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# Access to dialysis services: A systematic mapping review based on geographical information systems

**Benyamin Hoseini,[1,2] Nasser Bagheri,[3] Behzad Kiani,[2] Amirabbas Azizi,[4] Hamed Tabesh,[2] Mahmood Tara[2]**

*[1]Department of Health Information Technology, Neyshabur University of Medical Sciences, Neyshabur, Iran; [2]Department of Medical Informatics, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran; [3]Department of Health Services Research and Policy, College of Health and Medicine, Biology and Environment, Australian National University, Canberra, ACT, Australia; [4]Department of Health Information Technology, School of Allied Health Professions, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran*

Correspondence: Mahmood Tara, Department of Medical Informatics, Faculty of Medicine, Mashhad University of Medical Sciences, Park Square, Mashhad, Iran.
Tel.: +985138002428 - Fax: +985138002445.
E-mail: smtara@gmail.com

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Contributions: NB designed the study; BH searched for the literature. Then, the EndNote X5 (Thomson Reuters, New York, NY, USA) reference management software was applied to aggregate all the search strategy returns. Two reviewers (BH and BK) screened the exported articles in EndNote and compared them with the inclusion and exclusion criteria independently. Any disagreement was resolved by another reviewer (MT), who was also responsible for the supervision of the research. Each study was assessed independently by two reviewers for the eligibility criteria. The full text of the qualified studies was retrieved and saved. The eligible papers were read, tagged and summarized by one reviewer (BH) and then verified by the second reviewer (MT). Quality scores were assigned by two reviewers (BH and AA) and verified by the third reviewer (HT). BH wrote the draft of the paper. BK and BH reviewed the paper and made revisions.

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## Abstract

Equitable access to healthcare services constitutes one of the leading priorities of healthcare provision and *access to dialysis services* (ADS) has an essential impact on patients depending on renal dialysis. The many existing GIS-based ADS evaluations include various spatial and non-spatial factors affecting ADS. We systematically mapped and reviewed the available literature with reference to this area identifying gaps in current GIS-based ADS measurements and developing recommendations for future studies. A three-step, systematic mapping review of the available GIS-related evidence in PubMed, Embase, Web of science, Scopus, Science Direct and IEEE Xplore was performed in May 2016 and the information collected updated October 2017 by two independent selection processes. The quality of the studies was assessed using an informal, mixed-approach scoring system. Out of 1119 literature references identified, 36 were identified and used for final review after removal of duplicates, study screenings and applying inclusion/exclusion criteria. Given the contents of the selected studies, three study groups were identified and 41 factors with potential effects on ADS determined. These studies mainly addressed the potential and/or spatial aspects of ADS. Our systematic mapping review of the evidence revealed that current GIS-based measures of ADS tend to calculate potential ADS instead of a realized one. It was also noted that listed factors affecting ADS were mainly non-spatial bringing forth the hypothesis that designing an integrated ADS index could possibly produce better ADS score than those currently advocated. Some primary and secondary research suggestions are made and a list of recommendations offered.

## Introduction

Although equitable *access to healthcare services* (AHS) is a leading public health priority, the importance of AHS and the attention received from the policy managers differ from one disease to another. *Access to dialysis services* (ADS) is a crucial necessity for patients who have to travel to a dialysis facility three times a week (Mactier, 2007; Stephens *et al.*, 2013). Thus, poorly developed ADS lead to poor health outcomes such as increased morbidity and mortality (Moist *et al.*, 2008; Diamant *et al.*, 2010; Rucker *et al.*, 2011; Thompson *et al.*, 2012).

A vital aspect of AHS is the ease with which they can be accessed and used when needed (McLafferty, 2003). AHS has five main dimensions: accessibility, availability, accommodation, affordability and acceptability (Levesque *et al.*, 2013; Russell *et al.*, 2013; Saurman, 2016). The accessibility and availability dimensions are usually related to geographical factors and are therefore labelled *spatial accessibility* (Mao and Nekorchuk, 2013), while non-geographic-dependent dimensions such as affordability, accommodation and acceptability are considered non-spatial (Guagliardo, 2004). Additionally, AHS can be divided into two broad categories: potential AHS and realized AHS. The former is simply defined as the presence of enabling healthcare, while the latter is the actual use of its services (Andersen, 1995).

*Geographic information systems* (GISs) enable researchers in the healthcare field to apply combined spatial accessibility measures for the inspection of the equitability of resource allocation. Various studies have demonstrated the application of GIS tools which are useful for calculation and visualization of accessibility scores (Guagliardo, 2004; Yang *et al.*, 2006; Matsumoto *et al.*, 2012; Kiani *et al.*, 2017). Stephens *et al.* (2013) performed a GIS-based measure of ADS which included travel impedance to dialysis facilities as an indicator. A recent study performed in Iran by Kiani *et al.* (2017) revealed the importance of spatial accessibility to dialysis services and showed that this variable is strongly underestimated when potential travel time is calculated (Kiani *et al.*, 2017). They developed a comprehensive measure of revealed accessibility that includes travel time and some other spatial and also non-spatial factors into one indicator framework. However, their index does not include facility capacity. Matsumoto *et al.* (2012) designed an algorithm embedded in a GIS-based measure of ADS which demonstrates that patients cannot always be accepted by the nearest dialysis facility due to limited capacity. Another study performed in the US emphasized the acceptability dimension and revealed that dialysis patients may have a short travel time to one dialysis facility but might decide to go to another centre due to ethnic disparity (Saunders *et al.*, 2014). Some studies, mainly conducted in Britain (Roderick *et al.*, 1999; Christie *et al.*, 2005; White *et al.*, 2006; Judge *et al.*, 2012), calculated deprivation as an important ADS indicator which includes some major non-spatial factors. Deprivation can also potentially affect *need of dialysis services* (NDS) (Roderick *et al.*, 1999; Thomas, 2005; Yang *et al.*, 2006; Judge *et al.*, 2012). NDS is defined as the number of patients in an area who need dialysis (Yang *et al.*, 2006).

The diversity of GIS-based ADS measures include various indicators with spatial as well as non-spatial confounding factors that may confuse researchers and policymakers. A mapping exercise could potentially lead to a more conclusive index producing better scores than currently used. GIS-based methods are inherently spatial; some of them, such as the *two-step floating catchment area* (2SFCA), demonstrated the capability of integrating both spatial and non-spatial AHS factors into one framework (Bagheri *et al.*, 2008; McGrail and Humphreys, 2009; McGrail and Humphreys, 2015). Yang *et al.* (2006) provide a 2SFCA platform that integrates only dialysis patients and dialysis machines within a 30-minutes potential travel time catchment. Although this represents a certain progress, to the best of our knowledge, no study so far has made an attempt to develop a truly integrated GIS-based ADS index. In an effort to do so, we decided to focus on the gaps in the current approach to GIS-based ADS measures through a systematic review of the available literature. In addition, we aimed to develop recommendations and a list of factors affecting ADS that would improve the research on the measuring ADS based on GIS.

## Materials and Methods

A systematic mapping review of the available GIS-based literature was performed. It aimed to describe the extent of the study on a particular topic and to identify knowledge gaps in the study base, where further primary and/or secondary studies are needed (Grant and Booth, 2009).

### Search strategy

The scientific literature was explored with regard to relevant communications on ADS and the use of GIS. It was done in May 2016 and the information collected updated in October 2017. We included the following electronic databases: PubMed, Web of Science, Scopus, ScienceDirect, EMBASE and IEEE Xplore. Initially, the databases were systematically searched using a variation of access concept (access, accessibility, availability, affordability, acceptability, accommodation, utilization, deprivation, disparity and equity) in connection with spatial terms (geographic information, GIS, geomapping, location-allocation, and spatial analysis) and dialysis (dialysis, haemodialysis, renal and kidney). To combine the search terms within each category, we utilized the disjunction *OR*, and to combine categories we utilized the conjunction *AND*.

In order to identify additional relevant information related to ADS and GIS, the reference lists obtained were surveyed manually. To boost our search strategy further, we also looked for the so called gray literature, *i.e.* reports, standards, manuals and guidelines on the topic using general search engines such as Google. No date or study design limitation was imposed in any of the research steps described. The complete search strategy is available upon request.

### Eligibility criteria

After the literature search had been completed, the EndNote X5 (Thomson Reuters, New York, NY, USA) reference management software was applied to aggregate all search returns. The articles were then screened and each study assessed independently for eligibility by two of the authors in different combinations. A study was considered eligible for inclusion if it included assessment of ADS as the primary or secondary outcome, while it was excluded if i) it had not clearly reported and calculated ADS indicators; ii) it lacked a methodological description of the measurement of ADS or its indicators; or iii) it consisted of a letter to the editor, an editorial, general comments, a position paper or it was an unstructured paper.

The full text of the qualified studies was read, tagged and summarized by one author and verified by one other author. A brief flow diagram of the strategy is depicted in Figure 1.

### Data extraction

Studies deemed eligible for review underwent data extraction. For each paper, essential data items related to ADS measurement were extracted and fitted into a form with a choice of headings, such as ADS indicator; Factor(s) affecting the indicator; Method of measurement; Primary outcome measures; Secondary outcome measures; and Study design. Additional properties, such as conclusive comments and suggested measurement intervals, were also recorded when available and applicable.

## Quality assessment

Since systematic mapping reviews mainly aim to describe the state of the art of a particular topic, it is desirable to include communication types of a range as wide as possible. Due to the high diversity of study types in our review, this necessitated an informal quality assessment that was performed by classifying the literature by type of study. We used a mixed-approach scoring system as applied by Azizi *et al.* (2016) under similar circumstances (Azizi *et al.*, 2016). Quality scores were assigned by two authors and verified by a third author. The weight of the literature was assigned according to their study design by the quality scoring system. In this approach, papers such as reviews and *randomized controlled trials* (RCTs) achieved the highest score (score 4) while score one was the lowest score. In this approach, the gray literature was given score one as formal or expert consensus regarding quality score. The summary of the quality assessment approach is outlined in Table 1.

## Data analysis

Following mapping review methods, a tabular method for the synthesis of qualitative research findings was used. Also, the quantity and quality of the literature were characterized by study design and other key features, and need for some primary or secondary research was identified.

# Results

Out of 1119 literature items collected, 76 were deemed eligible for further full-text review. After reviewing the full-text studies for final content match, 36 were selected for the review. Further details pertaining to the included studies are shown in Figure 1.

## Characteristics of included studies

Three groups of studies were identified. The first group included eight cross-sectional studies addressing ADS and treating it as a primary outcome. The focus of these communications was the design of a GIS-based model intended for gauging the degree of ADS. They mostly calculated potential travel time (Roderick *et al.*, 1999; Christie *et al.*, 2005; White *et al.*, 2006; Yang *et al.*, 2006; Judge *et al.*, 2012; Matsumoto *et al.*, 2012; Stephens *et al.*, 2013) or facility capacity (White *et al.*, 2006; Yang *et al.*, 2006; Matsumoto *et al.*, 2012) as the key indicators of spatial accessibility. Some papers in this group also considered deprivation (Roderick *et al.*, 1999; Christie *et al.*, 2005; White *et al.*, 2006; Judge *et al.*, 2012) as an important, non-spatial indicator of ADS. One study designed a measure to calculate actual travel time revealed significant effects on the travel time of other non-spatial factors such as sex, income level, caregivers, transportation mode, education level, ethnicity and personal vehicle ownership. It demonstrated the large gap between potential travel time and actual travel time (Kiani *et al.*, 2017). Another study showed that ignoring facility capacity and accounting only for travel time when evaluating ADS may result in misleading conclusions (Matsumoto *et al.*, 2012). Further details pertaining to this group are outlined in Table 2.

The second group of studies (10 peer-reviewed papers) considered gauging ADS as a secondary outcome, while their primary outcome measures focused on the association between ADS and health-related outcomes (Tonelli *et al.*, 2007; Moist *et al.*, 2008; Diamant *et al.*, 2010; Rucker *et al.*, 2011; Thompson *et al.*, 2012; Miller *et al.*, 2014) determining the relationship between ADS and prevalence rates of dialysis patients (Kashima *et al.*, 2012) or designing models to locate dialysis facilities (Ayyalasomayajula *et al.*, 2011; Salgado *et al.*, 2011; Faruque *et al.*, 2012). Almost all of them calculated potential travel impedance as an indicator of ADS based on GIS.

Finally, the third group of 16 studies considered factors affecting ADS. Among them, were ten peer-reviewed articles (Smith *et al.*, 1985; Tonelli *et al.*, 2006; Hall *et al.*, 2008; Prakash *et al.*, 2010; Matsumoto *et al.*, 2013; Omrani-Khoo *et al.*, 2013; Rodriguez *et al.*, 2013; Plantinga *et al.*, 2014; Saunders *et al.*, 2014; Kiani *et al.*, 2017), one case series (Tshamba *et al.*, 2014), one proceeding (Richard *et al.*, 2009), and four gray literature items (Maheswaran *et al.*, 2003; Mactier, 2007; Levinson, 2011; Amy Martin, 2013).

Considering the contents of the total number of GIS-based studies discussed here and the literature extracted from their comprehensive reference lists, 41 factors affecting ADS were determined (Table 3). Travel impedance, especially travel time, were the main indicators of spatial accessibility, the rest were mostly non-spatial. Some studies emphasize that factors such as ethnicity or the patient's health insurance status also affect ADS (Kashima *et al.*, 2012; Thompson *et al.*, 2012; Saunders *et al.*, 2014), while other studies imply that they do not affect ADS (White *et al.*, 2006; Matsumoto *et al.*, 2012). The factors we found in our literature search and their frequency are given in Table 3.

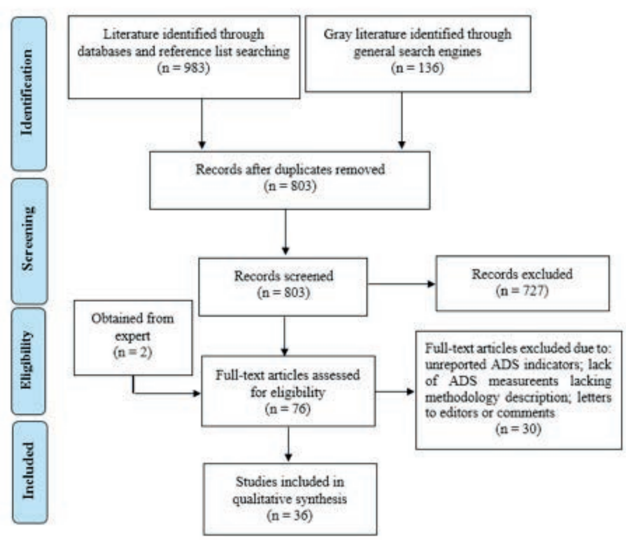


**Figure 1. PRISMA Flowchart of included and excluded studies.**

**Table 1. Classification according to evidence quality.**

| Type of evidence | Score |
|---|---|
| RCT*, meta-analysis, systematic review | 4 |
| Case-control, cohort studies, quasy-experimental studies | 3 |
| Observational studies (case reports, case series) | 2 |
| Formal/expert consensus | 1 |

*Randomized controlled trial.

## Discussion

Our systematic mapping review of the evidence revealed that current GIS-based measures of ADS tend to calculate potential ADS instead of a realized one (Table 2). Also, we found no study including both spatial and non-spatial dimensions of ADS into one framework that could produce a more realistic score than current attempts in this direction. However, in a recent study performed in Iran, Kiani *et al.* (2017) developed an integrated measure of ADS by calculating a reasonable measure of actual travel time in contrast to previous reports that mainly focus on estimated potential

**Table 2. List of studies aiming at a GIS-based measure of access to dialysis service (ADS): an extraction table.**

| Reference, country | Setting and study participant | Method employed | Indicators discussed | Component | Comment |
|---|---|---|---|---|---|
| Roderick *et al.*, 1999 England, UK | Renal facilities Number of patients: 5,715 | Multilevel modelling using Poisson regression based on patient postcodes matched to each census ward Dependent variable: the number of accepted patients (used as access indicator) Independent effects modelled: 1) age and sex; 2) census ward need factors and supply factors; and 3) district health authority level effects | Travel impedance Service availability Jarman index[a] Townsend index[b] Carstairs index[c] DoE Index[d] | Spatial accessibility Deprivation | All deprivation indices integrated as a customized index for best representing the deprivation component Emphasis on deprivation as the key indicator of both ADS[e] and NDS[f] but authors did not incorporate the components into one ADS[e] framework Emphasis on impact of diabetes, hypertension and socio-economic factors on NDS[f] but authors did not incorporate them in the model Paper implies that age and gender affect ADSe and ND[Sf] and matches ADSe indicators for these factors |
| Christie *et al.*, 2005 Wales, UK | Patient registers and main and satellite dialysis facilities Population: 2.4 million Number of patients: 1,514 | Calculated a fifth of small area deprivation using the Townsend index, three bands of travel time using GIS[g], RRT[h] prevalence, and comparing patients and population accessibility between catchments, and presenting estimates of RRTh prevalence in the population by a fifth of small area deprivation | Travel time, Townsend index | Spatial accessibility Deprivation | Travel time calculated as an indicator of spatial accessibility and deprivation calculated to compare RRTh prevalence between areas. The components were not incorporated into one ADSe framework Potential travel time calculated instead of actual travel time, and estimates of RRT[h] prevalence were lower in more deprived areas |
| White *et al.*, 2006 Wales, UK Wales | Main dialysis facilities Population: 2.9 million Number of patients: 2,173 (RRT[h]), 821 (HD[j]), 342 (PDk) | UK Renal Registry, Welsh population census data and WIMD[i] 2005 analyzed using GIS[g] patient location; dialysis facilities geocoded and travel time calculated. Facility capacity calculated using the number of dialysis consoles assuming two shifts of dialysis per day and each patient received thrice a week. Linear regression analysis of data based on a 7% increase in the number of dialysis patients per year | Travel time, Facility capacity, WIMD[i] | Spatial accessibility Deprivation | Travel time and facility capacity calculated as indicators of spatial accessibility separately, and the WIMD[i] calculated to compare catchments prevalence It was estimated there would be 1,400 patients on haemodialysis in Wales by 2014 Emphasis on contributing factors led to some socioeconomic f actors being addressed in the WIMD[i] but some others, such as age, were not addressed |
| Yang *et al.*, 2006 USA | Dialysis facilities (44), census block data and dialysis consoles (867) Number of patients: 3,722 | Two GISg-based methods, 2SFCA[l] and kernel density applied considering the number of dialysis consoles in each dialysis facility as the supply and the number of patients as the demand with a 30-minute threshold for travel time. Demand estimate based on the population in each census tract multiplied by 0.12% | Travel time, Facility capacity | Spatial accessibility | Both methods integrated two indicators to calculate spatial accessibility. The implied revealed need most likely the same as the potential need when analyzing current ADS[e]. The study implied that diabetes, hypertension, age, gender and race may influence the ND[f]S but this variable was not adjusted for them |

To be continued on the next page.

travel time (Christie *et al.*, 2005; White *et al.*, 2006; Yang *et al.*, 2006; Judge *et al.*, 2012; Matsumoto *et al.*, 2012; Stephens *et al.*, 2013) However, the results are still far from a truly realized ADS index since the key ADS indicator of facility capacity generally remains ignored.

Matsumoto *et al.* (2012) compared two GIS-based ADS measures, the capacity-distance model and the distance model, and found the former to be more realistic than the latter. In the capacity-distance model, which addresses both travel time and facility capacity, patients were forced to travel further due to capacity limitations at closer centres. Furthermore, an American study noted that proximity to dialysis services does not directly translate into

**Table 2. Continued from previous page.**

| Reference, country | Setting and study participant | Method employed | Indicators discussed | Component | Comment |
|---|---|---|---|---|---|
| Matsumoto<br>*et al.,*<br>2012<br>Japan | Dialysis facilities (98)<br>Number of patients: 7,374 | Travel time calculated by GIS[g] in two models: the distance model (travel time to nearest facility) and the capacity-distance model (both travel time and facility capacity).<br>The latter allowed facilities to accept the nearest patient (based on travel time) until capacity is full and then remit patients to the second-nearest facility run through facilities until all patients are accepted | Travel time, Facility capacity | Spatial accessibility | The distance model addresses only travel time to calculate spatial accessibility, while the capacity-distance model uses two ADS[e] indicators jointly to calculate spatial accessibility<br>Potential travel time calculated instead of real travel time;<br>no model considering non-spatial factors indicating a potential gap between calculated accessibility and real access, which is more than just the equity of travel time |
| Judge<br>*et al.,*<br>2012<br>UK | Renal Registry and England, UK local authority districts (354) | Multilevel Poisson regression models constructed separately for incidence and prevalence.<br>Travel times and dialysis facilities catchment areas estimated by GIS[g];<br>small area estimates of RRT[h] prevalence produced for all 354 local districts. | Travel time, IMDm | Spatial accessibility<br>Deprivation | Components not integrated into one ADS[e] framework Deprivation adjusted for socio-demographic differences but without adjusting is directly relative to NDS[f]<br>Potential travel time calculated instead of real travel time |
| Stephens<br>*et al.,*<br>2013<br>USA | Centers for Medicare and Medicaid services (5,007)<br>Number of patients: 332,117 | Three data points estimated:<br>(1) patients' location;<br>(2) location of dialysis facility currently serving patient;<br>and (3) location of replacement facility. GIS[g]-based calculation of travel impedance between them<br>Included calculations:<br>1. Travel impedance from patient location to current facility;<br>2. Travel impedance from patient location to replacement facility;<br>3. Incremental travel impedance for travel to replacement facility compared with travel to current facility | Travel time | Spatial accessibility | Actual data not obtained from each patient's original dialysis facility.<br>As it was assumed that patients utilize the closest location, potential accessibility was calculated<br>Indication that facility capacity is a key indicator of spatial accessibility to dialysis facilities,<br>but calculation of spatial accessibility not integrated with travel time.<br>Non-spatial factors emphasized although not integrated with the spatial accessibility component to calculate a more realistic ADSe |
| Kiani<br>*et al.,*<br>2017<br>Iran | Dialysis facilities (6)<br>Number of patients: 168 | Data for AAT[n] and other spatial or non-spatial variables gathered via a semi-structured questionnaire for patients.<br>Univariate analysis and univariate general linear model used to identify AAT[n] associated factors<br>Driving time and distance calculated using Google maps;<br>AAT of rural and urban analyzed separately | Travel impedance | Realized spatial accessibility | Non-spatial factors (sex, income level, caregivers, transportation mode, education level, ethnicity and personal vehicle ownership) influenced the revealed access identified in rural and urban groups but spatial factors were identified only in the former<br>AAT[n] calculated but some other important ADS[e] indicators such as facility capacity was ignored |

[a]A scoring system developed by the British general practitioner Brian Jarman (b. 1933) for the level of social deprivation; [b]a measure of material deprivation within a population; [c]an index of deprivation used in spatial epidemiology to identify socio-economic confounding; [d]an index of urban poverty published by the UK Department for Environment, Food and Rural Affairs designed to assess relative levels of deprivation in local authorities; [e]Access to dialysis services; [f]Need of dialysis services; [g]Geographical information systems; [h]Renal replacement therapy; [i]Welsh index of multiple deprivation; [j]Hemodialysis; kPeritoneal dialysis; lTwo-step floating catchment area; mIndex of multiple deprivation; [n]AAT actual access time.

access owing to potential racial segregation (Saunders *et al.*, 2014). However, both these studies calculated potential travel time. Meanwhile, many British studies (Roderick *et al.*, 1999; Christie *et al.*, 2005; White *et al.*, 2006; Judge *et al.*, 2012) emphasize the importance of non-spatial factors, *e.g.*, Kiani's *et al.* study (2017), considering deprivation as one of the main ADS indicators. Indeed, controversies in this field show a gap between calculated and real ADS. Although this study did not find any research integrating spatial and non-spatial factors into a GIS-embedded model for measuring ADS, various GIS-oriented studies join some spatial ADS indicators together to measure spatial accessibility (Yang *et al.*, 2006; Matsumoto *et al.*, 2012). For instance, Yang *et al.* compared two GIS-based methods, the 2SFCA approach and the kernel density method, in a case study on renal dialysis facilities in Chicago, USA. In this study, based on the main spatial ADS indicators travel time and facility capacity, the 2SFCA method produced better accessibility ratios overall (Yang *et al.*, 2006). Although, this work only integrated spatial ADS dimensions, it has provided a platform that has been successfully used in other contexts, especially in primary healthcare where an overall measure including both spatial and non-spatial factors of access is included (Wang and Luo, 2005; Bagheri *et al.*, 2008; McGrail and Humphreys, 2009; McGrail and Humphreys, 2015). For example, Bagheri *et al.* (2008) developed an integrated *access to primary healthcare* (APH) index which combined spatial accessibility, calculated by 2SFCA method, and a need index into one framework, while McGrail and Humphreys (2009, 2015) improved the 2SFCA method by introducing a concept based on three key components, *i.e.* spatial accessibility, population health needs and mobility.

The progress covered by this review, as well as the gaps revealed, raises the hypothesis that *an integrated ADS index should calculate access more realistically than current GIS-based measures*. However, further research examining whether this hypothesis is correct or not is needed. This mapping review provides some evidence-based recommendations that may help researchers and policymakers perform a primary study assessing this hypothesis. Three components of the 2SFCA platform should be addressed in order to construct an integrated ADS index, *i.e.* spatial accessibility, mobility and NDS.

Spatial accessibility must take into account both accessibility and availability. Travel time, discussed by most current studies, should be calculated as an indicator of accessibility with a threshold of 30 minutes as haemodialysis guidelines recommended (Mactier, 2007). However, actual travel time as proposed by Kiani *et al.* (Kiani *et al.*, 2017) should be used together with facility capacity, expressed as the number of dialysis machines (supply) to the number of patients (demand) in each facility (Yang *et al.*, 2006; Matsumoto *et al.*, 2012) that seems to be the key availability indicator. It is as important as the travel time and should be incorporated into the 2SFCA framework with an appropriate threshold to construct catchment areas more realistically. Patients need dialysis thrice a week according to current haemodialysis guidelines (Mactier, 2007), which means that each machine can serve up to four patients per week (two patients on even days and two patients on odd days) leading to a supply-to-demand ratio threshold of ¼. If, regardless of this threshold, all catchments are constructed with a radius of 30 minutes travel time, some of them might include patients more than their facility capacity.

Mobility is defined as the population's ability to overcome distance (Bisht *et al.*, 2010). Taking the relative population size of those aged either <18 years or >75 years as the measure of reduced personal mobility, McGrail *et al.* (McGrail and Humphreys, 2009)



**Table 3. Factors affecting access to dialysis services elicited from literature.**

| Factors/Variables | Rate | Factors/Variables | Rate |
|---|---|---|---|
| Patient age | 14 | Population density | 2 |
| Patient gender | 11 | Province need | 2 |
| Patient ethnicity | 13 | Nephrology beds | 3 |
| Patient's education status | 6 | Location of the patient's nephrologist | 1 |
| Marital status | 1 | Patient's familiarity with facility | 1 |
| Patient's income | 9 | Routine procedures at the facility | 1 |
| Patient's employment status | 5 | Availability of transportation | 3 |
| Patient's disability | 1 | Car ownership | 23 |
| Patient mobility | 4 | Road quality linking home and facility | 4 |
| Patient's comorbidities | 1 | Transportation mode | 3 |
| Patient's health insurance status | 7 | Travel cost | 17 |
| Home owner | 1 | Travel speed | 1 |
| Socioeconomic status of neighbourhood | 1 | Travel time | 3 |
| Location of dialysis patient's residence | 12 | Travel distance | 1 |
| Language status | 1 | Time of the day for dilalysis visit | 1 |
| Number of dialysis facilities | 2 | Degree of family support | 3 |
| Facility type (satellite or in-center) | 4 | Public assistance | 1 |
| Dialysis type needed* | 2 | Availability of human resources | 1 |
| Facility capacity | 10 | Deprivation | 10 |
| Number of dialysis consoles per facility | 9 | Climate conditions | 1 |
| Cost of care | 2 | | |

*haemodialysis (HD) or peritoneal dialysis (PD).

point out that the three indicators, *i.e.* households without a car, individuals with reduced mobility and public transport availability, measure different aspects of mobility and that correlations between them are small. Considering this nature of mobility, it seems useful to apply these three indicators when calculating mobility in the ADS context.

Revealed NDS (the actual demand) is most likely to be the same as the potential NDS when the current ADS is calculated (Yang *et al.*, 2006), but future ADS calculations will differ because the number of patients then is unclear, in particular as the prevalence of end-stage renal disease (ESRD) is increasing (Chadban *et al.*, 2003; Eggers, 2011). An easy way to estimate NDS is by multiplying the annual growth rate of demand at current demand (White *et al.*, 2006; Yang *et al.*, 2006). But an adjustment is needed if there is an increase in diabetes which is already anticipated (Roderick *et al.*, 1999; Yang *et al.*, 2006) and hypertension (Roderick *et al.*, 1999; Yang *et al.*, 2006), the two principal causes of ESRD. In addition, deprivation (Roderick *et al.*, 1999; Thomas, 2005; Judge *et al.*, 2012), age (Roderick *et al.*, 1999; Thomas, 2005), gender (Roderick *et al.*, 1999; Yang *et al.*, 2006) and ethnicity (Roderick *et al.*, 1996; Judge *et al.*, 2012) may influence the NDS differently in the future.

To our knowledge, this is the first systematic mapping review of the available literature aimed at identifying gaps in current GIS-based ADS measures and developing evidence-based recommendations. However, by limiting the search strategy by specifying it for the GIS category and developing a list of factors affecting ADS elicited, we may have lost evidence in studies exclusively focused on exploring factors affecting ADS. This would be true, even though we had a comprehensive list referencing the literature elicited from our systematic mapping review. However, this was secondary outcome measure of the study, and we suggest a systematic review with a wider scope that could list all factors affecting ADF. Although we did not systematically focus on seeking factors affecting NDS, we think that our findings related to estimating NDS are appropriate and enough. Moreover, we found that hospitalization rate (Rucker *et al.*, 2011) and mortality rate (Rucker *et al.*, 2011; Thompson *et al.*, 2012) are negatively associated with ADS, facts that can be used for validation of the integrated index of ADS, a proper validation of this index remains open for future study. Finally, even though we highlighted the absence of evidence-based recommendations incorporating indicators related to the acceptability dimension in an integrated ADS index, we could not alleviate this weakness of current GIS-based measures of ADS, which needs further research.

## Conclusions

Current GIS-based measures of ADS tend to calculate potential ADS instead of a realized one and there is a need to examine whether an integrated index of ADS can calculate a realistic score. Listed factors affecting ADS are mainly non-spatial encouraging the design of an integrated ADS index produce better ADS score than those currently advocated. The mapping review strongly suggests exploring the hypothesis that a combined index of ADS including most dimensions of ADS can be developed and produce a better ADS score than current available. The 2SFCA method may be capable of providing a platform for this aim as the study recommended and researchers and policymakers are encouraged to examine and validate this hypothesis.

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