome A, et al.[33]	Women and child health	NA	1	SB,LD
Jewell BL, et al.[34]	HIV	Prevention/treatment services	1,2,3	SB, LD, LHP, LR, FS
Blach S, et al.[35]	HCV	Diagnosis/treatment services, Screening service	2	LHP,LR
Bardet A, et al.[36]	Cancer	Diagnosis/treatment services	1,2,3	SB,LD,LHP,LR, DA, LT
Barocas J A, et al.[37]	HCV	Diagnosis/treatment services, Screening service	2	LHP,LR,GM
Fojo A, et al.[38]	HIV	Diagnosis/Prevention/treatment services, Screening service	1,2,3	SB,LD,LHP,LR, DA
Malizia V, et al.[39]	Soil transmitted helminth infection	Prevention services	2	LHP,LR,GM
Kim B, et al.[40]	TB	Diagnosis/treatment services	1,2	SB,LD,LHP,LR
Shaikh N, et al.[41]	Pediatric TB	BCG Vaccination programme	2	LHP,LR,GM
Mandrik O, et al.[42]	Colorectal cancer	Screening services	2,3	LHP,LR, FS, DA,LT
You et al.[43]	Influenza	Diagnosis/treatment services	1,2,3	SB, LD,GM, LT
Yong J HE, et al.[44]	Breast and colorectal cancer	Screening services	1,2,3	LD, LHP, LR,GM, DA
Yanev I, et al.[45]	End Stage Kidney Disease	Kidney transplantation delay	1,2,3	SB,LD,LHP,LR
Ward ZJ, et al.[46]	Cancer of breast, cervix, colorectal, prostate, and stomach	Delayed diagnosis	2,3	LHP,LR,GM,LT,DA
Tan EX, et al.[47]	Liver failure	Liver transplantation delay	1,2,3	SB,LD,LHP,LR
Rodriguez R, et al.[48]	Congenital heart disease	Treatment and surgery service	1,2	LD,LHP,LR, GM
Poelhekken K, et al.[49]	Breast cancer	Screening services	1,2,3	LD,LHP,LR, GM, DA
Nghiem N, et al.[50]	Cardiovascular disease	Diagnosis/treatment services	1,2,3	SI, LD,LHP,LR,GM,DA
Borlase A, et al.[51]	7 neglected tropical diseases (NTDs): soil-transmitted helminths, schistosomiasis, lymphatic filariasis, onchocerciasis, trachoma, visceral leishmaniasis, and human African trypanosomiasis	Mass drug administration and screening services	2,3	LHP,LR,GM,DA
Weiss D J, et al.[52]	Malaria	Prevention and treatment services	2,3	LR,LD,DA,LT
Shukla P, et al.[53]	Any disease	Under-utilization of routine health care services	2,3	FS,LHP, LR
Sethi K, et al.[54]	Ophthalmology cases	Ophthalmology visits	2,3	FS,LHP,LR
Sawicki G S, et al.[55]	Cystic Fibrosis	Restrictions on overall finances, staffing, licensure, and reimbursement of telehealth services	2	GM,LR

1. Social change affecting factors that influence health 2. Supply of health services 3. Demand for health services
[#]Abbreviations: HIV (Human immunodeficiency virus), SB (Shifts in behavior), LD (Government-enforced lockdowns), LHP (Lack of health personnel), LR (Lack of resources e.g., medicines), LT (Lack of transportation), FS (Fear of seeking services), DA (Difficulty in access), SI (Shortage of income for household), GM (Government mandates), STI (Sexually transmitted infections) TB (Tuberculosis), HCV (Hepatitis C)

Appendix Table 6 Models characteristics

Author	No. of models	Type of model	Category of simulation model				Second-order Uncertainty	Model application level	Disruption Timeframe (years)	Time horizon (years)	Study Timeframe	Stakeholder	Subgroup
			Compartmental	Agent-based	Discrete event/Markov	Micro-simulation							
Hogan AB, et.al.[4]	4	Simulation	✓✓✓✓				Sensitivity analysis (Univariate) Scenario analysis	Global	0.5-1	5	2020-2024	Involvement	No
Jewell BL, et al.[5]	5	Simulation	✓✓	✓		✓✓	Sensitivity analysis (Univariate) Scenario analysis	Regional	0.25-0.5	0.5-5	2020-2024	Involvement	No
Sherrard-Smith E et. al.[6]	2	Simulation	✓✓				sensitivity analysis (Univariate & multivariate) Scenario analysis	National	0.11-1	1	5/2020-4/2021	No	No
Roberton T, et.al.[7]	1	Mathematical (Simulation)*	NA				Scenario analysis	Global	0.08	0.25-1	Unclear	No	No
Toor J, et al.[8]	1	Mathematical (Simulation)*	NA				Sensitivity analysis (Univariate) Scenario analysis	Global	Unclear	10	2020-2030	No	No
Wifferen F, et al.[9]	4	Simulation	✓			✓✓✓	Sensitivity analysis (Univariate)	Regional	0.25	0.5-30	2020-2050	Involvement	
Malagon T, et al.[10]	1	Simulation				✓	Sensitivity analysis (Univariate)	National	1	10	3/2020-5/2021	Engagement	No
Stover J, et al.[11]	7	Simulation	✓✓✓✓	✓✓		✓	Sensitivity analysis (Univariate) Scenario analysis	Global	Unclear	50	2020-2070	No	No
Flanagan C, et al.[12]	1	Simulation				✓	Sensitivity analysis (Univariate) Scenario analysis	Regional	0.5	1	3/2020-3/2021	No	No
Borlase A, et al.[13]	1	Simulation				✓	Scenario analysis	Global	1	1 to 10	2020-2030	No	No
Silhol R, et al.[14]	2	Simulation	✓✓				Sensitivity analysis (Univariate) Scenario analysis	Local	0.25-1	1 to 5	2020-2024	No	No
Mitchell K, et al.[15]	1	Simulation	✓				Sensitivity analysis (Univariate) Scenario analysis	National	0.5	1 to 5	2020-2024	No	No
Gaythorpe K, et al.[16]	8	Simulation	✓✓✓✓	✓		✓✓✓	Scenario analysis	Global	1	10	2020-2021	Involvement	No
Alagoz O, et al.[17]	3	Simulation				✓✓✓	Sensitivity analysis (Univariate) Scenario analysis	National	0.5	10	2020-2030	No	No
Kim L, et al.[18]	1	Simulation			✓		Scenario analysis	Local	5	30	3/2020-2050	No	No
Smith M, et al.[19]	1	Simulation				✓	Scenario analysis	Global	0.5-1	10	2020-2030	No	No

Author	No. of models	Type of model	Category of simulation model				Second-order Uncertainty	Model application level	Disruption Timeframe (years)	Time horizon (years)	Study Timeframe	Stakeholder	Subgroup
			Compartmental	Agent-based	Discrete event/Markov	Micro-simulation							
Kitano T, et al.[20]	1	Simulation	✓				Sensitivity analysis (Univariate) Scenario analysis	National	1-10	9	2021-2030	No	No
Booton R, et al.[21]	1	Simulation	✓				Sensitivity analysis (Univariate) Scenario analysis	National	0.25-0.5	5	1/2020-2024	No	No
Burger E, et al.[22]	3	Simulation				✓✓✓	Scenario analysis	National	0.5-2	7	2020-2027	No	No
de Jonge L, et al.[23]	4	Simulation				✓✓✓✓	Sensitivity analysis (Univariate) Scenario analysis	Regional	0.25-1	30	2020-2050	No	No
Blumberg S, et al.[24]	1	Simulation	✓				Sensitivity analysis (Univariate) Scenario analysis	Global	1	4	Unclear	No	No
Hamley J, et al.[25]	2	Simulation				✓✓	Scenario analysis	Regional	1-2	10	2020-230	Involvement	No
Prada J, et al.[26]	3	Simulation				✓✓✓	Sensitivity analysis (Univariate) Scenario analysis	National	0.5-2	12	2018-2030	No	No
Kura K, et al.[27]	1	Simulation	✓				Scenario analysis	Regional	2	15	2019-2034	Involvement	
Jenness S, et al.[28]	1	Simulation	✓				Sensitivity analysis (multivariate) Scenario analysis	National	0.25-1.5	5	2019-2024	No	No
Xiridou M, et al.[29]	1	Simulation	✓				Sensitivity analysis (Univariate) Scenario analysis	National	1	7	2020-2026	No	No
McQuaid CF, et.al.[30]	1	Mathematical (Simulation)*		NA			Scenario analysis	National	0.5	5	2020-2024	No	No
Martin B, et al.[31]	1	Simulation	✓				Sensitivity analysis (Univariate) Scenario analysis	National	0.25	Unclear	Unclear	No	No
Cilloni L, et al.[32]	1	Mathematical			N A		Sensitivity analysis (Univariate)	National	2 scenarios; 1) a 2-month suspension followed by a 2-month restoration 2) a 3-month suspension followed by a 10-month restoration	5 years	2020-2025	Involvement	No
Jacome A, et al.[33]	1	Mathematical (Simulation)*		NA			Scenario analysis	National	Unclear	Unclear	2019-2021	No	No

Author	No. of models	Type of model	Category of simulation model				Second-order Uncertainty	Model application level	Disruption Timeframe (years)	Time horizon (years)	Study Timeframe	Stakeholder	Subgroup
			Compartmental	Agent-based	Discrete event/Markov	Micro-simulation							
Jewell BL, et al.[34]	1	Simulation	✓				Sensitivity analysis (Univariate)	Regional	0.25	5	2020-2025	No	No
Blach S, et al.[35]	1	Simulation			✓		Sensitivity analyses (Univariate) Scenario analysis	Global	1	10	2020-2030	No	No
Bardet A, et al.[36]	1	Simulation			✓		Sensitivity analyses (Univariate) Scenario analysis	National	Unclear	5	2018-2023	Involvement	No
Barocas J A, et al.[37]	1	Simulation				✓	Sensitivity analyses (Univariate) Scenario analysis	National	1.5	10	2020-2030	Involvement	No
Fojo A, et al.[38]	1	Simulation	✓				Probabilistic sensitivity analysis Scenario analysis	National	Unclear	5	2020-2025	No	No
Malizia V, et al.[39]	2	Simulation				✓✓	Scenario analysis	Global	Varied; 0.5, 1, and 1.5	10	2020-2030	No	No
Kim B, et al.[40]	1	Simulation	✓				Scenario analysis	National	Unclear	5	2020-2025	No	No
Shaikh N, et al.[41]	1	Mathematical (Simulation)*		NA			Sensitivity analysis (Univariate)	Global	0.25, 0.5	Unclear	Unclear	No	No
Mandrik O, et al.[42]	1	Simulation				✓	Probabilistic sensitivity analysis Scenario analysis	Local	Varied; 0.25, 0.5, 0.75, and 1	Varied; 5, 10, 20, 40	2020-2025 2020-2030 2020-2040 2020-2060	Engagement	Yes; Sex
You et al.[43]	1	Simulation				✓	Scenario analysis	Local	26 weeks	Unclear	2019-2020	No	No
Yong J HE, et al.[44]	2	Mathematical (Simulation)*				✓✓	Scenario analysis	National	3 months, 6 months and 12 months	Unclear	2020-2029	No	No
Yanev I, et al.[45]	1	Simulation			✓		Sensitivity analyses (Multivariate) Scenario analysis	National	6months	Unclear	Unclear	No	No
Ward ZJ, et al.[46]	5	Simulation				✓✓✓✓✓	Scenario analysis	National	Unclear	Unclear	2020-2023	Involvement	Yes; Sex
Tan EX, et al.[47]	2	Simulation			✓✓		Scenario analysis	Regional	1,3, 6 and 12 months	Unclear	2016-2020	No	No
Rodriguez R, et al.[48]	1	Mathematical			NA		Scenario analysis	National	6 months	Unclear	2019-2020	No	No
Poelhekken K, et al.[49]	1	Simulation				✓	Sensitivity analysis (Univariate)	National	3,6 and 12 months	2 Years	2019-2020	No	No

Author	No. of models	Type of model	Category of simulation model				Second-order Uncertainty	Model application level	Disruption Timeframe (years)	Time horizon (years)	Study Timeframe	Stakeholder	Subgroup
			Compartmental	Agent-based	Discrete event/Markov	Micro-simulation							
Nghiem N, et al.[50]	1	Simulation				✓	Sensitivity analysis (Univariate) Scenario analysis	National	Unclear	5 years	Lifetime	No	Yes; sex, ethinicit
Borlase A, et al.[51]	17	Mathematical (Simulation)*				✓✓	Scenario analysis	Regional	6,12 and 18 months	Unclear	2020-2030	No	No
Weiss D J, et al.[52]	7	Mathematical		NA			Scenario analysis	National	12 months	Unclear	2019-2020	No	No
Shukla P, et al.[53]	1	Mathematical (Simulation)*		NA			Scenario analysis	National	12 months	Unclear	2019-2020	No	No
Sethi K, et al.[54]	1	Simulation			✓		Scenario analysis	Local	8 weeks	Unclear	2019-2020	No	No
Sawicki G S, et al.[55]	1	Simulation				✓	Scenario analysis	National	Unclear	Unclear	2020-2021	No	

Stakeholder involvement: involvement of at least one stakeholder in any process of the study; Stakeholder engagement: engagement of all stakeholders before, during, and after the conduction of the study

* Mathematical models including models generated from Vaccine Impact Modeling Consortium (example, Lives Saved Tool (LiST)), dynamic model, model of TB with an age-specific contact matrix calibrated and static mathematical model

Global: Models applicable worldwide, Regional: Models applicable to a particular region (example: African, Asian, Pacific etc..), National: Models applicable to a nation, Local: Models applicable to an area within the country

Appendix Table 7 Effects of COVID-19 Disruptions Modelled

Author	Service Disrupted					Effects of Disruption				
	Prevention	**Diagnosis**	**Screening**	**Treatment**	**Others**	**Effects on Demand**	**Clinical**	**Humanistic**	**Economic**	**Public Health Goal**
Hogan AB, et.al.[4]	VMMC, pre-exposure prophylaxis, long-lasting insecticide-treated nets, and seasonal malaria chemoprevention	Use of molecular diagnostic tool	NA	ART, TB and Malaria clinical treatment	NA	↓ Demand	↑ Mortality	↓Risky behavior	NA	NA
Jewell BL, et al.[5]	Condom availability, VMMC, PMTCT care	HIV testing	NA	ART	NA	↓ Demand	↑ Mortality, morbidity	↓Risky behavior	NA	NA
Sherrard-Smith E et. al.[6]	Malaria chemoprevention and indoor residual spraying of insecticide	Malaria diagnosis	NA	Antimalarial treatment	NA	NA	↑ Mortality, morbidity	NA	NA	NA
Roberton T, et.al.[7]	Insecticide-treated nets or indoor residual spraying, preventative malaria medication treatment	NA	NA	Childbirth medication, measles medication	Availability of health workers and supplies of food			↑ Mortality	NA	NA
Toor J, et al. [8]	Routine immunizations	NA	NA	NA	Vaccination program	NA	↑ Mortality	NA	NA	NA
Wifferen F, et al.[9]	NA	Colorectal cancer colonoscopies	FIT	NA	NA	↑Demand	↑ Mortality, morbidity	NA	NA	NA
Malagon T, et al.[10]	NA	Endoscopies, colonoscopies, mammographies, computerized tomography scans and magnetic resonance imaging scans	NA	Cancer surgery, chemotherapy, radiotherapy	Surgery delay/cancellation	↓ Demand	↑ Mortality	NA	NA	NA
Stover J, et al.[11]	VMMC, PMTCT care	Diagnostic testing	NA	NA	NA	NA	↑ Mortality	↓Risky behavior	NA	NA
Flanagan C, et al.[12]	PMTCT care	NA	NA	ART	NA	↑Demand	↑ Mortality, morbidity	NA	NA	NA
Borlase A, et al.[13]	Mass drug administration	NA	NA	NA	Mass drug administration	NA	NA	NA	NA	Delay in reaching elimination target
Silhol R, et al.[14]	Condom availability	NA	NA	ART	NA	↑Demand	↑ Mortality, morbidity	↑ & ↓Risky behavior	NA	NA

Author	Service Disrupted					Effects of Disruption				
	Prevention	Diagnosis	Screening	Treatment	Others	Effects on Demand	Clinical	Humanistic	Economic	Public Health Goal
Mitchell K, et al. [15]	Condom availability, pre-exposure prophylaxis	NA	HIV testing campaign	ART	NA	↓ Demand	↑ Mortality, morbidity	↑ & ↓Risky behavior	NA	NA
Gaythorpe K, et al.[16]	Preventive vaccination campaigns	NA	NA	NA	Vaccination program	NA	↑ Mortality	NA	NA	Increased risk of outbreak
Alagoz O, et al.[17]	NA	Symptomatic cancer diagnosis	Mammography	Chemotherapy	NA	↓ Demand	↑ Mortality	NA	NA	NA
Kim L, et al.[18]	NA	NA	Abdominal Aortic Aneurysm screening	NA	NA	↓ Demand	↑ Mortality	NA	NA	NA
Smith M, et al.[19]	NA	Colposcopy	Cytology or primary HPV screening	Precancer treatment	NA	↓ Demand	↑ Mortality, morbidity	NA	NA	NA
Kitano T, et al.[20]	Routine vaccination	NA	NA	NA	Vaccination program	NA	↑ Morbidity	NA	NA	NA
Booton R, et al.[21]	NA	HIV testing	NA	ART	NA	NA	↑ Mortality, morbidity	↑ & ↓Risky behaviors	NA	NA
Burger E, et al.[22]	NA	Colposcopy	Primary cytology screening or cotest based screening	Excisional treatment	NA	NA	↑ Morbidity	NA	NA	NA
de Jonge L, et al.[23]	NA	Colonoscopy	FIT	NA	NA	NA	↑ Mortality ↑ Morbidity	NA	NA	NA
Blumberg S, et al.[24]	Mass drug administration	NA	NA	NA	Mass drug administration	NA	NA	NA	NA	Delay in reaching elimination target
Hamley J, et al.[25]	Mass drug administration	NA	NA	NA	Mass drug administration	NA	NA	NA	NA	Delay in reaching elimination target
Prada J, et al. [26]	Mass drug administration	NA	NA	NA	Mass drug administration	NA	NA	NA	NA	Delay in reaching elimination target
Kura K, et al.[27]	Mass drug administration	NA	NA	NA	Mass drug administration	NA	NA	NA	NA	Delay in reaching elimination target
Jenness S, et al.[28]	pre-exposure prophylaxis	NA	HIV screening	ART, STI treatment	NA	NA	↑ Morbidity	↓Risky behaviors	NA	NA
Xiridou M, et al.[29]	NA	STI testing	NA	NA	NA	NA	↑ Morbidity	↓Risky behaviors	NA	NA

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Author	Service Disrupted					Effects of Disruption				
	Prevention	Diagnosis	Screening	Treatment	Others	Effects on Demand	Clinical	Humanistic	Economic	Public Health Goal
McQuaid CF, et.al.[30]	NA	TB diagnosis	NA	TB treatment	NA	↓ Demand	↑ Mortality, morbidity	↓Risky behaviors	NA	NA
Martin B, et al.[31]	NA	Diagnosis	NA	Treatment	Elective hospital admissions	↑Demand	NA	NA	Financial loss	NA
Cilloni L, et al.[32]	PLHIV receiving IPT	TB diagnosis	NA	TB treatment	NA	↑Demand	↑ Mortality	↓Risky behaviors	NA	NA
Jacome A, et al.[33]	NA	NA	NA	NA	NA	NA	↑ Mortality, morbidity	↑ Risky behavior	NA	NA
Jewell BL, et al.[34]	Condom availability, VMMC ,pre-exposure prophylaxis	NA	NA	ART	NA	↓ Demand	↑ Mortality, morbidity	↑ & ↓Risky behavior	NA	NA
Blach S, et al.[35]	NA	HCV diagnosis	HCV screening	HCV treatment	NA	NA	↑ Mortality	NA	NA	NA
Bardet A, et al.[36]	NA	Cancer diagnosis	NA	Cancer treatment	NA	↑Demand	↑ Mortality	NA	NA	Overload in requirement of hospital resources
Barocas J A, et al.[37]	NA	HCV diagnosis	HCV screening	HCV treatment	NA	NA	↑ Mortality, morbidity	NA	NA	Delay in reaching elimination targets
Fojo A, et al.[38]	pre-exposure prophylaxis	HIV diagnosis	HIV testing	Viral suppression	NA	NA	↑ Mortality, morbidity	↓Risky behavior	NA	NA
Malizia V, et al.[39]	Preventive chemotherapy	NA	NA	NA	NA	NA	NA	NA	NA	↑ Catch-up time, ↓ probability of reaching the control target set by the WHO and delay in reaching the target
Kim B, et al.[40]	NA	Delayed TB diagnosis	NA	TB treatment failure	NA	NA	↑ Mortality, ↓morbidity (TB)	↓Risky behavior	NA	NA
Shaikh N, et al.[41]	BCG Vaccination program	NA	NA	NA	Vaccination program	NA	↑ Mortality	NA	NA	Pediatric TB outbreaks in future
Mandrik O, et al.[42]	FIT and Flexible sigmoidoscopy	NA	NA	NA	NA	↑Demand	↑ Mortality, morbidity	↓QALY	NA	NA
You et al.[43]	NA	Influenza diagnosis	NA	Influenza treatment	NA	NA	NA	↓Risky behavior, ↓DALY	Financial saving	NA
Yong J HE, et al.[44]	NA	NA	Cancer screening	NA	NA	↑Demand	↑ Mortality, ↑morbidity, additional advanced	NA	NA	NA

Author	Service Disrupted					Effects of Disruption				
	Prevention	Diagnosis	Screening	Treatment	Others	Effects on Demand	Clinical	Humanistic	Economic	Public Health Goal
							cancers diagnosis			
Yanev I, et al.[45]	NA	NA	NA	Delay in transplantation	NA	NA	↑ Mortality, morbidity	NA	NA	NA
Ward ZJ, et al.[46]	NA	Delayed diagnosis	NA	NA	NA	NA	↑ Mortality, morbidity, worse cancer stage at presentation, worse survival outcomes	NA	NA	NA
Tan EX, et al.[47]	NA	NA	NA	Delay in transplantation	NA	NA	↓ 1-year overall survival (OS), increased projected incidence of ACLF and HCC	NA	NA	NA
Rodriguez R, et al.[48]	NA	NA	NA	Congenital heart surgery	NA	NA	↑ Mortality, morbidity	NA	NA	Increase in backlog for surgery
Poelhekken K, et al.[49]	NA	NA	Tumor size of screen-detected breast cancers and interval cancer rate	NA	NA	NA	Increase in tumor size and interval cancer rate	NA	NA	NA
Nghiem N, et al.[50]	NA	Diagnosis	NA	Treatment	NA	NA	↑ Mortality, morbidity, HALYs and ↑ CVD incidence	↑ Unemployment	Additional health system costs	Increase in health inequities
Borlase A, et al.[51]	Mass drug administration	Diagnosis	Screening	NA	NA	NA	↑ Mortality, morbidity	NA	NA	Delay to achieving elimination goals
Weiss D J, et al.[52]	Insecticide – treated net coverage	NA	NA	Reduction in antimalarial drug coverages	NA	NA	↑ Mortality	NA	NA	Increased case count
Shukla P, et al.[53]	Preventative tests and Routine optometry care	Primary care visits and dental appointments	Screening	Chronic disease management	NA	NA	↑ morbidity	NA	NA	NA
Sethi K, et al.[54]	NA	Ophthalmology visits	Screening	Treatment	NA	NA	↑ morbidity	NA	NA	Increased retina clinic visits and telemedicine

Author	Service Disrupted					Effects of Disruption				
	Prevention	Diagnosis	Screening	Treatment	Others	Effects on Demand	Clinical	Humanistic	Economic	Public Health Goal
Sawicki G S, et al.[55]	NA	NA	NA	NA	Restrictions on overall finances, staffing, licensure, and reimbursement of telehealth services	NA	NA	NA	Detrimental financial impact	NA

[#]Abbreviations: VMMC (Voluntary medical male circumcision), ART (Antiretroviral therapy), TB (Tuberculosis), PMTCT care (Defined as pregnant and breastfeeding women receiving effective ART to prevent mother-to-child transmission), HIV (Human immunodeficiency virus), FIT (Faecal immunochemical test), STI (Sexually transmitted infection), PLHIV (People living with HIV), PMCTC (Prevention of mother-to-child transmission), IPT (Isoniazid preventive therapy), HCV (Hepatitis C), BCG (Bacillus Calmette–Guérin), ITN (Insecticide-treated net), QALY (Quality-adjusted life years), DALY (Difficulty Adjusted Life Years), ACLF (Acute on Chronic Liver Failure), HCC (hepatocellular carcinoma), HALY (Health-Adjusted Life Years), CVD (Cardiovascular disease)

Appendix Table 8 Effects of mitigation strategies

Author	Mitigation Strategy	Classification	Outcomes of Mitigation Strategy: Service	Clinical	Humanistic	Economic	Public Health Goal	Audience	Implicit/explicit
Jewell BL, et al.[5]	Reduce risky sexual behavior	1	NA	↓Morbidity	NA	NA	NA	Governments, donors, suppliers, and communities	Explicit
Sherrard-Smith E et. Al.[6]	Maintain supply of prevention medications	2	NA	↓Morbidity	NA	NA	NA	Unclear	NA
Roberton T, et.al.[7]	Maintain supply of treatment and prevention medications	2	NA	↓Mortality	NA	NA	NA	Policy makers, Government	Explicit
Toor J, et al.[8]	Increase supply of routine immunizations	2	Increased fully vaccinated persons	↓Mortality	NA	NA	NA	Policy makers, WHO and United Nations Children's Fund (UNICEF)	Explicit
Wifferen F, et al.[9]	Selective screening of higher risk colorectal cancer patients	3	NA	↓Mortality	NA	NA	NA	Policy makers	Explicit
Malagon T, et al.[10]	Increase cancer diagnostic testing and treatment supply	2	NA	↓Mortality	NA	NA	NA	Health system	Implicit
Stover J, et al.[11]	Increase access to HIV services	3	NA	↓Mortality	NA	NA	NA	Health system	Implicit
Borlase A, et al.[13]	Additional mass drug administrations	2	NA	NA	NA	NA	Improvement in reaching elimination target	Government	Explicit
Silhol R, et al. [14]	Reduce risky sexual behavior	1	NA	↓Morbidity	NA	NA	NA	Policymakers	Implicit
Mitchell K, et al.[15]	Reduce risky sexual behavior	1	NA	↓Morbidity	NA	NA	NA	Policymakers	Implicit
Alagoz O, et al.[17]	Increase breast cancer services, reduce screening for lower risk breast cancer patients	2, 3	NA	↓Mortality	NA	NA	NA	Government	Implicit
Kitano T, et al.[20]	Increase supply and coverage of immunizations	2	NA	↓Morbidity	NA	NA	NA	Government and health system	Implicit
de Jonge L, et al.[23]	Increase colorectal cancer screening services	2	NA	↓Morbidity and mortality	NA	NA	NA	Government	Explicit
Blumberg S, et al.[24]	Additional mass drug administration	2	NA	NA	NA	NA	Improvement in reaching elimination target	Government	Implicit
Hamley J, et al.[25]	Additional mass drug administration	2	NA	↓Morbidity	NA	NA	NA	Government	Implicit

Author	Mitigation Strategy	Classification	Outcomes of Mitigation Strategy: Service	Clinical	Humanistic	Economic	Public Health Goal	Audience	Implicit/explicit
Prada J, et al.[26]	Additional mass drug administration	2	NA	NA	NA	NA	Improvement in reaching elimination target	Government and policy makers	Implicit
Kura K, et al.[27]	Additional mass drug administration	2	NA	NA	NA	NA	Improvement in reaching elimination target	Government and health system	Explicit
Cilloni L, et al.[32]	Timely restoration of TB services with "catch up" campaigns for missed diagnosis	3,2	NA	↓Morbidity	NA	NA	NA	Unclear	NA
Barocas J A, et al.[37]	Providing additional resources to ramp up treatment	2	NA	↓Morbidity and mortality	NA	NA	NA	Government and health system	Explicit
Malizia V, et al.[39]	Semiannual and one round of community-wide preventive chemotherapy	2	NA	NA	NA	NA	Catch up will be speeded up	Government and health system	Explicit
Shaikh N, et al.[41]	Catch -up vaccination for missed	3	NA	↓Morbidity and mortality	NA	NA	NA	Government and policy makers	Implicit
Mandrik O, et al.[42]	Return-to screening scenarios/postponing screening for everyone	2	NA	↓Mortality	NA	Improve NMB	NA	Government	Explicit
Ward ZJ, et al.[46]	Surge capacity planning, health system capacity levels for detection and care for the increased cancer cases	2	NA	↓Morbidity and mortality, early diagnosis of cancer	NA	NA	NA	Policy makers and health system	Implicit
Nghiem N, et al.[50]	Primary prevention of CVD and additional job creation programs	2	NA	Primary prevention of CVD	Additional job creation programs			Government and policy makers	Explicit
Borlase A, et al.[51]	Additional community-based Mass drug administration or enhanced case finding through active screening	2	NA	↓Morbidity	NA	NA	Improvement in reaching elimination target, accelerate progress in reducing transmission in high-endemic areas	Government, WHO and health system	Implicit

1. Behavioral modification 2. Ensuring resources for services 3. Ensuring access to services which are on demand

#Abbreviations: TB (Tuberculosis), ART (Antiretroviral therapy), NMB (Net monetary benefit), CVD (Cardio vascular Disease)

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