

BMJ Open Healthcare accessibility in preconflict Syria: a comparative spatial analysis

Mhd Nour Audi ¹, Kevin M Mwenda ², Guixing Wei,² Mark N Lurie ³

To cite: Audi MN, Mwenda KM, Wei G, *et al.* Healthcare accessibility in preconflict Syria: a comparative spatial analysis. *BMJ Open* 2022;**12**:e059210. doi:10.1136/bmjopen-2021-059210

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (<http://dx.doi.org/10.1136/bmjopen-2021-059210>).

Received 14 November 2021

Accepted 04 April 2022



© Author(s) (or their employer(s)) 2022. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

¹Heilbrunn Department of Population and Family Health, Columbia University Mailman School of Public Health, New York, New York, USA

²Spatial Structures in the Social Sciences (S4), Population Studies and Training Center (PSTC), Brown University, Providence, Rhode Island, USA

³Brown University, School of Public Health, International Health Institute, Providence, Rhode Island, USA

Correspondence to

Dr Mhd Nour Audi;
nour.audi@columbia.edu

ABSTRACT

Introduction There is scarce information about the allocation of health resources in Syria. Pre-existing inequalities were further intensified after the 2011 conflict which displaced over 50% of the population. This study provides an analysis of health inequalities in Syria focusing on spatial access to public hospitals and employs data from 2010, just prior to the outbreak of conflict. Establishing a preconflict snapshot of the health system could serve as a helpful baseline assessment for future studies to measure the impact of the conflict on the health system. Such information could also offer systematic data to guide postconflict reconstruction efforts.

Methods We compared two methods to quantify the inpatient bed access: provider to population ratio (PPR) and two-step floating catchment area (2SFCA) method. We compared PPR calculated at the governorate level with population weighted 2SFCA score calculated at a resolution of 2 km by 2 km. We then aggregated at the governorate level, tested multiple catchment sizes and calculated Gini coefficient for each governorate.

Results We found high inequality in access to public hospitals across and within governorates, especially in the north and eastern regions, where all governorates ranked in the lowest two quintiles using both PPR and 2SFCA. Relatively small governorates in the west and the south had higher spatial access and less inequality. Testing variability in catchment size showed that even at 125 km catchment, 65% of the country had accessibility below national average.

Conclusion Methodologically, the use of 2SFCA provided more nuanced insights about hospital bed allocation than PPR. 2SFCA was able to account for the cross-boundary effect and road network quality. Realistic representation of health accessibility is possible in data-scarce settings such as Syria and could be adapted to assess health access inequalities in conflict and postconflict settings.

INTRODUCTION

Since 2011, the Syrian healthcare system has come under international attention. What started in March 2011 as a political uprising evolved into an armed conflict involving multiple state and non-state actors, causing the biggest wave of forced displacement since the second World War.¹ Over half the population (13 million) has been displaced within and outside the country.² One particular aspect of this conflict has been the systematic targeting of healthcare professionals and

Strengths and limitations of this study

- The study design uses minimally available data enabling further accessibility analysis over the conflict and postconflict period.
- We used the two-step floating catchment area method to test the influence of administrative boundaries and different hospital catchments on the perceived distribution of geographical accessibility.
- We approached the uncertainty around hospital catchment size by first assuming 60 km as the catchment and then testing a range of catchments between 5 and 125 km.
- Data from different sources were combined to represent the preconflict distribution of population and health facilities, but the lack of formal data may have introduced inaccuracies in the analysis.
- Our analysis assumes uniform availability of health services across all facilities, which may not reflect the entire situation as many patients from rural areas seek hospital care in major cities in Syria.

facilities.³ By 2013, almost 60% of the country's public hospitals had been destroyed⁴ and by January 2022, 602 attacks on over 348 different health facilities, mostly hospitals, had been documented.⁵ This vast destruction contributed to the sharp decline in people's ability to access healthcare, particularly secondary and tertiary care.⁶

Syrian population health status had been greatly impacted by the ongoing conflict. By 2013, the average life expectancy was less than expected by 6 years for men and by 5 years for women.⁷ This deterioration has been primarily attributed to direct mortality by war trauma and by the reemergence of communicable disease epidemics such as poliomyelitis, measles and acute bloody diarrhoea, and by rising complications of chronic diseases such as cardiovascular diseases.^{8,9}

These emerging burdens were compounded by the preconflict population health status. Syria had already gone through an epidemiological shift since the 1990s. The top causes of morbidity and mortality were chronic diseases such as ischaemic heart disease and stroke.¹⁰ Diabetes prevalence in Syria was

projected to be among the highest worldwide affecting 20% of all adults aged over 25 years by 2022.^{11 12} This baseline of high prevalence of chronic diseases combined with forced displacement, conflict-shaped poor living conditions and decreased ability to access healthcare was reflected in an increase in the burden of chronic diseases throughout the conflict.^{13–15}

Only scarce information is available about the functionality and distribution of healthcare facilities in Syria both before and during the conflict. It was only until 2014 that the WHO and the Syrian Ministry of Health (MoH) started monitoring public hospital functionality across the country through the Health Resources and Services Availability Mapping System.¹⁶ In addition, several international non-governmental organisations (INGOs) have been monitoring the military targeting and destruction of health facilities mainly in non-state controlled areas. Nonetheless, current monitoring systems are fragmented and do not provide a comprehensive view of the healthcare facilities status for all stakeholders across the whole country.¹⁷ Private and non-profit health facilities were not included in any assessment until 2019 although they share a significant portion of healthcare service provision.^{1 4} Furthermore, current monitoring systems only assess public hospitals functionality in terms of infrastructure status, equipment and human resources without taking into consideration other factors that affect population access, such as population density and geographic distance.¹⁶

Integrating health accessibility assessment in ongoing and postconflict health system reconstruction could enhance financial and operational efficiency and strengthen centralised health governance.¹⁸ The evaluation of health accessibility over the course of the conflict could offer insight into the impact of attacks on healthcare, forced displacement, siege and destruction of roads, among other conflict characteristics.

Access to healthcare is a complex concept defined as achieving all five domains of health accessibility: approachability; acceptability; availability and accommodation; affordability; appropriateness.¹⁹ Spatial accessibility accounts for the interaction between the population and health facilities in terms of location, distribution and density, taking into consideration travel impedance and transportation routes.^{20 21}

There are several widely used spatial accessibility techniques including counting the number of facilities contained within a given spatial unit, counting the number of facilities within a given distance to a point of origin, and calculating the minimum distance to the nearest facility from a point of origin. A more thorough review can be found in Higgs and Neutens.^{22 23} This study uses the two-step floating catchment area (2SFCA) method to measure spatial accessibility because it simultaneously accounts for population distribution, facility capacity and distribution, and road network-based travel impedance measured in distance units.²⁴

Applying geospatial techniques to understand health access in protracted conflicts is rare.²⁵ To the best of our

knowledge, this paper is the first to assess the preconflict distribution of spatial accessibility in Syria. This limited knowledge about health accessibility in Syria is partially due to limited studies on the distribution of healthcare resources in Syria, beyond national level aggregates. After the break of the conflict, understanding the status of healthcare accessibility became more challenging due to the rapidly changing situation (including targeting of health facilities), the development of the parallel health system and the multiple waves of forced displacement. All of these changes were accompanied by differential changes in transportation infrastructure and availability, including roads closures, damage and military check points, as well as unavailability of vehicles and fuel. In the absence of reliable data on transportation speeds and inequities we decided to use travel distance in this study.

Since mid-2012 when the situation became recognised as a conflict, the Syrian health system entered a new phase of fragmentation.²⁶ The spread of military operations was accompanied with the establishment of conflict front lines, and utilisation of siege, including withholding of public health services.³ The international and local health response involved an array of UN agencies, INGOs and local organisations, each with different priorities and challenges when it came to establishing health facilities. For example, health facilities in besieged areas were built to prioritise security due to the ongoing military targeting of health facilities.²⁷ Consequently, local health accessibility was not always taken into account when constructing new facilities. Those newly emerging complexities are challenging our intricate understanding of the health system in Syria, in particular the change in health accessibility throughout the conflict.

This study describes the development of the Syrian healthcare system prior to the conflict, focusing on secondary and tertiary care described hereafter as hospital care. We then calculate the preconflict spatial accessibility using the 2SFCA, processing data from 2010. We chose to focus on public hospitals given their major share in the hospital care system prior to the conflict with 70% of total inpatient beds capacity, their role throughout the conflict as a key partner for the international humanitarian sector, and data availability.²⁸ The study aims to establish an understanding of preconflict status of health inequities through the lens of spatial accessibility to hospitals.

The healthcare system in Syria 1946–2011

Before 1946, Syria was under the French mandate. During this period, hospital care was provided by 35 hospitals with a total of 1700 beds. The majority of these hospitals were concentrated in the two main cities, Damascus and Aleppo, and were built by the state; a few were run by European missionaries. Only two hospitals at that time served the whole northeastern region.²⁹

After attainment of national independence in 1945, a period of political chaos including consecutive military coups persisted until 1970 when Hafez Al Assad consolidated his control over Al Baath ruling party that

established a socialist government. By 1984, there were 41 state-run hospitals and 139 private hospitals in Syria. The state hospitals averaged 200 beds each, while the private hospitals averaged only 20 beds each. Although by that time almost each governorate had at least one hospital, the majority of hospitals still remained in the cities of Damascus and Aleppo; both had 23 (56%) of all the state's hospitals, although they comprised 25% of the national population.³⁰

The healthcare system during that period resembled the Semashko model of healthcare delivery used throughout the Soviet Union and Eastern Europe until 1990s.³¹ It was characterised with centralised decision-making and emphasised specialisation of services and inpatient care. Family medicine and primary healthcare (PHC) had minimum roles in provision of healthcare beyond preventive services such as immunisation. People depended mainly on private specialised clinics to receive outpatient care. A referral system did not exist. Health system financing had a complex bureaucratic structure involving multiple institutions such as the ministry of finance.³²

Before and during the conflict PHC is the responsibility of MoH in state-controlled areas. PHC centres are classified into three tiers based on the population in their administrative unit, province, district and village. The lower village tier is supposed to provide basic maternal and child health services while province-level centres are supposed to provide a range of curative and preventive services. The third tier includes hospitals, polyclinics and specialised centres such as TB centres in major towns that provided specialised services such as management of chronic diseases.

Between 2000 and 2010, the healthcare system experienced reforms as part of the government move toward economic liberalisation. This period witnessed an increase in the number of private hospitals (figure 1).

Health services provided by public hospitals are free of charge except in autonomous hospitals that are allowed to charge patients for services at minimal cost, typically much less than the cost in the private sector although with questionable quality. Other major providers of healthcare

in Syria are the ministry of higher education (MoHE) and the ministry of defence (MoD) each operating their own hospitals and outpatient clinics. Other public institutions also run curative outpatient services exclusively for their own cadre.³²

Since 2011 and amid the outbreak of the conflict, both local civil society and international humanitarian actors started to play a key role in providing health services. The systematic targeting of healthcare workers and health facilities, and the cut of public healthcare services led the humanitarian sector to become the sole provider of hospital care in non-state controlled areas.³³

By 2010, MoH was the main provider of hospital care operating 90 hospitals with 13 907 beds which comprised 50% of the total hospitals' beds in Syria available for the public. The largest and the most resourced hospitals were managed by MoHE operating 14 hospitals concentrated in the main cities of Damascus, Aleppo and Latakia. Similar to the US Department of Veterans Affairs, Syrian MoD operated 18 hospitals providing services exclusively to soldiers, veterans and their families. Moreover, the ministry of interior operated two hospitals each in Damascus and Aleppo that exclusively served law enforcement personnel. The private sector operated 376 hospitals contributing to 8962 (32%) of the total number of beds in the country.^{32 34}

METHODS

Study area

Syria is a relatively small country when compared with other countries in the Middle East/North Africa (MENA) region. It is located on the eastern side of the Mediterranean Sea. Before the conflict in 2011, Syria was classified as a lower middle income country with a total population of in 2010 estimated at around 21 409 655 people living on a total area of 183 630 km².^{35 36}

Syria is composed of areas with diverse geographical characteristics. To the west, the coastal region on the Mediterranean is mountainous with a relatively low population density living mostly in small villages and four cities on the coast. Further inland is a plain region with similar population distribution. The eastern region is split by the Euphrates River into the north-east and south-east regions. Compared with the west, the eastern region has less population density that is concentrated in urban centres close to water features. In the south, a mountain range extends down in the south-west which is relatively more developed and heavily populated in comparison with the south-east region. The most populated areas are around the cities of Damascus in the south, and Aleppo in the north. The distinction between high and low populated areas facilitates our intended analysis (figure 2A).

Data

Four datasets were used in this study: namely, hospitals data, road network data, administrative boundaries and population data in Syria (online supplemental table 1).

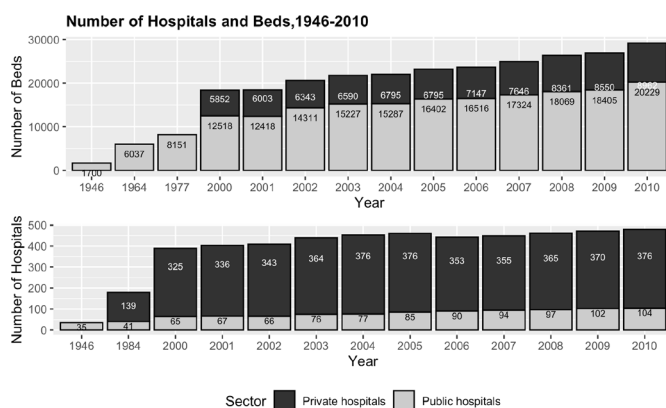


Figure 1 Public and private hospitals and number of beds (1946–2010).

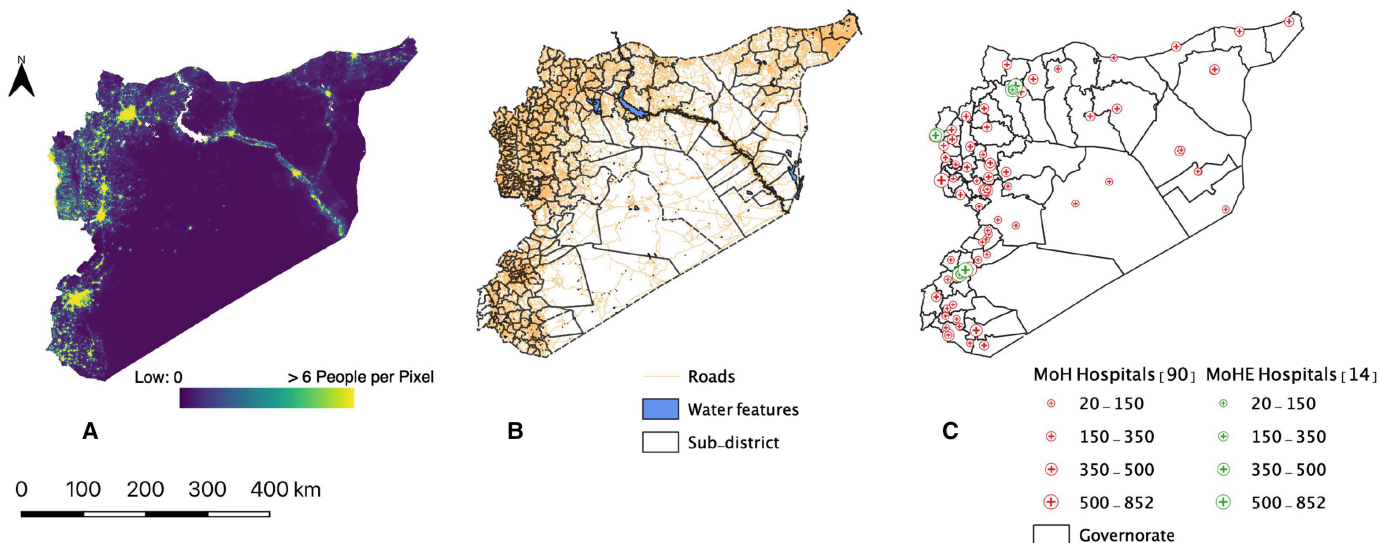


Figure 2 (A) Population distribution in Syria, 2010. (B) Administrative boundaries, road network and water features in Syria, 2010. (C) Distribution of Public hospitals and their number of beds in Syria 2010. Hospitals affiliated with Ministry of Health (MoH) in red and hospitals affiliated with Ministry of Higher Education (MoHE) in green.

We acquired public hospital data from MoH in Syria. Information includes name, street address, and the number of beds³⁴ (online supplemental table 2) Hospitals owned by MoH and MoHE were considered as public hospitals in this study. MoD and the two police hospitals were excluded, given their inaccessibility to the general population and the lack of data about their capacity and location. The analysis was applied to the two resulting groups.

Roads and administrative boundaries datasets were obtained from Open Street Map (OSM) and the United Nations Office for the Coordination of Humanitarian Affairs, respectively. Syria is divided into 14 governorates and 60 districts which are further divided into 272 sub-districts, the latter representing the smallest administrative unit. We used unconstrained gridded population distribution from the WorldPop project, based on the work of Stevens *et al*^{35–37} (figure 2A and B).

Patient and public involvement

We did not include patient or public involvement in the conduction of this study. All datasets were publicly available.

Data preparation

A geographical information systems (GIS) database was compiled using ArcGIS V.10.6.³⁸ Hospitals' locations were geocoded manually and validated by cross-comparison with two voluntary mapping sources, Google maps and OSM. All hospitals are presented as points in a shapefile, including associated attributes like the number of beds (figure 2C)

The population data are a grid of a cell size (resolution) of 100 m by 100 m. Population density per cell represents 2010 estimates derived from the 2004 national census, the latest census before the conflict. We resampled the population grid in ArcGIS by upscaling to a resolution of 2 km

by 2 km, to simplify the analysis and decrease processing time without losing much of the spatial fine-scale of the data. Differences between 100 m and 2 km² resolutions can be found in the supplement (online supplemental table 3). We used travel distance as the impedance to generate hospitals' catchment areas using existing road networks. We assumed that road network data represents the preconflict state of transportation infrastructure in Syria. To the best of our knowledge, no major road construction has been documented since 2011. Furthermore, we have not come across any existing publicly available datasets that have mapped road destruction over the course of the conflict.

Provider-to-population ratio

Measures of spatial accessibility can be classified into four categories. Provider-to-population ratios (PPRs), distance to nearest provider, average distance to a set of providers, and gravitational models of provider influence.^{22 23}

An example of PPRs is hospital beds per 10 000 people where the total number of available beds in a geographic region is divided by total population in that same area. This indicator is one of WHO's 100 core health indicators³⁹ and has been used to evaluate and compare health services availability across and within countries.⁴⁰ PPRs have been used extensively in Syria to monitor health service delivery, the impact of humanitarian funding and attacks on healthcare.⁴¹ To compare between spatial and non-spatial indexes of health access we calculated hospital beds per 10 000 people at the governorate level given the common use of governorate level aggregates in the Syrian context.

The 2SFCA method

An enhancement to PPRs is floating catchment areas (FCAs).²⁴ FCAs that originate from provider and population locations allow the catchment area of each provider

and population to ‘float’ based on the distances between each pair, instead of using fixed boundaries.

The size of the catchment area is predetermined by a choice of reasonably maximum travel impedance, where all the services contained within that threshold are considered accessible to the population, with all other services inaccessible otherwise. In addition to the utilisation of a predetermined catchment area, the foundations for FCAs are rooted in the spatial interaction economic theory which assumes that the benefit expected from the spatial interaction between the supply (healthcare facility) and demand (area of residence) must outweigh the cost of travel between the origin and destination. Therefore, the catchment size in the FCA methods represents a maximum threshold distance, beyond which this interaction cannot be established.⁴²

We implemented the 2SFCA method, a further enhancement to FCA. The 2SFCA consists of two steps as follows:

First step: For each hospital j , search all population grid centroids k that are within travel impedance d_0 from the hospital location j and compute the hospital-to-population ratio R_j within the catchment area:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} P_k} \quad (1)$$

Where P_k is the population within grid k whose centroid falls within the catchment $d_{kj} \leq d_0$, S_j is the number of beds at hospital location j , and d_{kj} is the distance between k and j .

Second step: For each population grid centroid i , search all hospitals locations j that are within the threshold travel impedance d_0 from location i and sum up the hospital-to-population ratios R_j at these locations:

$$A_i^F = \sum_{j \in \{d_{ij} \leq d_0\}} R_j \quad (2)$$

Where A_i^F represents the accessibility at population grid level i based on the two-step FCA method, R_j is the hospital-to-population ratio at hospital location j whose centroid falls within the catchment centred at i (that is, $d_{ij} \leq d_0$, and d_{ij} is the distance between i and j).

A larger value of A_i^F indicates a better accessibility at a population grid. The first step corresponds to the assigning of an initial ratio to each service area centred at hospital locations, and the second step corresponds to summing up the initial ratios in the overlapped service areas where the catchment areas centred around population grid centroid have access to multiple hospital locations.

To compare between aggregated spatial accessibility and hospital beds per 10000 people at the governorate level, we calculated population weighted average spatial access to hospitals within a governorate (a_c)

$$a_c = \frac{\sum_{i \in c} A_i P_i}{\sum_{i \in c} P_i} \quad (3)$$

Where c denotes an individual governorate; A_i is the spatial access to hospitals at location i , calculated from equation (2); and P_i is the population at i .⁴³

We decided to employ the 2SFCA for this study given its established robust use in spatial accessibility studies. Furthermore, we were inclined to develop a systematic way of choosing the parameters of spatial accessibility that take the contextual health inequalities into consideration.

We decided to test variability in 2SFCA scores over different catchment sizes and consequently chose a catchment threshold in the middle of the catchment range that was tested. Choosing different catchments would have affected our results and conclusions. In particular, the Gini index scores would have been higher at lower catchment sizes.

Catchment size variability analysis

There is no definite method to stipulate the catchment size for health facilities. A reasonable catchment size a person is willing to travel to access hospital care may vary according to factors related to the person and factors related to the health service in need.⁴⁴ We applied multiple catchment sizes and examined the distribution of the 2SFCA results over a range of catchment sizes between 5 and 125 km, starting from a potentially walking distance of 5 km then incrementally increasing catchment size by 5 km until 50 km, by 10 km until 90 km, then at a maximum catchment of 125 km. We tested catchment sizes at other values to explicate the variability in the results.

The Gini coefficient

The Gini coefficient is an established method of measuring wealth and health inequality.⁴⁵ It has wide use in spatial health studies.^{46–48} The Gini coefficient output ranges between 0 and 1, where 0 represents perfect equal access between all population locations, while the Gini coefficient of 1 represents perfect inequality between all population locations. Spatial accessibility values of the 2SFCA method at a 2 km by 2 km resolution were calculated at 60 km catchment under StataSE V.15 using `ineqdec0` program.⁴⁹ Gini coefficients were calculated to represent inequality of spatial accessibility within governorates. It was also used to understand the effect of catchment size variability on the inequality in spatial access at the national level.

RESULTS

General description

In 2010, there were 104 public hospitals with 20 305 beds in Syria included in the analysis. The average number of beds per MoH and MoHE hospitals was 165 and 392 respectively with capacity ranged from 20 to 820 bed per hospital.

Governorates varied in area and density of the road network. The smallest governorate is Damascus with 117 km² and had the highest road network density of 15.4 km of roads per km². The largest governorate is Homs with 40 468 km² and had the lowest road density of 0.3 km per km². The summary of population, hospital

Table 1 Characteristics of Governorates

Governorate	Total population (%)	Hospitals	Beds (%)	Area (km ²)	Road density (km per km ²)
Al-Hasakeh	1 527 517 (7)	5	870 (4.3)	23 169	0.8
Aleppo	4 896 890 (23)	13	2727 (13.5)	19 891	1.1
Ar-Raqqa	952 985 (4)	4	610 (3)	17 627	0.6
As-Sweida	373 432 (2)	2	600 (3)	6358	0.7
Damascus	1 806 127 (8)	15	3510 (17.3)	117	14.3
Dar'a	1 036 236 (5)	9	910 (4.5)	3834	1.2
Deir-ez-Zor	1 252 916 (6)	5	655 (3.2)	25 157	0.3
Hama	1 644 291 (8)	7	1459 (7.2)	11 095	0.9
Homs	1 816 797 (8)	13	1740 (8.6)	43 231	0.3
Idleb	1 517 529 (7)	4	696 (3.4)	5416	1.5
Lattakia	1 015 573 (5)	8	2863 (14.2)	2388	1.9
Quneitra	91 029 (0.5)	1	200 (1%)	1718	0.7
Rural Damascus	2 800 986 (13)	13	2455 (12)	26 259	0.5
Tartous	800 339 (4)	5	1010 (5)	1874	1.8
Total	21 532 647	104	20 305 (100)	188 134	

beds, and road network aggregated at the governorate level is provided in [table 1](#).

Hospital service capacity and spatial access

PPR of hospital beds density per population at the governorate level reveals that hospital bed capacity is better in the west and the south than the north and the east. The governorates of Lattakia on the coast and Quneitra in the south had the highest hospital bed capacity at 28.2 and 22 beds per 10 000 people, respectively, while the governorates of Idlib in the northwest and Deir-ez-Zor in the east had the lowest capacity of 4.6 and 5.2 bed per 10 000 people, respectively (online supplemental table 4) and ([figure 3A](#)).

2SFCA analysis

[Figure 3B](#) shows population-weighted average of spatial accessibility estimated by the 2SFCA method at 60 km catchment. Similar to the pattern of hospital beds density per population PPR, the northern and eastern regions have generally low accessibility compared with the western and the southern west regions.

The 2SFCA method provides a finer-scale perspective on spatial access after taking into account population distribution and cross boundary effect at a 2 km by 2 km resolution. The highest accessibility values exist to the west along the coastline, and in the central part of the country. Accessibility in the western and the southwestern regions is more homogeneous and higher than accessibility in the northern and the eastern regions. The central part of the country shows a distinct pattern of very low accessibility in proximity to very high accessibility values.

[Figure 3C](#) shows the distribution of access inequality within governorates using Gini coefficient of 2SFCA scores at 2 km by 2 km population grid. The highest

inequality in accessibility to hospital care was within Deir-ez-Zor (0.72) and Homs (0.7). Damascus had the least inequality (0.04).

Aggregating spatial accessibility values to subdistrict and governorate level masks regional differences, especially in the central region. The central Homs governorate and its eastern subdistricts had high average accessibility although the majority of the region has low access at 2 km by 2 km resolution ([figure 3D–F](#)).

When comparing governorates access rank between the two methods, we find that Quneitra governorate in the southwest decreased from the second to the ninth rank, and Rural Damascus governorate increased from the ninth to the second rank. The remaining governorates had minimal change in their rank between the two indices (online supplemental table 4).

Catchment size variability analysis

[Figure 4](#) shows 2SFCA results at the 2 km by 2 km population grid plotted as inpatient bed per population ratio over the catchment size. The horizontal line represents the arithmetic mean of inpatient bed per population at the national level, which is equal to the total number of inpatient beds divided by the total population. As the catchment size increases, the inpatient bed per population ratio at the 2 km by 2 km population grid fluctuates until it occupies a stable area around the national mean. At the 60 km catchment, 72% of the country area is under the national mean and 30% has no accessibility. Even at 125 km catchment, 65% of the country area is still below the national arithmetic mean and 11% has no accessibility.

[Figure 5](#) shows the SD of 2SFCA results at the 2 km by 2 km population grid. SD generally decreases and fluctuates as the catchment size increases. Increasing the catchment size from 7 to 15 km and from 30 to 50 km resulted

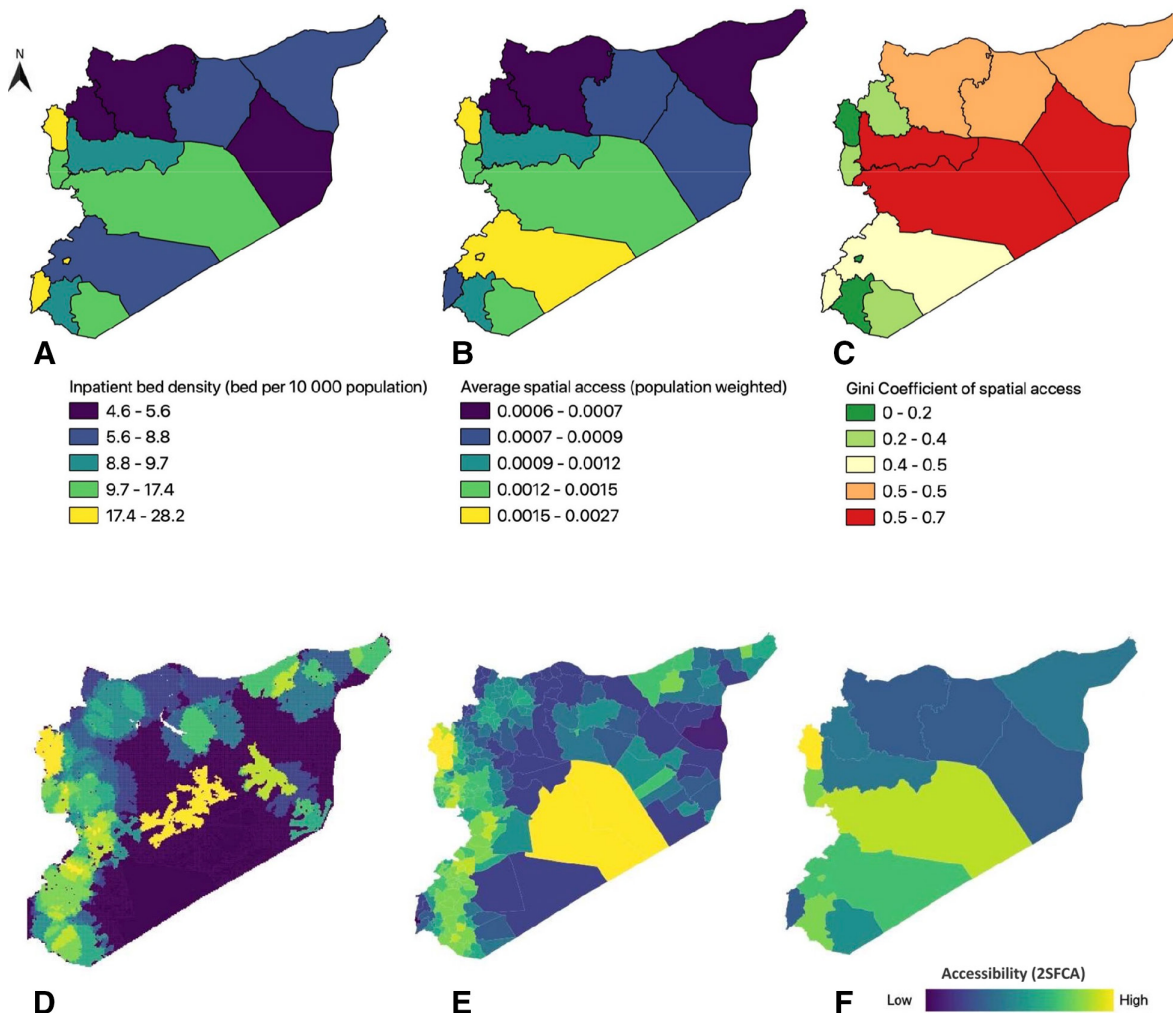


Figure 3 Top row: Quintiles choropleth maps for (A) inpatient bed density (B) spatial accessibility to public hospitals in Syria (2010), population-weighted average (C) Gini coefficient of spatial access to public hospitals within governorate. Bottom row: spatial accessibility to public hospitals at 60 km catchment (D) 2 km by 2 km resolution; (E) arithmetic mean at the subdistrict level; (F) arithmetic mean at the governorate level. 2SFCA, two-step floating catchment area.

in higher variability of 2SFCA values, increasing the SD. In contrast, Gini coefficient shows a strong negative relation with catchment size. It can be explained by the fact that as the catchment size increases, the accessibility scores are harmonised since most hospitals can be reachable to all population, and vice versa.

DISCUSSION

In 2010, prior to the conflict in Syria, lower accessibility to hospital care could be distinguished in the north and eastern regions using spatial accessibility modelling. The 2SFCA method revealed nuanced insights about access inequities across and within Syrian governorates, insights that were not visible when using non-spatial indices such as PPR. Rural Damascus governorate had a wide variation in access rank between PPR and 2SFCA method due to 2SFCA method's ability to account for the cross-boundary effect between Damascus (that has a higher supply of inpatient beds) and the surrounding rural Damascus region encompassed by the 60 km catchment size.

Aggregating accessibility scores using administrative boundaries masked areas with low access. Homs governorate had a high accessibility mainly due to two hospitals located in areas with a low population. At the 2 km by 2 km grid level, swaths of low access areas become evident given the lack of hospitals and population scarcity in the eastern part of Homs governorate.

The four governorates of Damascus, Lattakia, Dar'a and Tartous had the highest equity in accessibility to hospital care as measured by the Gini coefficient given their relatively small area and even distribution of population and hospitals across these governorates. This was not the case for Deir-*ez-Zor*, Homs and Hama, which had a relatively larger area and had a more dispersed population.

Although the results highlight patterns of inequality in accessibility in the preconflict phase, the information presented here provides a chance to discuss health system reform, governance, and resource allocation in fragile and postconflict settings. Identification of areas with lowest accessibility can facilitate prioritisation,

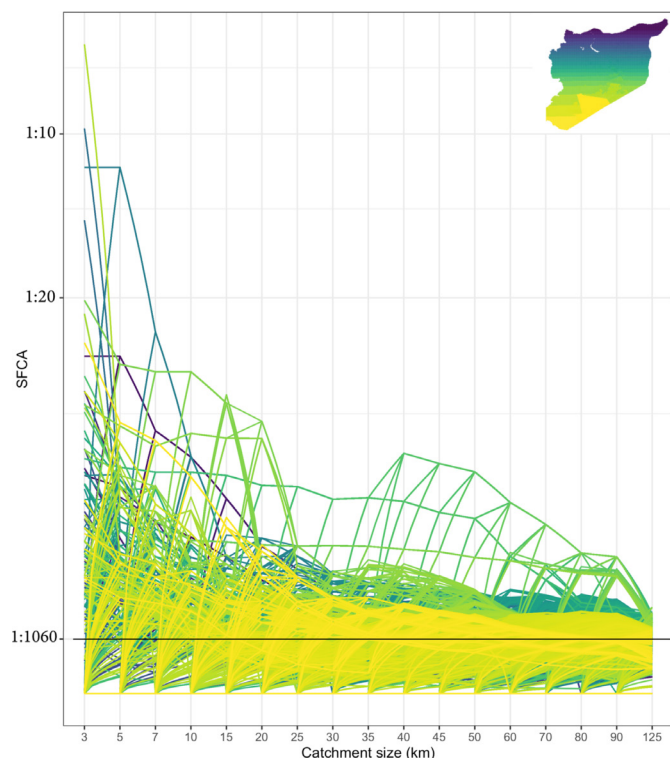


Figure 4 Hospital bed per population ratio using 2SFCA at the 2 km by 2 km population cell as a function of catchment size. Each line represents the change in the 2SFCA accessibility score for a 2 km by 2 km population cell over the change in hospitals catchment size. Most variability occurs at the local scale (<15 km). The horizontal solid line represents the total inpatient bed capacity per population at the national level (1:1060). 2SFCA, two-step floating catchment area.

construction and reconstruction of facilities as needed, in areas with current and preconflict low accessibility.

Reconstruction of Health systems in postconflict settings could risk cementing preconflict and conflict perpetuated inequalities in healthcare accessibility. Unless motivated by restorative justice and human rights, reconstruction policy could end up adding a third layer of health inequalities on top of the preconflict and conflict layers.⁵⁰ Triple burden for health reform in postconflict



Figure 5 (Top) Gini coefficient and (bottom) SD of hospital bed per population ratio using 2SFCA at the 2 km by 2 km population cell as a function of catchment size. Three picks of variability are at 3 km, 15 km and 50 km catchment size. Gini coefficient is showing a perfect negative relation with catchment size. 2SFCA, two-step floating catchment area.

settings has been described in settings such as Uganda where health system reform led to emerging challenges, including rising accessibility inequalities between rural and urban areas.⁵¹

Our analysis can be extended to conflict and post-conflict settings using information on hospitals location, capacity and functioning status, displacement of people, roads status and conflict front lines. Tracking changes in healthcare accessibility over the course of the conflict could offer insights into the consequent impact on health. For example, loss of supplies due to attacks on health facilities, increase of demand due to internal displacement and transportation disruptions due to siege of entire communities.

Testing a range of catchment sizes revealed further insights on accessibility. Some sections in the eastern region remained without access even at 125 km catchment given the road network underdevelopment in those areas. Larger catchment sizes resulted in lower inequality at the national level. Put differently, when the catchment size increases, a higher supply of inpatient beds becomes potentially available over wider area. This phenomenon causes the accessibility score to decrease in relatively high accessibility areas as more population is added to the demand side, and to increase in low accessibility areas as a higher supply of inpatient beds is gained.

Catchments between 7–25 km and 30–60 km exhibited fluctuation in accessibility scores due to the disappearance and emergence of outlier points. This is likely due to the heterogeneous distribution of population. The change in variability in accessibility between 7–25 km catchment may reflect the size of urban centres while the variability change between 30 and 60 km catchment may reflect the distance between towns. Testing access variability over multiple catchments in urban areas with a homogeneous population distribution showed no such fluctuation in variability.⁴⁴

This study faced multiple challenges related to data accuracy. First, to create the master list of preconflict public hospitals, data from old MoH records had to be manually geocoded and cross-checked with publicly available data sources, the latter of which included two additional hospitals. Second, the population dataset used in our paper is the only one available data for Syria¹¹ at the desired high resolution. Furthermore, the population raster dataset contains projected estimates based on the latest census conducted in 2004. These estimates may have introduced uncertainty in population distribution given the internal migration of around 1 million from the northeastern region between 2007 and 2010 due to drought and loss of livelihood.⁵² In addition, this population dataset did not adjust for building footprints, potentially underestimating population in urban areas.⁵³ This in turn may inflate the measures calculated in the step 1 of 2SFCA. Generally, such an issue would result in urban areas having comparatively higher accessibility scores.

Due to its relatively intuitive application, 2SFCA has become a popular method. However, three major

limitations are: (1) It is a binary measure and thus suffers from edge effects (all locations outside of the catchment are assumed to have zero access); (2) It uses fixed catchment sizes that ignore the variation in travel distance, especially between urban and rural areas and (3) It does not consider distance decay within catchments (ie, all locations inside of the catchment are assumed to have equal access).^{54 55} Addressing those limitations in the future could include expanding the sensitivity analysis to include testing multiple population areas sizes with different shapes, and attempting to estimate catchment size using empirical data from health facilities.

Testing different catchment sizes could have been substituted with using travel time as the impedance, instead of distance. However, we chose to use distance given the lack of accurate information on roads speed limit in preconflict Syria. While it may have been possible to estimate walking speed and perhaps the speed of other modes of transportation, we felt that in conflict settings the use of speed limits may not fully reflect the differential access to transportation means to a reasonable degree of significance towards estimating inequalities in accessing hospital care.^{56 57} Extending the analysis into the conflict phase may present notable challenges if there is need to account for differences in access to and means of transportation by population and region.

The objective method of deciding an ideal catchment area is still under debate.²² Such a challenge of measuring spatial accessibility in a region that includes both urban and rural areas similar to Syria has driven the application of new methods such as dividing health supplier catchment depending on town size (smaller towns serve smaller catchment areas).⁵⁸ Among multiple enhancements to the 2SFCA method, Luo and Whippo proposed the Variable 2SFCA (V2SFCA), which adds two more steps to determine the catchment sizes incrementally by increasing the catchment size until a pre-specified base population and PPR criteria are met.^{59 60} We decided to use 2SFCA given its straightforward application and to make the case for comparison between spatially-aware methods and PPRs in a setting where PPRs are the common accessibility indicators.

PPRs have several limitations in their ability to measure spatial patterns in healthcare services. They do not account for movement of people across boundaries to neighbouring areas, which could lead to inaccurate assumptions at the country level. Furthermore, PPRs do not account for distance decay effect on access, thus assuming equal access for all individuals within each geographical boundary. Using PPRs in regression models would lead to Errors-in-Variables bias due to unmeasured variation in spatial access that would weaken the estimated relation between spatial access and the outcome of interest.^{22 42}

CONCLUSION

This study is among the first to quantify the spatial distribution of hospital care in Syria. The preconflict situation depicts what is considered the best status of the Syrian healthcare system before the impacts of attacks on health facilities, among other violations of international humanitarian law. Our results show considerable inequalities in potential access to public hospitals in 2010.

This study investigates the pattern of spatial accessibility of hospital care in Syria in 2011 prior to the current conflict. We describe the development of the health system in Syria between 1946 and 2011 with focus on hospital care. While using non-spatial indices of health system capacity allowed for the comparison at the governorate level, the use of the 2SFCA method revealed nuanced insight about access inequalities across and within Syrian governorates, particularly in the north and eastern regions.

Since 2011, Syria has experienced dramatic upheaval with more than half million dead and over 13 million being displaced inside and outside the country.⁶¹ There is no doubt the conflict has worsened pre-existing inequalities and led to new vulnerabilities.⁶² Analysis of geographical accessibility at different phases of the conflict can inform health system reform, including rebuilding of facilities. Instead of building the health system back to its preconflict status, humanitarian and development agencies could use insights from such analyses to minimise inequalities in health access.

The use of non-spatial indices such as PPRs is common in the Syrian context.⁴ PPRs and preconflict administrative boundaries may obscure dynamic realities of health accessibility in fragile settings characterised by displacement and dominance of INGOs, leaving less significance for administrative boundaries in humanitarian response coordination.¹⁸ This study shows that spatially aware modelling of health access using minimally available data can offer more realistic representation of health access in fragile settings.

Postconflict health system reconstruction should account for pre-existing inequalities. Functioning and equitable health system can have a sustainable impact on population health, state-building and support peace-building efforts in countries suffering from protracted conflicts.⁶³ Preconflict accessibility analysis can enhance our understanding of conflicts' impact on health, and how health inequalities could increase, last or emerge in postconflict settings. Future research is required to assess equity of access during health system rebuilding, and how preconflict access level could be compared with conflict and postconflict levels.

This study reflects the significance of spatial access modelling in understanding preconflict level of health inequalities and offers a space to discuss health access equity in health reform, planning and coordination in fragile settings.

Twitter Mhd Nour Audi @nour__Audi

Acknowledgements MNA is grateful to Brown University for its generous support. KM and GW are grateful to the Population Studies and Training Center at Brown University, which receives funding from the NIH (P2C HD041020), for general support.

Contributors All authors contributed to the design of the study. MNA constructed the spatial dataset, performed the analysis, designed the visualisations and drafted the manuscript. KMM and GW interpreted the results and with MNL critically revised the manuscript. GW supported the coding and analysis. All authors read and approved the final manuscript. MNA acts as guarantor for the final manuscript.

Funding This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors. MNA was supported through the Todd 87 and Christine Fischer Graduate Fellowship in Public Health Fund from Brown University.

Map disclaimer The inclusion of any map (including the depiction of any boundaries therein), or of any geographic or locational reference, does not imply the expression of any opinion whatsoever on the part of BMJ concerning the legal status of any country, territory, jurisdiction or area or of its authorities. Any such expression remains solely that of the relevant source and is not endorsed by BMJ. Maps are provided without any warranty of any kind, either express or implied.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Data are available upon reasonable request.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Mhd Nour Audi <http://orcid.org/0000-0002-8134-108X>

Kevin M Mwenda <http://orcid.org/0000-0002-1709-7350>

Mark N Lurie <http://orcid.org/0000-0002-3153-1715>

REFERENCES

- Ben Taleb Z, Bahelah R, Fouad FM, *et al.* Syria: health in a country undergoing tragic transition. *Int J Public Health* 2015;60:63–72.
- Gr F. Refugees i UHC for. UNHCR - Global Trends 2019: Forced Displacement in 2019 [Internet]. UNHCR Global Trends, 2019. Available: <https://www.unhcr.org/globaltrends2019/> [Accessed 5 Mar 2021].
- Fouad FM, Sparrow A, Tarakji A, *et al.* Health workers and the weaponisation of health care in Syria: a preliminary inquiry for the Lancet-American University of Beirut Commission on Syria. *Lancet* 2017;390:2516–26.
- WHO EMRO | HeRAMS reports | HeRAMS | Syrian Arab Republic [Internet]. Available: <http://www.emro.who.int/syr/information-resources/herams-reports.html> [Accessed 12 Apr 2018].
- A Map of Attacks on Health Care in Syria [Internet]. Available: <http://syriamap.phr.org/#/en> [Accessed 2 Feb 2022].
- Coutts A, McKee M, Stuckler D. The emerging Syrian health crisis. *Lancet* 2013;381:e6–7.
- Mokdad AH, Forouzanfar MH, Daoud F, *et al.* Health in times of uncertainty in the eastern mediterranean region, 1990–2013: a systematic analysis for the global burden of disease study 2013. *Lancet Glob Health* 2016;4:e704–13.
- Ismail SA, Abbara A, Collin SM, *et al.* Communicable disease surveillance and control in the context of conflict and mass displacement in Syria. *Int J Infect Dis* 2016;47:15–22.
- Sharara SL, Kanj SS. War and infectious diseases: challenges of the Syrian civil war. *PLoS Pathog* 2014;10:e1004438.
- Rastam S, Al Ali R, Maziak W, *et al.* Explaining the increase in coronary heart disease mortality in Syria between 1996 and 2006. *BMC Public Health* 2012;12:754.
- Albache N, Al Ali R, Rastam S, *et al.* Epidemiology of type 2 diabetes mellitus in Aleppo, Syria. *J Diabetes* 2010;2:85–91.
- Al Ali R, Mzayek F, Rastam S, *et al.* Forecasting future prevalence of type 2 diabetes mellitus in Syria. *BMC Public Health* 2013;13:507.
- Amara AH, Aljunid SM. Noncommunicable diseases among urban refugees and asylum-seekers in developing countries: a neglected health care need. *Global Health* 2014;10:24.
- Doocy S, Lyles E, Akhu-Zaheya L, *et al.* Health service utilization among Syrian refugees with chronic health conditions in Jordan. *PLoS One* 2016;11:e0150088.
- Alawa J, Zarei P, Khoshnood K. Evaluating the provision of health services and barriers to treatment for chronic diseases among Syrian refugees in turkey: a review of literature and Stakeholder interviews. *Int J Environ Res Public Health* 2019;16. doi:10.3390/ijerph16152660. [Epub ahead of print: 25 07 2019].
- Developing Health Centers and Hospitals Indices for Syria, Based on HeRAMS dataset 2014 [Internet]. WHO, 2015. Available: http://applications.emro.who.int/dsaf/EMROPUB_2017_EN_19363.pdf?ua=1
- Ekzayez A. *Attacks on healthcare in the Syrian conflict* [Internet]. Chatham House, 2021: 41. <https://www.chathamhouse.org/sites/default/files/2021-11/2021-11-23-attacks-on-healthcare-in-syria-ekzayez.pdf>
- Hierink F, Rodrigues N, Muñiz M, *et al.* Modelling geographical accessibility to support disaster response and rehabilitation of a healthcare system: an impact analysis of Cyclones Idai and Kenneth in Mozambique. *BMJ Open* 2020;10:e039138.
- Levesque J-F, Harris MF, Russell G. Patient-centred access to health care: conceptualising access at the interface of health systems and populations. *Int J Equity Health* 2013;12:18.
- Khan AA. An integrated approach to measuring potential spatial access to health care services. *Socioecon Plann Sci* 1992;26:275–87.
- Guagliardo MF. Spatial accessibility of primary care: concepts, methods and challenges. *Int J Health Geogr* 2004;3:3.
- Higgs G. A literature review of the use of GIS-based measures of access to health care services. *Health Serv Outcomes Res Method* 2004;5:119–39.
- Neutens T. Accessibility, equity and health care: review and research directions for transport geographers. *J Transp Geogr* 2015;43:14–27.
- Luo W, Wang F. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B: Planning and Design* 2003;30:865–84.
- Garber K, Fox C, Abdalla M, *et al.* Estimating access to health care in Yemen, a complex humanitarian emergency setting: a descriptive applied geospatial analysis. *Lancet Glob Health* 2020;8:e1435–43.
- ICRC. Syria: ICRC and Syrian Arab Red Crescent maintain aid effort amid increased fighting - ICRC [Internet], 2012. Available: <https://www.icrc.org/en/doc/resources/documents/update/2012/syria-update-2012-07-17.htm> [Accessed 5 Feb 2022].
- Akik C, Semaan A, Shaker-Barbari L, *et al.* Responding to health needs of women, children and adolescents within Syria during conflict: intervention coverage, challenges and adaptations. *Confl Health* 2020;14:37.
- World Health Organization. *Syrian Arab Republic annual report 2018*. Cairo: WHO Regional Office for the Eastern Mediterranean, 2018.
- Commins D, Lesch DW. *Historical dictionary of Syria*. Scarecrow Press, 2013: 521.
- Library of CongressCollelo T. *Syria: a country study*. 3rd ed. Washington, D.C: Federal Research Division, Library of Congress : For sale by the Supt. of Docs., U.S. G.P.O. (Area handbook series), 1988: 334.
- Borowitz M, Atun R. The unfinished journey from Semashko to Bismarck: health reform in central Asia from 1991 to 2006. *Centr Asian Surv* 2006;25:419–40.
- WHO. Health System Profile Syria [Internet]. Online: World Health Organization Regional Office for the Eastern Mediterranean, 2006. Available: <http://apps.who.int/medicinedocs/documents/s17311e/s17311e.pdf>

- 33 Duclos D, Ekzayez A, Ghaddar F, *et al.* Localisation and cross-border assistance to deliver humanitarian health services in North-West Syria: a qualitative inquiry for *The Lancet-AUB* Commission on Syria. *Confl Health* 2019;13:20.
- 34 مرافق صحية [Internet]. Available: <http://www.moh.gov.sy/Default.aspx?tabid=198&language=ar-YE> [Accessed 25 Mar 2019].
- 35 World Bank. The Toll of War: The Economic and Social Consequences of the Conflict in Syria [Internet], 2017. Available: <http://www.worldbank.org/en/country/syria/publication/the-toll-of-war-the-economic-and-social-consequences-of-the-conflict-in-syria>
- 36 Stevens FR, Gaughan AE, Linard C, *et al.* Disaggregating census data for population mapping using random forests with remotely-sensed and ancillary data. *PLoS One* 2015;10:e0107042.
- 37 Worldpop. Syrian Arab Republic 100m Population [Internet]. University of Southampton, 2015. Available: <http://www.worldpop.org.uk/data/summary/?doi=10.5258/SOTON/WP00261> [Accessed 29 Apr 2019].
- 38 ArcGIS Desktop Release 10.6. *Environmental systems research Institute (ESRI)*. Redlands CA, 2018.
- 39 Global Reference List of 100 Core Health Indicators (plus health-related SDGs) [Internet]. World Health Organization, 2018. Available: <https://apps.who.int/iris/bitstream/handle/10665/259951/WHO-HIS-IER-GPM-2018.1-eng.pdf?sequence=1&isAllowed=y> [Accessed 30 May 2020].
- 40 World Health Organization. *Monitoring the building blocks of health systems: a handbook of indicators and their measurement strategies*. Geneva: World Health Organization, 2010: 92.
- 41 HeRAMS. *Bi-Annual report, Public Hospitals in the Syrian Arab Republic* [Internet]. Cairo: WHO Regional Office for the Eastern Mediterranean, 2020. <https://applications.emro.who.int/docs/syrl/EMRLIBSYR258E-eng.pdf?ua=1>
- 42 Chen X, Jia P. A comparative analysis of accessibility measures by the two-step floating catchment area (2SFCA) method. *International Journal of Geographical Information Science* 2019;33:1739–58.
- 43 Pan J, Zhao H, Wang X, *et al.* Assessing spatial access to public and private hospitals in Sichuan, China: the influence of the private sector on the healthcare geography in China. *Soc Sci Med* 2016;170:35–45.
- 44 Luo W. Using a GIS-based floating catchment method to assess areas with shortage of physicians. *Health Place* 2004;10:1–11.
- 45 Van Ourti T, Erreygers G, Clarke P. Measuring Equality and Equity in Health and Health Care. In: *Encyclopedia of Health Economics* [Internet]. Elsevier, 2014: 234–9. <https://linkinghub.elsevier.com/retrieve/pii/B9780123756787002054>
- 46 Wang X, Yang H, Duan Z, *et al.* Spatial accessibility of primary health care in China: a case study in Sichuan Province. *Soc Sci Med* 2018;209:14–24.
- 47 Brown MC. Using gini-style indices to evaluate the spatial patterns of health practitioners: theoretical considerations and an application based on Alberta data. *Soc Sci Med* 1994;38:1243–56.
- 48 Feldacker C, Ennett ST, Speizer I. It's not just who you are but where you live: an exploration of community influences on individual HIV status in rural Malawi. *Soc Sci Med* 2011;72:717–25.
- 49 Jenkins SP. Estimation and interpretation of measures of inequality, poverty, and social welfare using Stata [Internet]. Stata Users Group. (North American Stata Users' Group Meetings 2006). Report No.: 16, 2008. Available: <https://ideas.repec.org/p/boc/asug06/16.html> [Accessed 25 Aug 2019].
- 50 Kruk ME, Freedman LP, Anglin GA, *et al.* Rebuilding health systems to improve health and promote statebuilding in post-conflict countries: a theoretical framework and research agenda. *Soc Sci Med* 2010;70:89–97.
- 51 Macrae J, Zwi AB, Gilson L. A triple burden for health sector reform: 'post'-conflict rehabilitation in Uganda. *Soc Sci Med* 1996;42:1095–108.
- 52 Kelley CP, Mohtadi S, Cane MA, *et al.* Climate change in the fertile Crescent and implications of the recent Syrian drought. *Proc Natl Acad Sci U S A* 2015;112:3241–6.
- 53 Stevens FR, Gaughan AE, Nieves JJ. Comparisons of two global built area land cover datasets in methods to disaggregate human population in eleven countries from the global South. *International Journal of Digital Earth* 2019;0:1–23.
- 54 Luo W, Qi Y. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health Place* 2009;15:1100–7.
- 55 Griffith DA. The boundary value problem in spatial statistical analysis. *J Reg Sci* 1983;23:377–87.
- 56 Mugo NS, Dibley MJ, Damundu EY, *et al.* "The system here isn't on patients' side"- perspectives of women and men on the barriers to accessing and utilizing maternal healthcare services in South Sudan. *BMC Health Serv Res* 2018;18:10.
- 57 Ramadan M, Tappis H, Uribe MV, *et al.* Access to primary healthcare services in Conflict-Affected fragile states: a subnational descriptive analysis of educational and wealth disparities in Cameroon, Democratic Republic of Congo, Mali, and Nigeria. *Int J Equity Health* 2021;20:253.
- 58 McGrail MR, Humphreys JS. The index of rural access: an innovative integrated approach for measuring primary care access. *BMC Health Serv Res* 2009;9:124.
- 59 Luo W, Whippo T. Variable catchment sizes for the two-step floating catchment area (2SFCA) method. *Health Place* 2012;18:789–95.
- 60 Ma L, Luo N, Wan T, *et al.* An improved healthcare accessibility measure considering the temporal dimension and population demand of different ages. *Int J Environ Res Public Health* 2018;15:2421.
- 61 UNHCR Global Trends - Forced displacement in 2020 [Internet]. UNHCR Flagship Reports. Available: <https://www.unhcr.org/flagship-reports/globaltrends/> [Accessed Feb 11 2022].
- 62 Bornemisza O, Ranson MK, Poletti TM, *et al.* Promoting health equity in conflict-affected fragile states. *Soc Sci Med* 2010;70:80–8.
- 63 Martineau T, McPake B, Theobald S, *et al.* Leaving no one behind: lessons on rebuilding health systems in conflict- and crisis-affected states. *BMJ Glob Health* 2017;2:e000327.