ESC European Society of Cardiology

European Journal of Cardiovascular Nursing (2023) **22**, 832–840
https://doi.org/10.1093/eurjcn/zvad086

Methods Corner

Spatial methods for measuring access to health care

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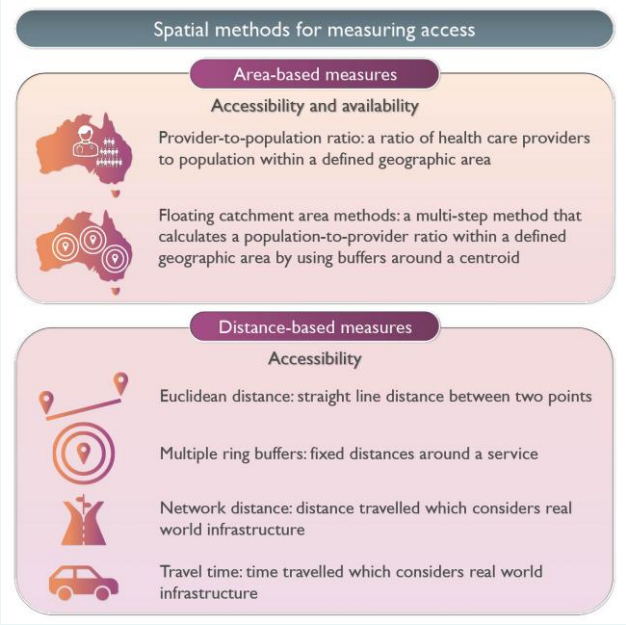
Received 10 August 2023; accepted 11 August 2023; published 17 August 2023

Access to health care is a universal human right and key indicator of health system performance. Spatial access encompasses geographic factors mediating with the accessibility and availability of health services. Equity of health service access is a global issue, which includes access to the specialized nursing workforce. Nursing research applying spatial methods is in its infancy. Given the use of spatial methods in health research is a rapidly developing field, it is timely to provide guidance to inspire greater application in cardiovascular research. Therefore, the objective of this methods paper is to provide an overview of spatial analysis methods to measure the accessibility and availability of health services, when to consider applying spatial methods, and steps to consider for application in cardiovascular nursing research.

Central Illustration



Keywords Access • Geographic information systems • Health service accessibility • Spatial analysis

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Learning objectives

- Understand spatial methods to measuring access in health research.
- Identify opportunities for the application of spatial methods in research.
- Understand the steps to consider when applying spatial methods in research.

Introduction

As an indicator of health-care system performance and equitable provision of care, access to health care comprises spatial and aspatial dimensions which reside at the intersection of consumers and health services.[1,2] Expanding on Penchansky and Thomas' (1981) definition of the dimensions of access (*Table 1*), aspatial access includes affordability (e.g. cost of health care), acceptability (e.g. attitudes towards services), and accommodation (e.g. how services are organized).[1,3,4] There are other aspatial dimensions of access that have since been added, including awareness and timeliness.[5,6] Spatial access encompasses geographic factors affecting the accessibility (e.g. proximity of services to consumers) and availability (e.g. location and capacity of services) of health services.[1,3–5] Thus, spatial methods for measuring access consider the geographical distribution and characteristics of services and consumers and how this relates to the ability for consumers to obtain the services they need (i.e. potential access) or continue using services (i.e. realized access).[5] The objective of this methods paper is to provide an overview of spatial analysis methods to measure accessibility and availability, when to apply spatial methods, and steps to consider for application in cardiovascular disease nursing research.

Nursing research applying spatial methods to measure the accessibility and availability of health services is in its infancy when compared with other disciplines, such as public health. A systematic review of Australian evidence[7] retrieved one study which analysed the spatial distribution of mental health nurses using the Accessibility/Remoteness Index of Australia (ARIA+) Remoteness Areas and identified an inequitable distribution across rural and remote communities.[8] This same review identified 22 articles that examined access to dental services, 16 articles that examined access to general practice services, and 4 articles that examined access to cardiac services which included both specialist and nursing care.[7] Internationally, there is evidence of nurse-led ecological research applying geospatial methods in the community health and public health setting, which supports the potential for a greater application of spatial methods in nursing research.[9] Given the application of spatial methods in health research is a rapidly developing field alongside the increased availability of geospatial data sources[9,10] and health geography more broadly,[11] it is timely to provide guidance to encourage greater application in cardiovascular disease nursing research.

Table 1 Spatial and aspatial dimensions of access spatial dimensions

Spatial dimensions	Aspatial dimensions
Accessibility: proximity of services to consumers with consideration of travel distance and time	**Affordability:** cost of health care for service providers and consumers
Availability: location and capacity of services to meet consumer and community demand	**Acceptability:** attitudes towards services from a provider and consumer perspective
	Accommodation: how services are organized and structured
	Awareness: communication about services between providers, consumers, and communities
	Timeliness: ability for service to be provided to consumers when required

Spatial methods to measure accessibility and availability

There is a range of spatial analysis methods that can be applied in cardiovascular nursing research to examine accessibility and availability (Central Illustration). Examples of spatial methods are presented in *Table 2* and are grouped by area-based measures and distance-based measures. Application is largely determined by the research scope, objectives, and available data sources.

Area-based measures examine the characteristics and relationships of health services and populations at an aggregate level within a defined geographical area and generally consider both accessibility and availability of services.[7] A defined geographical area may be a postcode/ZIP code, state/territory/county/province, or another region as defined by government census data, policy, or health service catchments. Two commonly applied spatial methods to measure access at an area level include the provider-to-population ratio and floating catchment area, of which there are multiple variations that account for distance decay (i.e. with increasing distance, there is a decline in spatial interactions) and travel time.[12] A limitation to applying area-based measures is they are often subject to spatial biases, such as the Modifiable Areal Unit Problem (MAUP) (i.e. how the spatial scale applied will influence findings) and ecological fallacy (i.e. incorrect inference between spatial scales). This means the results of an area-based approach will depend on the geographical boundaries used in the spatial analysis.[18] For example, the geographical boundaries defined by an administrative data set will yield different findings to an area-based approach using state, province, or county geographical boundaries.

There are a variety of distance-based measures that are commonly applied to measure health service accessibility. These include Euclidean distance (i.e. linear distance between two points), multiple ring buffers (i.e. rings at specified distances around a point of interest), network distance (e.g. distance travelled on a road network), and travel time.[7,15] A review of Australian research identified that distance-based measures, such as modelled travel distance or time along a road network, were more commonly used to measure accessibility in health research when compared with area-based measures.[7]

Applying distance-based measures requires making assumptions about populations including vehicles and driving characteristics and local traffic conditions and that populations travel the shortest route.[15] More complex spatial modelling can be used to examine spatial accessibility with consideration of different travel speeds, travel modes, and times (e.g. day and night time). For example, Rauch *et al.*[19] modelled the accessibility of stroke centres in the district of Münster, Germany, with consideration of the different locations of day and night time populations and the effect of different traffic conditions (e.g. speed limits and congestion of major roads), and identified that these variables mediated with service accessibility. Other environmental factors, such

Table 2 Spatial analysis methods to measure dimensions of accessibility and availability

Spatial access dimensions	Spatial analysis method	Description	Considerations for application
Accessibility and availability	**Area-based measures** • Provider-to-population ratio[12] • Floating catchment area method (e.g. two-step floating catchment area method which combines multiple variables into an index and three-step floating catchment area method which includes the addition of travel time weights)[12,13]	• A ratio of health care providers to population within a defined geographic area (e.g. region, province, county, or otherwise defined).[12] • A multi-step method that calculates a population-to-provider ratio within a catchment area by using circular buffers (i.e. an area) around a centroid.[14] Note there are various iterations of this method which account for distance decay and travel time.[12]	• Although simple to compute, this method does not account for consumers receiving care outside of the defined geographic region, is unable to identify variation within the region, and assumes providers within a region are equally accessible to all populations.[12] • Does not consider spatial movement data and, unless distance decay is accounted for, assumes all services within a catchment area are equally accessible by those residing within the area. A strength is that this method considers both availability and accessibility.[12]
Accessibility	**Distance-based measures** • Euclidean distance • Multiple ring buffer • Network distance • Travel time	• Straight-line distance between two points.[10] • Generate multiple buffers at specified distances around a point of interest (e.g. health service).[17] • The distance (miles, kilometres) between two locations travelling along a road or public transport network (multi-modal).[15] • The time travelled (minutes, hours) along a road network or other route (e.g. foot paths) between two locations.[15]	• Relatively simple to compute but does not account for travel time, road networks, or topological structures.[16] • Similar considerations as Euclidean distances. Given this, the distance of buffer rings can be arbitrary.[17] • Accounts for real-world infrastructure (e.g. roads) to provide a more realistic indication of distance but does not account for other variables that impact speed.[15] • Considers real-world infrastructure and time required to travel, offering a more accurate representation.[15]

Adapted from Supplementary File 3 Wood *et al.*[7]

as weather patterns (e.g. rainfall and extreme heat) may also need to be considered with distance-based measures. Spatiotemporal analysis methods can be applied to examine the effects of weather patterns (e.g. extreme heat days and wet seasons) on accessibility. Research applying an advanced spatiotemporal analysis method (e.g. modified kernel density two-step floating catchment area model and spatial autocorrelation) identified that accessibility to public hospitals is impacted by weather (e.g. heavy rain affects travel time).[20]

Underlying area-based and distance-based spatial methods examine the relationship between data points (e.g. providers, health services, and location of consumers) and identify spatial patterning (e.g. proximity, distribution, and clustering). The theoretical underpinning of identifying spatial patterns is Tobler's first law of geography which states:

> *Everything is related to everything else, but near things are more related than distant things.*[21] (p.1)

Given a natural relationship between data points, particularly data points that are proximal as explained by Tobler's law,[21] there are considerations for analysing spatial data and examining spatial patterning. Spatial dependence and spatial autocorrelation are fundamental to exploratory spatial data analysis.[22] Spatial dependence refers to the concept that neighbouring variables are more related than those further apart,[23] whereas spatial autocorrelation is a statistical technique that calculates correlation within variables across a global or local georeferenced space.[24] Spatial autocorrelation can provide insights into the spatial data set's characteristics, relationships, or underlying patterns.

When to apply spatial methods

The application of spatial methods to measure access has widespread usage, including undertaking a needs analysis of populations within a defined geographic region, evaluating services and programmes, and identifying opportunities to scale programmes. Using spatial methods to measure the accessibility and availability of health services is important in health research to inform policy and planning, particularly for populations residing in regional, rural, and remote communities.[5] International examples of spatial research examining the accessibility and availability of services of relevance to nursing research are presented in *Table 3*.

Of studies with a focus on the geographical distribution of the health workforce, area-based measures have been applied, including the provider-to-population ratio (less common in contemporary peer-

Table 3 Examples of access research applying spatial methods of relevance to nursing

Citation (country)	Focus	Data sources	Spatial methods applied (spatial unit)	Findings
Geographical distribution of the health workforce				
Naylor *et al.*[25] (USA)	Spatial accessibility of physicians and non-physicians (including nurse practitioners)	National Plan and Provider Enumeration System; Medicare; United States Census block level population data	Variable distance enhanced two-step floating catchment area method which included a distance decay effect. (ZIP Code Tabulation Areas)	Spatial accessibility of physicians and non-physicians was not evenly distributed across ZIP Code Tabulation Areas.
Sutarsa *et al.*[8] (Australia)	Spatial distribution of mental health nurses	National Health Workforce Dataset	Area-based population-to-provider ratio (mental health nurses per 100 000 persons) using ARIA+ to define remoteness areas. (Local government area)	An inequitable distribution of mental health nurses was identified for rural and remote communities in Australia which has implications for service access.
Shah *et al.*[26] (Canada)	Spatial accessibility of family physician and nurse practitioner services	Canadian Institute for Health Information; Statistics Canada	Three-step floating catchment area method with a distance decay effect. (Census consolidated subdivisions)	Inequities in the distribution of family physician and nurse practitioner services across rural and remote regions of two provinces were identified.
Consumer access to health services				
Beks *et al.*[27] (Australia)	Utilization of telehealth services by Aboriginal and Torres Strait Islander Peoples	Aboriginal Community Controlled Health Organisation (ACCHO) service data	Undertaken as part of a mixed-method evaluation. A descriptive approach was applied using frequency counts of telehealth consultations per postcode. Area-level socioeconomic economic status was assigned by postcode. (Postcode)	Telehealth services were accessed by Aboriginal and Torres Strait Islander Peoples who were geographically dispersed in the ACCHO service region. Majority of consultations (77%) were delivered to Peoples residing in areas characterized by high levels of socioeconomic disadvantage and low levels of advantage.
Bray *et al.*[28] (Australia)	To examine spatial accessibility to cerebrovascular accident reperfusion services in Victoria	Ambulance Victoria data	Locations of patients and reperfusion centres were mapped, and drive times were computed using 2010 and 2015 data sets. The proportion of patients within a 60-minute drive time and 180-minute drive time, were calculated for analysis (patient and service (x and y) location)	Between 2010 and 2015, an increase was identified in the proportion of suspect cerebrovascular accident patients within a 60-min drive time to a reperfusion centre indicating improved spatial accessibility.
Clark *et al.*[29] (Australia)	To examine the spatial accessibility of chronic heart failure management programmes and general practice services for populations with chronic heart failure	Size and locations of chronic heart failure management programmes; National Centre for Social Applications of Geographic Information Systems data set	Locations of heart failure management programmes and general practice services were mapped using address-level data. Estimated numbers of people living with chronic heart failure were mapped using the census collection districts (Collection District)	Inequity in the provision of chronic heart failure management programmes were identified, particularly for persons residing in rural areas.
Coffee *et al.*[30] (Australia)	To measure road network accessibility to cardiac services before and after a cardiac event	Multiple including Australian Bureau of Statistics Australian Standard Geographic Classification 2006 and Census of Population and Housing 2006; Bureau of Meteorology	Used geographic information systems to model road network accessibility to cardiac services at a population level. (Collection District)	Identified that 71% of the Australian population (2006) had very good access to cardiac services.

Continued

Table 3 *Continued*

Citation (country)	Focus	Data sources	Spatial methods applied (spatial unit)	Findings
Collins *et al.*[17] (Australia)	To examine relationships between distance to radiotherapy services, socioeconomic groups, and mastectomy rates across rural and metropolitan settings	Evaluation of Cancer Outcomes Registry; Australian Bureau of Statistics; Socioeconomic Index for Areas	Euclidean distance was calculated using patient suburb and location of radiotherapy treatment centre. Area-level socioeconomic data was appended to suburbs using a spatial join. Multiple ring buffers also applied to analysis. (Statistical Area Level 1)	Increased rates of mastectomy were strongly associated with distance to radiotherapy treatment centre for women who travelled 100–200 km, compared with those who were within a 100 km radius.
Lechowski and Jasion[31] (Poland)	Spatial accessibility of primary health care in rural areas	National Health Fund; OpenStreetMap; Central Statistical Office	Multiple methods were applied including network analysis, characteristics of normal point distribution, Theil index, and spatial autocorrelation. (Statistical localities)	It was identified that the average distance from rural statistical localities to primary health-care facilities was 5 km. Accessibility was poorer in the northern and eastern localities.
Khakh *et al.*[32] (Canada)	Spatial accessibility of primary health-care services by different travel modes in Calgary	City of Calgary data; Alberta Health Services data; Open Calgary; Statistics Canada	A network analysis of time for each mode of travel identified which included driving along roads (private vehicle, taxi, or others), walking on a sidewalk, and a multi-modal network (sidewalks, bus routes, and train lines). (Dissemination area)	Spatial accessibility to primary health-care services was highest for people with a private car and lower for people using multi-modal means.
Toms *et al.*[33] (Australia)	Spatial accessibility of primary care and area-level variation in cardiometabolic risk factors	Pathology data; primary care provider data; 2011 Australian Census of Population and Housing	An access index score was calculated for each Statistical Area Level 1 using a two-step floating catchment area method. Multilevel logistic regression models were allocated to individual cardiometabolic risk factor data. (Statistical Area Level 1)	Greater spatial accessibility of primary care was associated with a reduction in the odds of low high density lipids and obesity, but not other cardiometabolic risk factors included in the study.

reviewed research but still commonly applied in reports and national benchmarking of the workforce) and variations on floating catchment area methods which consider multiple variables (e.g. service provider availability, consumer travel time, and distance decay) to develop an index. What is clear from these examples is that across studies (and countries), approaches to undertaking spatial analysis can vary,[7] including the spatial unit applied which is largely informed by policy (e.g. funding models), census information, health workforce data sets, data availability, and privacy laws. This makes it difficult for findings to be generalizable across countries and needs to be taken into account when interpreting the implications of studies in international reviews of evidence for translation into policy.[34]

Of studies with a focus on consumer access to health services, various spatial methods have been applied including linking multiple data sources. Examples of data sources that can be linked include administrative data sets (e.g. health data sets), national census data, and infrastructure data. Considerations for using existing data sources for spatial analysis include the possibility of incomplete or missing data and limited variables for analysis.

There are other applications of spatial methods that could be considered in cardiovascular nursing research. This includes using spatial methods to map the location of services or programmes described by studies retrieved through systematic review searching to identify geographical gaps in service or programme implementation.[34–36] A descriptive spatial method can also be used to describe the characteristics of participants utilizing services (i.e. realized access) as part of mixed-method studies or be undertaken as a standalone exercise.[37] Spatial characteristics of participants can also be triangulated with other data sources (e.g. qualitative interviews) to elicit an analysis of access which also considers aspatial dimensions of access (e.g. acceptability).[27] Research focusing only on the spatial availability or accessibility of services within a region will not consider how acceptable services are for consumers which will mediate with whether a consumer chooses to use the service or not.[2,38] For example, for Aboriginal and Torres Strait Islander Peoples in Australia, this includes the cultural acceptability of health care provided which will impact the accessibility of services from a consumer perspective.[39]

Steps to consider for application in nursing research

There are four steps to consider when applying spatial analysis methods to measure access in nursing research. These are (i) develop a spatial research question, (ii) identify data sources with spatial variables, (iii) choose a spatial analysis method and undertake analysis, and (iv) report and disseminate spatial findings (*Figure 1*).

Figure 1 Steps to consider when applying spatial analysis methods.

Step 1: Develop a spatial research question

Once familiarized with the context of applying a spatial research approach, it is important to develop a spatial research question that aligns with the research aims and objectives. The mnemonic Population, Intervention, Comparison, Outcome, and Scale (PICOS) can be applied (*Table 4*).[40] A comprehensive spatial research question should identify the population to be studied (e.g. population receiving the nursing intervention and nursing workforce), intervention (if applicable), comparator (if applicable), spatial outcome or exposure of interest (e.g. distance to services), and scale (e.g. spatial scale and temporal scale).

An example of a spatial research question with a cardiovascular disease focus developed from Bray *et al.*[28] is as follows:

For patients transported by a road ambulance with a suspected cerebrovascular accident (P), requiring reperfusion (I), what proportion of patients have a transport time within 60 min by road (O), in Victoria, Australia (S)?

Step 2: Identify data sources with spatial variables

As part of identifying data sources that are appropriate for answering the developed spatial research question, it is important to become familiar with what spatial data sources are available and the characteristics of these data sources. Spatial data can come in different formats, with the most commonly available being vector data (e.g. a discrete data point such as a home address or defined catchment areas such as postcodes). The smaller the resolution of spatial data available (e.g. consumer address vs. consumer postcode/ZIP code), the more likely it is to generate a good understanding of what you seek to analyse. Data sources with direct policy and practice relevance should be prioritized.[41]

Depending on the scope of the spatial research question, it may be necessary to link multiple data sources (e.g. administrative data sets or survey data with national census data or geographical classification systems). Data sources selected should be the best possible available to the researcher to answer the research question. In the first instance, it may be of value to have a discussion with a local health informatics team to understand what data sources are available for research purposes and what the ethical requirements are. Depending on the data source, it may be necessary to obtain a letter of permission from the data custodian to have access to the data source for analysis[27,37] in addition to a formal ethical review of the research proposal from a Human Research Ethics Committee, particularly if address-level data are sought. Developing a data management plan from the outset of your research and in accordance with institutional research policies is important for identifying how data sources (including identifiable data) will be accessed, stored, and managed throughout your research project.

Step 3: Choose a spatial analysis method and undertake analysis

The choice of spatial analysis method will largely depend on the research question and data sources available for analysis. A suite of methods are available (*Table 2*). Providing a justification for the method selected will be required in the context of the research question. It may be appropriate to reach out to academic institutions and spatial experts to provide guidance around this. It is important to note that the choice of method will affect the spatial findings. As part of this, identifying the spatial scale of analysis is key. It is important to use a spatial scale that will identify sufficient variation at the finest resolution available. There are limitations to this such as privacy and data collection issues. Although data can be aggregated into larger spatial units to explore the relationship between variables, researchers should be cautious in applying the interpretation of aggregate findings to smaller spatial units (e.g. MAUP).[9] Often, researchers will be limited by what data are available for analysis.

A geospatial information system (GIS) (e.g. ArcGIS®) is used to support the analysis of spatial data using visualization and layers of data.[9] An example of a visual output developed using GIS is provided (*Figure 2*) which mapped the locations of consumers accessing health services. This example applied ring buffers to illustrate proximity to the service (based upon Euclidean distance) and was overlaid on the road network to permit future distance and time calculations for more detailed analysis if required. This exercise was undertaken to scope opportunities for new models of service delivery to improve accessibility for consumers. There are plenty of online materials, courses, and manuals available which equip new users with basic skills to undertake spatial analysis using GIS. It is important to have the support of a more experienced user and protected time to develop skills.

Table 4 Developing a spatial research question and identifying data sources

Step 1: PICOS research question elements		Step 2: Data sources
P (Population)	Population to be studied	• Census data sets • Patient databases • Survey data • Health workforce databases
I (Intervention)	Nursing intervention, prognostic factor, or spatial exposure of interest	• Medical records • Mortality databases
C (Comparison)	Comparator—if applicable	
O (Outcome)	Spatial outcome of interest	• Distance or time to services • Distribution ratios
S (Scale)	Spatial or temporal scale of analysis	• Geographic region and spatial unit • Duration and time

Step 4: Report, disseminate, and translate spatial findings to policy

Although quality criteria for spatial analysis do not currently exist,[11] there are key elements to include in the reporting of findings. The Spatial Lifecourse Epidemiology Reporting Standards statement provides guidance for this.[42] Elements specific to spatial analysis include reporting the type of spatial data used, spatial methods applied, and software used for analysis.[42] As with all research, it is recommended

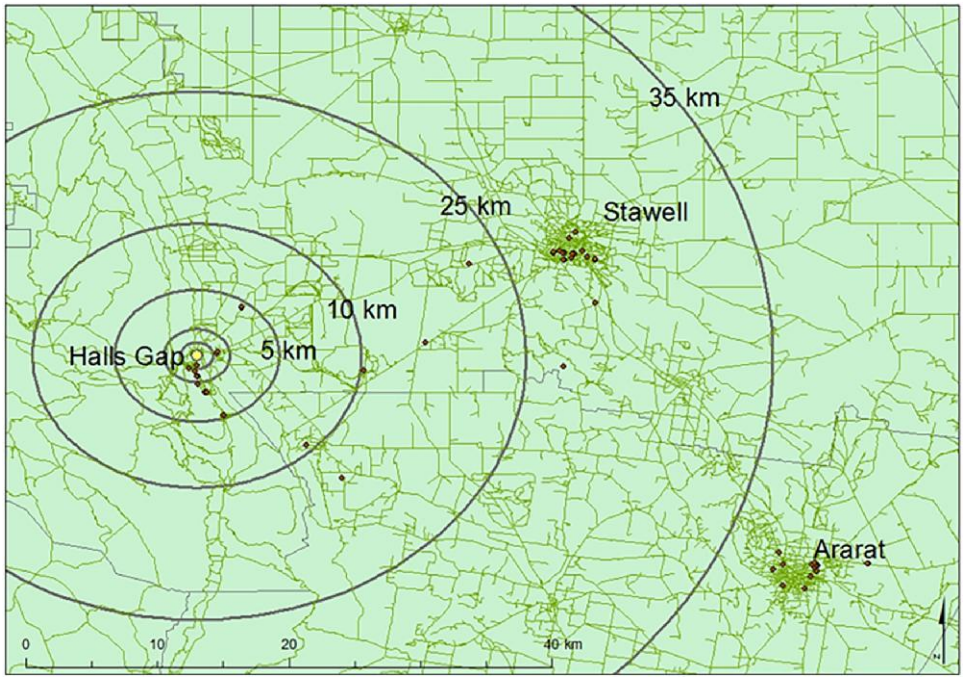

Figure 2 Example of a visual output developed using ArcGIS®.

to report the underlying assumptions that informed analysis and interpretation[3] and limitations of the approach used.[42] Common limitations include incompleteness or a lack of variables for analysis in administrative data sets, use of area-level measures (e.g. area-level indexes of economic status) as a proxy for individual measures, and spatial bias (e.g. MAUP).[42]

In the reporting and dissemination of spatial findings, it is important to consider the political context and implications for policy and practice translation. Examples include identifying gaps in the spatial accessibility of services to inform service planning (e.g. reperfusion services for patients with suspected stroke[28] and availability of cardiac services[43]) and to compare findings with existing national cardiovascular disease indicators (e.g. Australian Heart Maps[44]) and population health data sets. Sharing spatial findings with relevant stakeholders (e.g. health service executives) and policymakers (e.g. departments of health) is an important policy translation activity. As part of this, it is important to be mindful that stakeholders and policymakers may not have an understanding of spatial research and to explain in lay terms spatial methods applied, findings, and implications in the context of relevant policy or data sets.

Conclusion

Given the application of spatial methods in health research is a rapidly developing field, alongside health geography more broadly, it is timely for a greater application in cardiovascular nursing research. As the largest proportion of the health workforce, nurses are well placed to undertake research that examines spatial access, specifically the accessibility and availability of health services for consumers. Considering the four steps provided is a starting point for undertaking spatial research.

Funding

H.B., S.M.W., and V.L.V. are researchers funded by the Australian Government Department of Health and Aged Care Rural Health Multidisciplinary Training program.

Conflict of interest: None declared.

Data availability

No new data was created for this methods paper, rather information was obtained from included studies. Data sharing is not applicable in this article.

Author contributions

H.B. led the conceptualization and drafting of the manuscript. S.M.W. and V.L.V. contributed to the conceptualization and drafting of the manuscript and provided a critical review of the final version. R.A.C. provided initial recommendation and a critical review of all drafts.

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