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Access to the COVID-19 services during the pandemic - a scoping review

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Abstract

Appropriate accessibility to coronavirus disease 2019 (COVID-19) services is essential in the efficient management of the pandemic. Different geospatial methods and approaches have been used to measure accessibility to COVID-19 health-related services. This scoping review aimed to summarize and synthesize the geospatial studies conducted to measure accessibility to COVID-19 healthcare services. Web of Science, Scopus, and PubMed were searched to find relevant studies. From 1113 retrieved unique citations, 26 articles were selected to be reviewed. Most of the studies were conducted in the USA and floating catchment area methods were mostly used to measure the spatial accessibility to COVID-19 services including vaccination centres, Intensive Care Unit beds, hospitals and test sites. More attention is needed to measure the accessibility of COVID-19 services to different types of users especially with combining different non-spatial factors which could lead to better allocation of resources especially in populations with limited resources.

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Key words: COVID-19; spatial accessibility; spatial equity; resource management; Iran.

See online Appendix for additional materials.

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Introduction

Appropriate access to healthcare services is one of the important aspects of managing infectous disease pandemics including coronavirus disease 2019 (COVID-19) (Mohammadi *et al*., 2021). These healthcare services include a wide range of hospitals, intensive care units, test centres, and now vaccination facilities (Silalahi *et al*., 2020; Kang *et al*., 2020; Lakhani, 2020; Boitrago *et al*., 2021; Lakhani and Wollersheim, 2021). Lack of resources and massive volume of requests for healthcare services need a robust geospatial analysis approach to optimize such services (MohammadEbrahimi *et al*., 2021). Some studies have been conducted to measure accessibility to COVID-19 health and medical care services worldwide with different approaches and research questions (Mollalo *et al*., 2021). Synthesizing the results of these studies would help both researchers and healthcare policymakers to develop more innovative and efficient work in the future.

Access to healthcare services has been defined in different ways (Hoseini *et al*., 2018). However, most see them as a concept where the degree of access plays a large role. Access can be categorized into spatial and non-spatial (Kiani *et al*., 2017), where the former is related to geographical access and measured by geographical indices such as distance and travel time. The latter, however, is more about non-geographical indices, such as services cost, acceptability and accommodation. Some studies have also measured an integrated accessibility access score, including spatial and non-spatial factors (Hashtarkhani *et al*., 2020). For example, Mohammadi *et al*. (2021) aimed at estimating the potential spatial access to COVID-19 vaccination centres in an urban area and used travel time as a spatial factor and the age structure of urban neighbourhoods as a non-spatial one. In addition to the number and type of factors, spatial and non-spatial, used in various studies, different methodologies based on catchment areas, distance, and density are used. Different studies have been conducted to measure geospatial accessibility to COVID-19 services, but no study has summarized these studies. Thus, this work aimed at a scoping review encompassing any spatial accessibility methods to any of COVID-19 services. The results can be used as a guide to geospatial accessibility studies.

Materials and methods

This Scoping review was conducted according to the Preferred

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Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) framework (Tricco *et al*., 2018).

Eligibility criteria

The eligibility criteria for this scoping review were: i) written in English language; ii) peer-reviewed original research articles; iii) focused on the spatial access to healthcare for COVID-19 services; iv) published after 2019.

We excluded conference papers, review articles and non-peer-reviewed articles, such as editorials and grey literature communications. We also excluded studies that did not focus on spatial access to COVID-19 healthcare services, such as access to nature or urban green spaces or studies on spatial access with regard to other diseases. Finally, we excluded studies about the distribution of facilities in various regions since we were not interested in healthcare facility distributions without any accessibility formulation.

Search sources

We systematically searched all published articles in PubMed, Scopus and Web of Science to identify relevant articles. The search was conducted without any geographic limitations and took place on 10 November 2021. The search strategy were outlined by an experienced researcher and then refined via team discussion. Three main concepts, *i.e.* COVID-19, accessibility and geographical information systems (GIS), were used to extract relevant citations.

The summary of the keywords terms used for PubMed are shown in Table 1. Detailed information regarding search strategies in Scopus and Web of Science databases is presented in the supplement (Table S1). The retrieved articles were imported into Endnote X9 reference manager software (Clarivate Analytics, Philadelphia, PA, USA) and then duplicate records were removed.

Selection of sources of evidence

We performed the selection of studies in three phases. The articles were first reviewed by title and type of study with irrelevant studies excluded, then the abstracts were read to reveal if the foci were relevant for our approach. Finally, articles were selected for inclusion by reading the full text. Two reviewers evaluated the titles, abstracts and full text of all identified publications. If required, disagreements were resolved by discussion with other reviewers until consensus was reached.

Data charting process

Two reviewers developed the data-charting form together and extracted the data from the included papers. They pulled the relevant data from included articles independently. Disagreements were resolved by discussion between the reviewers or by further assistance of a third reviewer.

Data item

The data items collected in this scoping review were: i) title of the article; ii) first author and publication year; iii) country; iv) geographical reach; v) type of service; vi) primary methods for measuring accessibility; vii) software used; viii) aim of study; ix) key findings; x) spatial factors calculated; xi) non-spatial factors; xii) target groups.

Synthesis

A geographical map and chart visualized the geographical and temporal distribution of the included studies. We grouped the studies by the methods used for measuring spatial accessibility. These methods were categorized into three main groups: Euclidean distance (ED), gravity models, and cost distance and network analysis (CDNA).

Results

Selection of sources of evidence

The initial search of the electronic databases identified 1113 publications after removing duplicate publications. Based on title and abstract, 1062 studies were excluded. The remaining 51 articles were assessed for eligibility by reviewing the full text of the articles, a procedure that excluded a further 25 articles. Finally, 26 articles were included in this scoping review. The PRISMA flow diagram of the included studies is shown in Figure 1.

Table 1. Concepts and keywords considered to build search strategy in PubMed.

Theme	Keywords/medical subject headings
COVID-19	Keywords "COVID*" OR "COVID-19" OR "COVID19" OR "Coronavirus" OR "nCoV Infection" OR "SARS-CoV-2" Medical subject headings "SARS-CoV-2" OR "COVID-19" OR "COVID-19 Testing" OR "COVID-19 Vaccines"
Accessibility	Keywords Inequality OR equality OR equity OR inequity OR access* OR "travel time*" OR "travel distance*" OR availabl* OR "catchment area" OR "distribution"
Geographical information systems (GIS)	Keywords "geographical distribution" OR "geographic distribution" OR "spatial access*" OR "geospatial access*" OR "geographic access*" OR "spatial analysis" OR "geospatial analysis" OR "geographic mapping" OR "geographic information system" OR "geography information system" OR "geographical information system" OR "geographical mapping" OR "travel time*" OR "travel distance*" OR "GIS" OR "ArcGIS" Medical subject headings "Geographic Information Systems"

*Any stacking character after the keyword was also considered as a keyword.

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Characteristics of included studies

The articles were either published in 2020 (n=9, 35%) or in 2021 (n=17, 65%). Figure 2A shows the geographical distribution of the included studies. As seen in Table S2. most studies concerned only one country, but some of them examined several, *e.g.*, 14 European countries were examined in a single study (Bauer *et al*., 2020) and another study examined 44 sub-Saharan African counties (Geldsetzer *et al*., 2020). Most studies were conducted in the United States (USA) (n=7, 26.9%) followed by China (n=4, 15.3%) and Brazil (n=3, 11.5%). Figure 2B shows the number of studies at different geographical scales (country, province or city). Most studies were carried out at the city level (n=10, 38.4%); only two were conducted at the international level as mentioned above (Bauer *et al*., 2020; Geldsetzer *et al*., 2020).

Figure 2C (and Table S2) shows the type of service studied. Most of them measured accessibility to vaccination sites (n=7, 26.9%), Intensive Care Unit (ICU) beds (n=6, 23.1%), hospitals (n=6, 23.1%) and COVID-19 test sites (n=4, 15.4%). Other less common types of services considered were negative pressure isolation rooms (NPIRs) (Kim *et al*., 2020), fever clinics (Yong *et al*., 2021) and palliative care facilities (Lakhani, 2020).

All seven of the studies that focused on spatial access to vaccination sites had optimization goals and measured their suitability based on distribution and coverage. The only non-spatial factor used in these studies was age (n=5, 19.2%). Table S1 (in Appendix) describes the characteristics of each included paper.

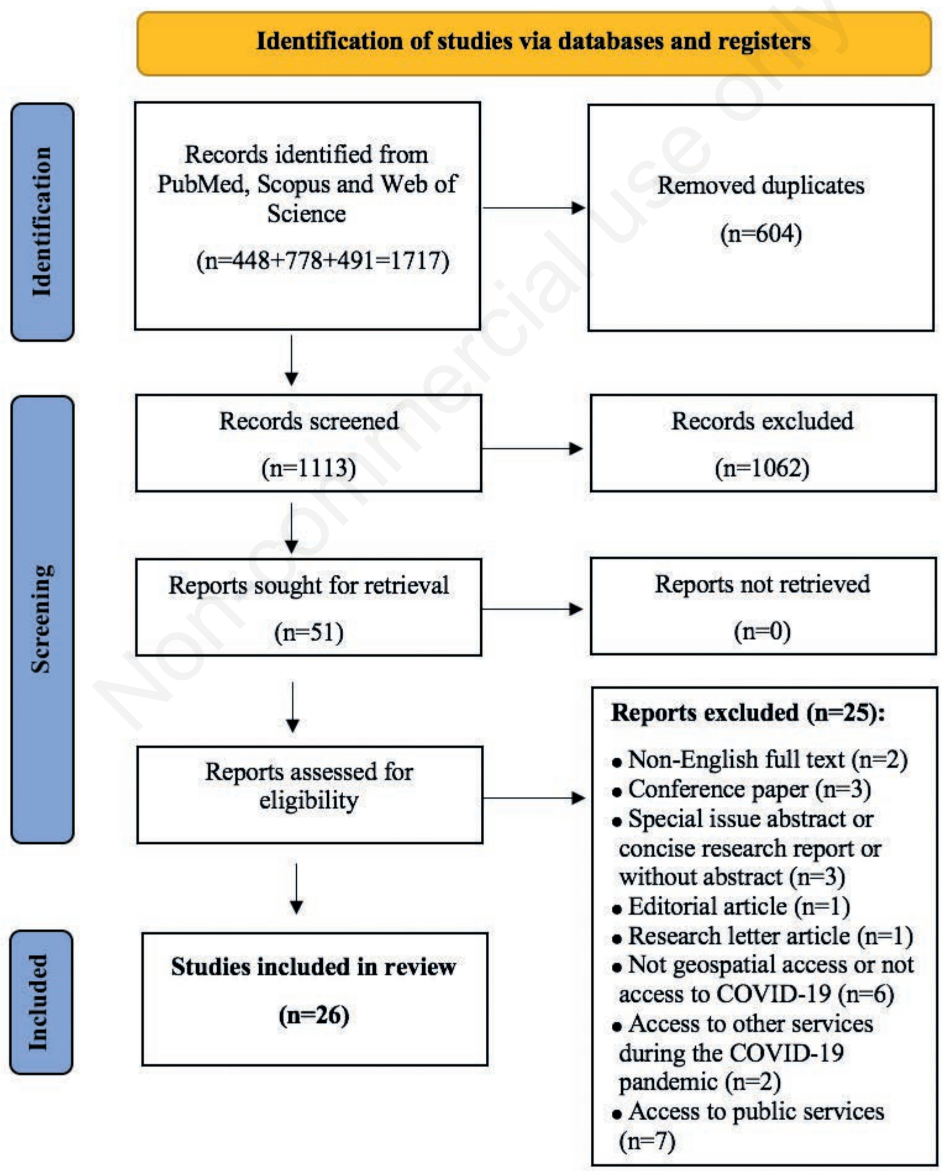

Figure 1. PRISMA flow diagram of the included studies.

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Main approach

Included studies used various methods to measure spatial accessibility as follows: ED models (n=2, 7.6%), CDNA (n=13, 50%) and gravity models (n=11, 42.4%).

Euclidean distance

The simplest method for calculating geographical access to healthcare services is the Euclidean distance. This method creates a straight line of travel to measure the accessibility of services (Guagliardo, 2004; Noor *et al*., 2009). We found two such studies, one measuring the accessibility to vaccination sites (Alemdar *et al*., 2021) and the other to COVID-19 test sites (Hernandez *et al*., 2021).

Gravity models

Unlike the ED approach, Gravity modelling considers both availability and accessibility across defined spatial units. This method includes the capacity of a facility, competition between facilities and the ability to estimate values using numerous methods (Neutens, 2015; Ouma *et al*., 2021). All of the 11 studies in this category used variations of the Floating Catchment Area method (FCA), which is a particular case of the gravity model (Table S1). The most used method in this category was the two-step floating catchment area (2SFCA) (n=4, 15.3%), which was used to calculate access to ICU beds (Boitrago *et al*., 2021), COVID-19 test sites (Tao *et al*., 2020), NPIRs (Kim *et al*., 2020) and hospitals

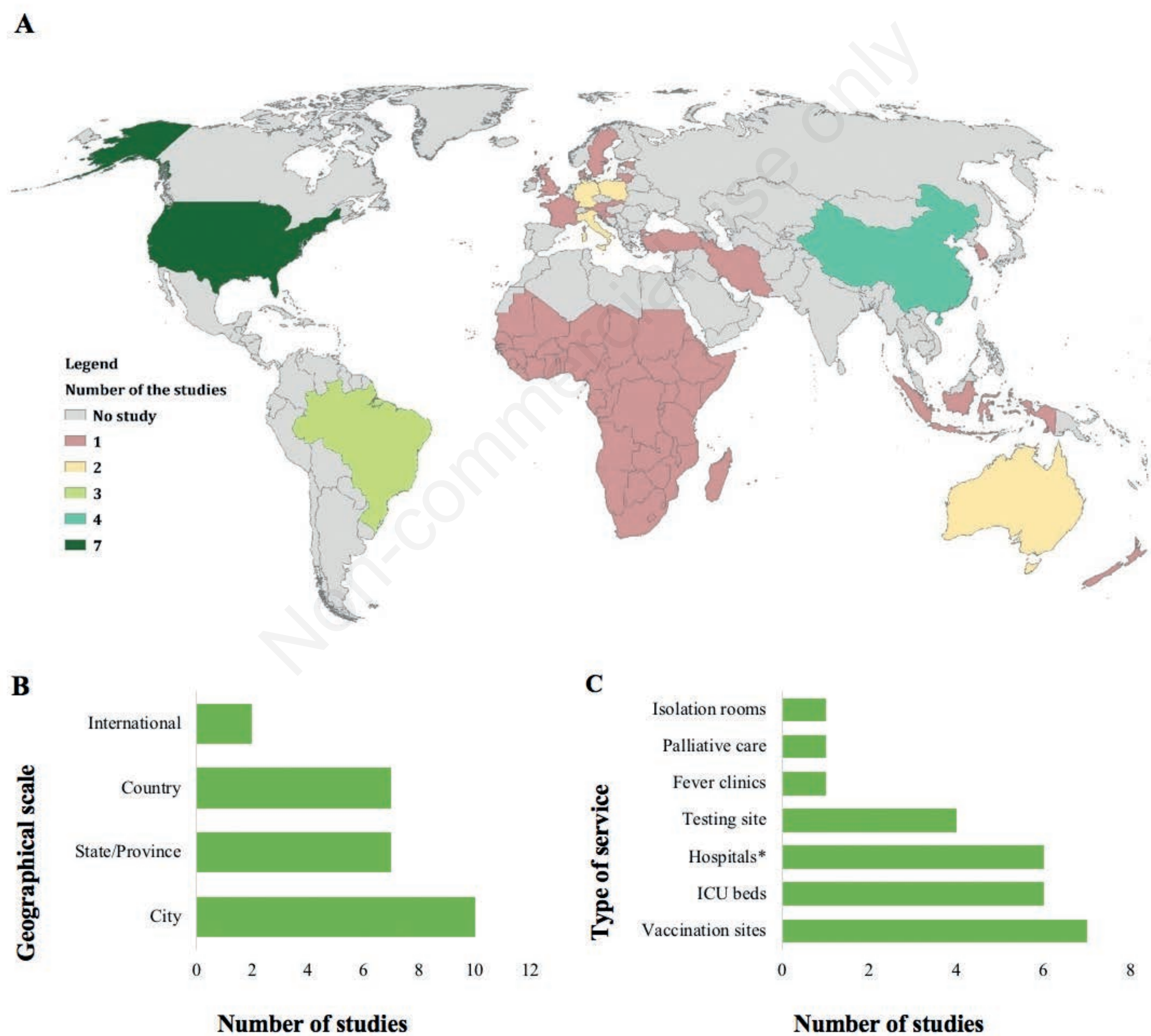

Figure 2. Characteristics of included studies.

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(Zhao *et al*., 2020). All of these studies reported heterogeneous access as they included both rural and urban areas.

Three of the included studies employed the enhanced two-step floating catchment area (E2SFCA), which is an advanced version of 2SFCA (Hashtarkhani *et al*., 2020). This method was used to calculate access to ICU beds (Bauer *et al*., 2020; Pecoraro *et al*., 2021). In the study by Bauer *et al*. (2020), geographical access to ICU beds varied significantly across European countries, and low accessibility was associated with a higher proportion of fatalities, while Pecoraro *et al*. (2021) found that regions with high-density cities tended to concentrate ICU hospitals and beds in highly populated zones leaving rural areas without this critical care service. Anorther study (Ghorbanzadeh *et al*., 2021) used both E2SFCA and 2SFCA to measure the accessibility to ICU beds. They found that the 2SFCA method overestimates the accessibility in areas with lower numbers of ICU beds. Importantly, both methods revealed that many regions have inadequate access to this kind of service. Mohammadi *et al*. (2021) used E2SFCA to measure COVID-19 vaccination coverage finding that GIS can quantify the suitability of existing healthcare centres in urban areas and optimize coverage, thereby achieving more efficient vaccination,

Pereira *et al*. (2021) used a balanced floating catchment area (BFCA) to measure access to ICU beds and mechanical ventilators and found that almost 50% of the vulnerable population had poor access to these facilities. The application of the novel BFCA approach illustrates how this approach can have important, often overlooked implications for policy planning by considering competition effects in access to healthcare.

One study (Kim *et al*., 2020) used the three-step floating catchment area (3SFCA) method and found that serious cases can vary across periods in rural areas, where there often is a lack of healthcare resources and developed transportation systems. Such areas are more likely to be overwhelmed by recurrent COVID-19 waves.

Kang *et al*. (2020) developed a parallel computing approach called P-E2SFCA to measure the accessibility of healthcare resources to both COVID-19 patients and vulnerable populations at risk. Using a parallel computing strategy based on (https://cybergis.illinois.edu or https://dl.acm.org/), they showed that P-E2SFCA run-time is six-time faster than that of E2SFCA.

Cost distance and network analysis

When cost distance is combined with network analysis the nearest healthcare service provider or the optimum location can more easily be discovered (Noor *et al*., 2006; Owen *et al*., 2010; Ouma *et al*., 2021). Due to the overlap and concurrent use of these two methods, we considered them together under the abbreviation CDNA. Thirteen studies (Table S2) used this approach, which uses a more intuitive way defining accessibility when measuring travel time. CDNA is a more realistic representation of access as people find it easier to relate to the time it takes to get to a health facility than to the distance itself (Nesbitt *et al*., 2014; Noor *et al*., 2006; Ouma *et al*., 2021).

The Origin-Destination (OD) cost matrix identifies and measures the most inexpensive routes from several origins to several destinations. It shows the movements of people in a particular area and is a conventional and commonly used approach for modelling the spatial and temporal distribution of travel demand. The OD cost matrix aims to find a solution that addresses traffic flow constraints by showing surroundings as a matrix of actual achievable spaces (Silalahi *et al*., 2020). One study used Beere's road network (Beer and Brabyn, 2006) and the OD cost matrix to measure access to COVID-19 vaccination sites finding that many people could not only face significant travel times to potential vaccine delivery sites, but communities with elevated risk of COVID-19 and severity of disease could also amount to obstacles since travel to and from them would be restricted (Whitehead *et al*., 2021). OD cost matrix has also been used to measure access to the palliative care and related health services (Lakhani, 2020). Results presented in this study showed the spatial analysis could identify priority areas with elderly people suffering from disability who also had low access to health services (Lakhani, 2020).

Some of the studies used location-allocation modelling from network analysis toolbox to measure spatial accessibility and resource allocation. The method based on the location set covering problem (LSCP) identifies the minimum number of facilities locations in such a way that each demand point has at least one facility within a certain distance or a standard time (Marianov and Revelle, 1994). One study measuring the accessibility to fever clinics (Yong *et al*., 2021) found that this approach actually reduced travel time for medical treatment in the community, thus improving accessibility. Another study used mathematical programming to compute the optimal selection of vaccination sites (Leithauser *et al*., 2021) finding a clear trade-off between the travel distances and the required number of vaccination facilities.

Google Maps application programming interface (API) has the potential to measure the travel times between service providers and potential users. One study using this approach (Hu *et al*., 2020) measuring access to test sites showed that the drive time to testing sites was significantly negatively associated with the COVID-19 incidence rate implying the importance of good accessibility to test sites for all.

The standard deviational ellipse (SDE) tool can be used to summarize the spatial characteristics of geographic features, such as central tendency, dispersion and directional trends. Using the Network Analyst tool extension and OD cost matrix to calculate access to the referral hospitals in combination with the SDE to model the distribution of COVID-19 cases, Silalahi *et al*. (2020) found the need for additional referral hospitals specializing in the treatment of COVID-19. They also found the spatial illustration of the growth of the COVID-19 in support of the implementation of social distancing (Silalahi *et al*., 2020).

One of the capabilities of network analysis is the creation of Thiessen tesselation (also known as Voronoi polygons) that shows the access coverage of each service site (Yamada, 2016). This method can identify areas with poor accessibility. Two studies based on this approach identified spatial inequalities in vaccination sites and proposed activation of additional sites, either located at *ad hoc* places or using a mobile vaccination approach (Krzysztofowicz and Osinska-Skotak, 2021), while Zheng *et al*. (2021) used this method for an analysis of the distribution of referral hospitals designated for COVID-19 patients.

Closest facility is part of the network analysis family of spatial tools. It measures the cost of travel between incidents and health facilities and determines which are closest to each other. One study employed this approach to measure access to vaccination sites used for both influenza and COVID-19 (Guhlincozzi and Lotfata, 2021). They found geographical methods useful for the study of weaknesses and strengths in the health infrastructure and discovered that combining influenza and COVID-19 vaccination sites would significantly reduce geographic access for many people, particularly those with limited mobility (Guhlincozzi and Lotfata, 2021). A study using this tool to measure accessibility of point of care test (POCT) site locations (Lakhani and Wollersheim, 2021) showed that residents closest to POCT sites located in urban locations would have a much lower travel time, but that this was not necessarily so in rural locations.

Two studies used travel time and distance to calculate access to medical facilities. Zhou *et al*. (2021) found that although accessibility to medical facilities in the peripheral areas of a community in general were inferior compared to those in the central regions, there was spatial inequality of medical resources within and across districts implying that relevant accessibility data could be rapidly identified even with open-source data. Using the same technique, Geldsetzer *et al*. (2020) determined that the COVID-19 pandemic has caused a far higher need for hospital services among older than younger people; approximately 10% of adults aged ≥60 years across sub-Saharan Africa have an estimated travel time to the nearest hospital of 6 hours or longer.

ArcGIS Pro's zonal statistics and the Hotspot Analysis Tool (ESRI, Redlands, CA, USA) were used by Rocha *et al*. (2021) to ensure the effective implementation of the national COVID-19 vaccination access plan in Brazil. They concluded that innovative strategies like measuring spatial accessibility are needed to address the challenges posed by implementing a new scheme covering the whole country (Rocha *et al*., 2021).

Software

The most used software for analysing data respectively, were ESRI's ArcMap (n=8, 30.7%), ArcGIS Pro (n=7, 26.9%), R software (https://www.r-project.org/) (n=3, 11.5%), Baidu Map (https://github.com/Dafrok/vue-baidu-map) (n=3, 11.5%) that were utilized in three of the Chinese studies (Zhao *et al*., 2020; Yong *et al*., 2021; Zhou *et al*., 2021). QGIS (https://qgis.org) (n=2, 7.7%) was used by Hernandez *et al*. (2021) and Pecoraro *et al*. (2021). Other software applications were: AccessMod (https://www.accessmod.org/) (Geldsetzer *et al*., 2020), OpenTripPlanner (https://www.opentripplanner.org/) (Pereira *et al*., 2021), Open Source Routing Machine (http://project-osrm.org/) (OSRM) (Kim *et al*., 2021), Python 3 (https://www.python.org/) (Leithauser *et al*., 2021), Google Maps Distance Matrix API (https://developers.google.com/) (Hu *et al*., 2020), CyberGIS-Jupyter & Virtual ROGER (https://dl.acm.org/) (Kang *et al*., 2020). Some studies used more than one type of software.

Discussion

The studies included in this study were largely conducted in developed countries; a few in middle-income countries but only one represented low-income countries (Geldsetzer *et al*., 2020). Obviously, low-income and middle-income countries have limited resources to control the spread of infectious diseases, in particular the current COVID-19 pandemic. However, the basic principle of spatial access is the same for all, even if less developed countries are in a more difficult situation compared to developed countries when it comes to implementation of effective health care management. In addition, there was a dearth of health care facilities in low-income countries long before the COVID-19 pandemic (Geldsetzer *et al*., 2020), however, the problem became aggravated when COVID-19 struck resulting in a catastrophic inequality with respect to healthcare access (Kim *et al*., 2021). The distribution of hospitals and the number of ICU beds cannot be changed overnight, but access studies can influence planning and future organization. Most of the studies in the developed world reported inadequate geographic distribution rather than lack of facilities, inequalities that can be solved using GIS optimization techniques.

Although COVID-19 is a pandemic, the impact differs between countries. Importantly, almost all of the publications reviewed had been conducted in areas of countries during periods of high COVID-19 risk. According to the Worldometer website (www.worldometers.info/coronavirus), the accumulated number of reported cases per million inhabitants climbed to particularly high levels in Europe, less so in the Americas, while the numbers of cases were surprisingly few in China, mainly due to rigorous lockdown early on, which strongly limited transmission.

Access measurements

The FCA method, a descendant of the original gravity model, is frequently used to measure the accessibility of COVID-19 services which is possibly due to FCA being simplistic and easy to understand. In the 2SFCA approach, as the name implies, the computation consists of two steps: i) computing the provider-to-population ratio for each health care catchment; and ii) allocating providers to populations by determining which providers fit the catchment of each population, which sums up the population-to-provider ratios obtained in the first step of the procedure. While traditional gravity methods are very often used in transport geography, including cumulative opportunities, they are not commonly applied in healthcare research, presumably because the spatial choice of alternative providers is not valued as such in most health settings. Still, the 2SFCA has emerged as a key measure of spatial accessibility in the health care area (McGrail, 2012). Recent variations, such as the E2SFCA, 3SFCA, P-E2FCA and BFCA noted in various communications reviewed here, either account for distance-decay within a catchment area or can be used for variable catchment sizes. These different variations of the original CFA approach demonstrate that the operation can be appropriate at different scales as well as between rural and metropolitan areas. They also show the utility of combing the distance-decay function and the variable catchment size function in measuring healthcare access across different geographical regions.

Network analysis and online mapping platforms like Google Map (https://www.google.com/maps/) and Open Street Map (https://www.openstreetmap.org/) have been used to estimate the travel time from population centroids to service areas. These methods need more sophisticated approaches to simulate real-world situations like traffic and urban infrastructures. However, they are far better than simple approaches of measuring accessibility, such as regional availability, which only measure the provider to population ratios in the administrative areas.

Strengths and limitations

The term 'access', even when applied to a limited area such as infectious diseases, is closely connected to context. Thus, accessibility varies in different countries and times as well as between urban and rural areas. Evidently, the greatest difference concerns access to hospitals and ICU beds, which are in short supply in low-income and middle-income countries. Given these great variations, it is clear that different methods cannot be tested in equal or at least similar situations, a fact particularly difficult to achieve with only 26 papers under review. However, a relatively good coverage was still possible. For example, six papers (23%) in the present study focused on ICU beds and ventilators (Table S2) leaving ample room for collecting information on test sites, vaccination centres

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and other aspects of accessibility. On the other hand, even if some of the studies reported age as an important factor in measuring accessibility to COVID-19 services, only one employed an age-integrated model to measure accessibility (Mohammadi *et al.*, 2021). It is important to also consider non-spatial factors as it could potentially improve the spatial accessibility in the real-world situation, and too few of the studies reviewed included a focus on these factors to assist functional conclusions. It would be useful to pay attention to the role of non-spatial factors when designing access studies in the future.

Conclusions

GIS plays an important role in measuring the spatial accessibility to COVID-19 services. Vaccination sites, ICU beds, hospitals and test sites have been studied. Most of the studies used various extensions of the FCA method to discover inequalities in access to COVID-19 services. Among them, studies involving more complex measures to estimate the travel time coverage of COVID-19 services provided more realistic measures than distance-based approaches did. Few of the studies involved non-spatial factors in access method formulation, something that needs greater attention in future studies. Accessibility methods can lead to better allocation of resources and optimize them, especially in larger areas and in developing countries where there are limited resources.

References

Alemdar KD, Kaya Ö, Çodur MY, Campisi T, Tesoriere G, 2021. Accessibility of vaccination centers in COVID-19 outbreak control: A gis-based multi-criteria decision making approach. ISPRS. Int J Geo-inf 10(10). [Epub ahead of print].

Bauer J, Bruggmann D, Klingelhofer D, Maier W, Schwettmann L, Weiss DJ, Groneberg DA, 2020. Access to intensive care in 14 European countries: a spatial analysis of intensive care need and capacity in the light of COVID-19. Intensive Care Med 46:2026-34.

Beere P, Brabyn L, 2006. Providing the evidence: Geographic accessibility of maternity units in New Zealand. N Z Geog 62:135-43. [Epub ahead of print].

Boitrago GM, Mônica RB, Silva DM, Cerroni MP, Cortez-Escalante JJ, Almiron M, Terabe SH, Rocha TAH, 2021. Restructuring of emergency services to COVID-19 in Brazil: a space-time analysis from February to August 2020. Epidemiol Serv Saude 30:e2020791.

De Luca C, Libetta A, Conticelli E, Tondelli S, 2021. Accessibility to and availability of urban green spaces (UGS) to support health and wellbeing during the COVID-19 pandemic - the case of Bologna. Sustainability 13(19). [Epub ahead of print].

Geldsetzer P, Reinmuth M, Ouma PO, Lautenbach S, Okiro EA, Barnighausen T, Zipf A, 2020. Mapping physical access to health care for older adults in sub-Saharan Africa and implications for the COVID-19 response: a cross-sectional analysis. Lancet Healthy Longev 1:E32-E42.

Ghorbanzadeh M, Kim K, Ozguven EE, Horner MW, 2021. Spatial accessibility assessment of COVID-19 patients to healthcare facilities: A case study of Florida. Travel Behav Soc 24:95-101.

Grigsby-Toussaint DS, Shin JC, Jones A, 2021. Disparities in the distribution of COVID-19 testing sites in black and Latino areas in new York City. Prev Med 147.

Guagliardo MF, 2004. Spatial accessibility of primary care: concepts, methods and challenges. Int J Health Geogr 3:3.

Guhlincozzi AR, Lotfata A, 2021. Travel distance to flu and COVID-19 vaccination sites for people with disabilities and age 65 and older, Chicago metropolitan area. J Health Res [Epub ahead of print].

Hashtarkhani S, Kiani B, Bergquist R, Bagheri N, Vafaei-Nejad R, Tara M, 2020. An age-integrated approach to improve measurement of potential spatial accessibility to emergency medical services for urban areas. Int J Health Plann Manage 35:788-98.

Hernandez JH, Karletsos D, Avegno J, Reed CH, 2021. Is COVID-19 community level testing effective in reaching at-risk populations? Evidence from spatial analysis of New Orleans patient data at walk-up sites. BMC Public Health 21:632.

Hoseini B, Bagheri N, Kiani B, Azizi A, Tabesh H, Tara M, 2018. Access to dialysis services: A systematic mapping review based on geographical information systems. Geospat Health 13:577.

Hu T, Yue H, Wang CZ, She B, Ye XY, Liu R, Zhu XY, GuanWHW, Bao SM, 2020. Racial Segregation, Testing Site Access, and COVID-19 Incidence Rate in Massachusetts, USA. Int J Environ Res Public Health 17:24.

Kang JY, Michels A, Lyu FZ, Wang SWH, Agbodo N, Freeman VL, Wang SWH, 2020. Rapidly measuring spatial accessibility of COVID-19 healthcare resources: a case study of Illinois, USA. Int J Health Geogr 19(1). [Epub ahead of print].

Kiani B, Bagheri N, Tara A, Hoseini, B, Tara M, 2017. Haemodialysis services in the northeastern region of Iran. Geospat Health 12:561.

Kim H, Kim D, Paul C, Lee CK, 2020. The Spatial Allocation of Hospitals With Negative Pressure Isolation Rooms in Korea: Are We Prepared for New Outbreaks? Int J Health Policy Manage 9:475-83.

Kim K, Ghorbanzadeh M, Horner MW, Ozguven EE, 2021. Identifying areas of potential critical healthcare shortages: A case study of spatial accessibility to ICU beds during the COVID-19 pandemic in Florida. Transp Policy (Oxf) 110:478-86.

Krzysztofowicz S, Osinska-Skotak K, 2021. The use of GIS technology to optimize COVID-19 vaccine distribution: a case study of the city of Warsaw, Poland. Int J Environ Res Public Health 18(11). [Epub ahead of print].

Kuupiel D, Adu KM, Bawontuo V, Adogboba DA, Drain PK, Moshabela M, Mashamba-Thompson TP, 2020. Geographical accessibility to glucose-6-phosphate dioxygenase deficiency point-of-care testing for antenatal care in Ghana. Diagnostics 10 (4). [Epub ahead of print].

Lakhani A, 2020. Which Melbourne metropolitan areas are vulnerable to COVID-19 based on age, disability, and access to health services? using spatial analysis to identify service gaps and inform delivery. J Pain Symptom Manage 60:E41-4.

Lakhani A, Wollersheim D, 2021. COVID-19 test sites in Victoria approaching Stage 4 restrictions: evaluating the relationship between remoteness, travel time and population serviced. Aust N Z J Public Health. [Epub ahead of print].

Leithauser N, Schneider J, Johann S, Krumke SO, Schmidt E, Streicher M Scholz S, 2021. Quantifying COVID19-vaccine location strategies for Germany. BMC Health Serv Res 21(1). [Epub ahead of print].

Non-commercial use only

McGrail MR, 2012. Spatial accessibility of primary health care utilizing the two step floating catchment area method: an assessment of recent improvements. Int J Health Geogr 11:50.
Marianov V Revelle C, 1994. The queuing probabilistic location set covering problem and some extensions. Socioecon Plann Sci 28:167-78.
Mell I Whitten M, 2021. Access to nature in a post COVID-19 world: Opportunities for green infrastructure financing, distribution and equitability in urban planning. Int J Environ Res Public Health 18:1-16.
MohammadEbrahimi S, Mohammadi A, Bergquist R, Dolatkhah F, Olia M, Tavakolian A, Pishgar E, Kiani B, 2021. Epidemiological characteristics and initial spatiotemporal visualisation of COVID-19 in a major city in the Middle East. BMC Public Health 21:1373.
Mohammadi A, Mollalo A, Bergquist R, Kiani B, 2021. Measuring COVID-19 vaccination coverage: an enhanced age-adjusted two-step floating catchment area model. Infect Dis Poverty 10(1). [Epub ahead of print].
Mollalo A, Mohammadi A, Mavaddati S, Kiani B, 2021. Spatial analysis of COVID-19 vaccination: A scoping review. Int J Environ Res Public Health 18(22). [Epub ahead of print].
Nesbitt RC, Gabrysch S, Laub A, Soremekun S, Manu A, Kirkwood BR, Amenga-Etego S, Wiru K, Höfle B, Grundy C, 2014. Methods to measure potential spatial access to delivery care in low- and middle-income countries: a case study in rural Ghana. Int J Health Geogr 13:25.
Neutens T, 2015. Accessibility, equity and health care: review and research directions for transport geographers. J Transp Geogr 43:14-27.
Noor AM, Alegana VA, Gething PW, Snow RW, 2009. A spatial national health facility database for public health sector planning in Kenya in 2008. Int J Health Geogr 8:13.
Noor AM, Amin AA, Gething PW, Atkinson PM, Hay SI, Snow RW, 2006. Modelling distances travelled to government health services in Kenya. Trop Med Int Health 11:188-96.
Ouma P, Macharia PM, Okiro E, Alegana, V, 2021. Methods of measuring spatial accessibility to health care in Uganda. pp. 77-90 in Practicing Health Geography, Ed. PT Makanga, Springer International Publishing.
Owen KK, Obregón EJ, Jacobsen, KH, 2010. A geographic analysis of access to health services in rural Guatemala. Int Health 2:143-9.
Pecoraro F, Luzi D, Clemente F, 2021. Spatial inequity in access to intensive care unit beds at regional level in Italy. Stud Health Technol Inform 281:809-13.
Pereira RHM, Braga CKV, Servo LM, Serra B, Amaral P, Gouveia N, Paez A, 2021. Geographic access to COVID-19 healthcare in Brazil using a balanced float catchment area approach. Soc Sci Med 273. [Epub ahead of print].
Rocha TAH, Boitrago GM, Monica RB, de Almeida DG, da Silva NC, Silva DM, Terabe SH, Staton C, Facchini LA, Vissoci JRN, 2021. National COVID-19 vaccination plan: using artificial spatial intelligence to overcome challenges in Brazil. Cien Saude Colet 26:1885-98.
Sharma J, Mahajan A, Bakhshi S, Patil V, Verma N, Radhakrishnan V, Singh A, Kayal S, Seth R, Pushpam D, Arora RS, 2022. The impact of COVID-19 pandemic on access to treatment for children with cancer in India and treating center practices. Cancer 128:579-86.
Silalahi FES, Hidayat F, Dewi RS, Purwono N, Oktaviani N, 2020. GIS-based approaches on the accessibility of referral hospital using network analysis and the spatial distribution model of the spreading case of COVID-19 in Jakarta, Indonesia. BMC Health Serv Res 20(1). [Epub ahead of print].
Sun Y, Hu X, Xie J, 2021. Spatial inequalities of COVID-19 mortality rate in relation to socioeconomic and environmental factors across England. Sci Total Environ 758. [Epub ahead of print].
Tao R, Downs J, Beckie TM, Chen YZ, McNelley W, 2020. Examining spatial accessibility to COVID-19 testing sites in Florida. Ann GIS 26:319-27.
Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, Moher D, Peters MDJ, Horsley T, Weeks L, Hempel S, Akl EA, Chang C, McGowan J, Stewart L, Hartling L, Aldcroft A, Wilson MG, Garritty C, Straus SE, 2018. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Int Med 169:467-73.
Whitehead J, Scott N, Carr PA, Lawrenson R, 2021. Will access to COVID-19 vaccine in Aotearoa be equitable for priority populations? N Z Med J 134:25-34.
Yamada I, 2016. Thiessen polygons. pp. 1-6 in D. Richardson, N. Castree, M.F. Goodchild, A. Kobayashi, W. Liu, R.A. Marston (Eds.), International encyclopedia of geography: people, the earth, environment and technology. Available from: https://doi.org/10.1002/9781118786352.wbieg0157
Yong Q, Liu DL, Li GQ, Wu WS, Sun WJ, Liu SJ, 2021. Reducing exposure to COVID-19 by improving access to fever clinics: an empirical research of the Shenzhen area of China. BMC Health Serv Res 21:959.
Zhao P, Li S, Liu D, 2020. Unequable spatial accessibility to hospitals in developing megacities: New evidence from Beijing. Health Place 65:102406.
Zheng L, Li J, Hu W, Duan P, 2021. Analysis of the spatial range of service and accessibility of hospitals designated for coronavirus disease 2019 in Yunnan Province, China. Geocarto In. [Epub ahead of print].
Zhou ZQ, Xu Z, Liu AQ, Zhou S, Mu L, Zhang X, 2021. Mapping the accessibility of medical facilities of wuhan during the COVID-19 pandemic. ISPRS Int J Geo-inf 10(5). [Epub ahead of print].

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