A Systematic Review of Geographic Information System Applications in Pediatric Health Services Access and Utilization: A Study of Current and Future Research Directions

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CERTIFICATE OF APPROVAL

This is to certify that the Master's Capstone Project of

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ABSTRACT

Background

Access to appropriate and timely health care services is an important component of achieving health for children and critical in reducing morbidity and mortality. The increasing availability of data, informatics and ubiquity of computing in health care has allowed for the development of new tools and applications to study access and utilization of health care services. Geographic information systems (GIS) has the advantage of allowing the exploration and study of spatial relationships and health outcomes, health care services, and populations.

Objective

To conduct a systematic review of peer-reviewed articles on the applications of GIS in understanding health care access and utilization for children using the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols. Our assessment of the literature is expanded by a discussion of the limitations in current GIS work and future directions of GIS applications in pediatric health care access and utilization research.

Methods

English language studies published peer-reviewed journals were identified by searches of PubMed and EMBASE from January 2000 to December 2017 that focused on applications of GIS and geospatial analysis in pediatric health care services research. Two reviewers screened studies based on title, abstract, and full text. Identified studies included in the review were assessed for the risk of bias. Any disagreements in the review process that could not be resolved led to the involvement of a third reviewer. The overall quality of evidence was then assessed.

Results

The final analysis yielded 25 research studies that reported on the use of GIS in pediatric health services research. There was a large variety of clinical outcomes and non-clinical outcomes reported by the studies that ranged from vaccination rates and mortality to density of health care providers to pediatric populations for health care planning purposes. Most studies were observational in study design. Studies ranged from very low to moderate scores for overall quality. Significant variation exists regarding spatial analysis methodology and reporting of methods and results.

Conclusions

Applications of GIS in understanding access and utilization of pediatric health services had significant variation in content and methodology. While the quality of evidence was limited by the design and methodology of most studies, the overall impact of GIS allowed for a better understanding of spatial relationships with regards to pediatric health care access and utilization. Future research needs to focus on developing improved study designs that go beyond descriptive analysis, more standardized approaches to geospatial analysis methodology, and improved standards for reporting geographic analysis results.

INTRODUCTION

Access to appropriate and timely health care services is an important component of achieving health for children and critical in reducing morbidity and mortality. Access can be defined and measured by whether a population with health care needs can enter the medical system and utilize health services when needed.[1] Access to health care can be viewed through the dimensions of availability, accessibility, accommodation, affordability and acceptability. Access to health care services can limited by financial, cultural, language, socioeconomic, transportation and geographic barriers.[2,3] Some examples of studies related to access of care may include spatial proximity to a hospital or the ratio of health care providers to a population in an area.[4-6]

Utilization of health care services can also be studied, and while related, access to health services research is different. Studying utilization can often be challenging due to the need to obtain more granular individual patient level data. Subsequently, there have been fewer studies that have examined detailed patterns of service utilization as compared to studies of access to health care services.[7] Some examples of studies related to utilization of health care services include understanding how many times a pediatric patient has seen a dentist to adhere to recommendations or quantifying emergency department visits. Understanding access and utilization of health care services is important for a variety of reasons including advising health care policy, health system design planning, understanding and reducing disparities in care as well as determining ways to improve individual and population health.[8-10]

The increasing availability of data, informatics and ubiquity of computing in health care has allowed for the development of new tools and applications to study access and utilization of health care services. Geographic information system (GIS) is a tool that is increasingly used in health care due to the advancement of informatics science, the availability of data and an acceptance that location factors and environmental factors influence health status, access and utilization. Geographic information systems (GIS) are software and hardware that are used together for the storage, management, retrieval, manipulation, analysis, modeling and visualization of geographical data. Classical uses of GIS have been used for disease epidemiology, disaster management and environmental health studies. Perhaps, the earliest use of mapping in medicine to improve health care was in 1854 when Dr. John Snow studied the cholera outbreak in London and traced disease epidemiology to water pumps based on simple mapping techniques.[11]

The contemporary use of GIS and methods of geospatial analysis are relatively recent with GIS only assigned its own Medical Subject Heading (MeSH) term in 2003 by the US National Library of Medicine. The number of scientific articles on GIS in health published each year has increased dramatically, underscoring the usefulness in GIS as a tool to investigate health care issues.[12-14] Spatial analysis, the tools employed in GIS applications is a more recent addition with its MeSH term created in 2013.

In particular, GIS has the advantage of allowing the exploration and study of spatial relationships and health outcomes, health care services and populations. In addition to health care data and health system data, unique to GIS is the need for geographically referenced data. Geographically referenced data allows for an understanding and calculation of distance and time traveled by different modalities such as car, airplane, public transportation or walking. The process of geographically referencing data is called geocoding. Geocoding is the process of assigning coordinates such as latitude and longitude to a specified location using data granularity that can be relatively nonspecific as zip code or census block data or as specific as a home address.[15,16] Challenges exist as to the process of geocoding since geographic data can vary in scale which can limit GIS analysis.[17-20] Furthermore, geocoding and geospatial analysis needs to be conducted with a respect for ensuring patient privacy in research.[21,22]

Geospatial analysis in health care access and utilization research has led to an understanding of the distance-decay effect. This concept has been described as the decreasing utilization of health care services that occurs with increasing distance of a person's residence from a health care facility or system.[23,24] This phenomenon has been documented in geospatial studies of health care and has been demonstrated in different countries, patient populations such as pediatric and adults, different medical conditions and treatments.[25-29] Distance decay and other geographic barriers to accessing and utilizing health care services are important to understand and model. GIS has been used to facilitate geospatial analysis and further the understanding of the impact distance and spatial relationships have on medical care. Applications of GIS in understanding health care systems and services is important for multiple stakeholders including, public health officials, health care administrators, policy makers, and health care providers.

While there have been increasing number of publications related to the application of GIS and understanding health care access and utilization, there has only been one narrative review and two systematic reviews published. The narrative review was published in 2004 and had the main objective of reviewing the use of GIS-based measures to understand health care access and outcomes.[30] The review did not focus on the pediatric population and was conducted in a time when GIS and computing systems was not as ubiquitous as modern day GIS analysis. One systematic review focused exclusively on malaria and anemia disease states with pediatric health and did not specifically assess health care resource access and use.[31] The other systematic review focused only on adult populations and in global north countries.[32] To date, there has not been narrative review or systematic review of the applications of GIS towards understanding pediatric health care access and utilization.

Given the importance of understanding access and utilization of health care services and the rising use and research on GIS, our primary objective was to conduct a systematic review of peer-reviewed articles that study how GIS is being utilized to understand health care access and utilization for children. We did this by systematically describing and analyzing the breadth of peer-reviewed literature using the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P).[33,34] Furthermore, our assessment of the literature is expanded by a discussion of the limitations in current GIS work and future directions of GIS applications in pediatric health care access and utilization research.

METHODS

Eligibility Criteria

Studies were identified based on queries that focused on the applications of GIS and geospatial analysis methods in pediatric (≤ 18 years old) health care access and utilization research that were published in English in peer-reviewed journals. Particularly, studies were included that had assessed the spatial proximity of health care services relative to the pediatric patient by quantifying distance traveled or time traveled. Publication dates included in the search were between January 1, 2000 through December 31, 2017.

Studies excluded were those that were non-peer reviewed, review articles, abstracts, conference proceedings and papers that primarily compared methodology. Other exclusion criteria were studies that did not focus exclusively on pediatric patients only. In particular, populations that included adults or pregnant populations were excluded from analysis. Telemedicine studies were also excluded.

Information Sources

Queries of the electronic databases PubMed and EMBASE were conducted to identify studies for this review.

Search Strategy and Screening

The systematic review search was conducted in PubMed and EMBASE by one reviewer [JMT] and with the input and expertise of a Health Sciences Librarian [SEM]. The specific search query can be found in ***Appendix 1***. Medical Subject Heading (MeSH) terms were used including: "Geographic Information System", "Health Services Research", "Health Services Accessibility", and "spatial analysis." Other terms and keywords were also combined with the MeSH terms which included "children", "child", and "pediatric." The EMBASE database was also queried with a combination of keywords and terms including "Geographic Information System", "GIS", "spatial analysis", "geospatial", "health services research", "health care access", "health care utilization," and terms and keywords for "children", "child", and "pediatric."

The results of the PubMed and EMBASE searches were then combined in Endnote reference manager software (v. X8.2, *Clarivate Analytics*, Philadelphia, PA). Duplicates were identified by the software and manually reviewed [JMT] prior to removing duplicates. Two reviewers [JMT, AFS] then screened the article titles for relevance based on title and designated them accept, reject or further review. The two reviewers then screened the abstracts of the articles that were designated accept or further review. A third reviewer [JAG] adjudicated any conflicts between the initial two reviewers. The full text electronic version of the articles accepted after the abstract screening were then obtained via institutional access. The full article texts were reviewed to determine if they met inclusion criteria and if they employed GIS and geospatial analysis for understanding pediatric health care access and utilization. Reference sections from selected manuscripts were reviewed by hand to identify other relevant studies that were not found in the electronic query of PubMed and EMBASE. While review articles and non-peer reviewed manuscripts were not included, reference sections of these were also manually reviewed.

Data Extraction

The full text versions of manuscripts were reviewed and a predesigned form was used to extract relevant data from the manuscripts. Data were extracted into Microsoft Excel spreadsheets. The data items extracted were based on general descriptive summaries of each manuscript including study objective, population type, data source, sample size, study geographic location and if there were any funding sources. These items were also used to determine the possible risks of bias and to further demonstrate the type of studies and variation. In addition, data was also extracted using another predesigned form that reviewed and collected information the variation in study methodology for geospatial analysis among the studies. These variables included primary outcome, reported method of measurement, geocoding method, origin and destination points and if the geographic level for which geographic study data was presented in any data visualizations.

Risk of Bias Assessment and Quality of Evidence

Studies that were included in the systematic review were assessed for risk of bias. The Cochrane Risk of Bias Criteria was used to assess each of the 25 studies.[35] The risk of bias assessment included broad factors such as selective reporting, blinding of participants and personnel, blinding of outcome assessment and whether there was incomplete outcome data. Risk of bias assessment and reporting was evaluated as low risk, moderate risk or high risk. Three reviewers [JMT, AFS and JAG] graded the studies.

The overall quality of evidence was then assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system for grading evidence.[36] GRADE evaluations take into account the quality of the evidence based on factors such as study method and limitations, indirectness of evidence, risk of bias, inconsistency, imprecision, publication bias, magnitude of effect, consideration of other plausible confounding factors and the possibility of dose-response relationships. A predesignated form was selected to assist with evaluation using the GRADE criteria which can be found in ***Appendix 2***.[37] Three reviewers [JMT, AFS and JAG] graded the studies with a discussion and use of this form. The quality of evidence was considered for two groups of articles identified in this review as the 19 studies that focus on access to pediatric health care services and the remaining 6 that focused on utilization of pediatric health care services. Overall quality of evidence for the groups of studies was then rated on one of four levels, high, moderate, low and very low based on the GRADE criteria. Based on GRADE the definitions for the evidence quality can be described as:

- **High Quality** – further research is very unlikely to change our confidence in the estimate of effect.
- **Moderate Quality** - further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
- **Low Quality** – further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
- **Very Low Quality** - any estimate of effect is very uncertain.

Data Synthesis

Due to the study design and anticipated fact that most of the studies in geographic information system science are observational with heterogeneity by reported outcome measure and methodology, a qualitative synthesis rather than meta-analysis was conducted. Methods used to apply geographical analysis or spatial analysis were also assessed.

RESULTS

Figure 1 is the study selection flow diagram. The PubMed search query yielded 829 articles and the EMBASE search yielded 453 articles. After comparison of the two search results, 133 articles were removed due to duplication of articles. The total number of unique articles from the initial literature search was 1149 references. After screening titles for relevant articles to GIS in pediatric health services research 952 articles were rejected and 197 were then screened for content based on their abstracts. A review of these abstracts for relevance led to a rejection of 167 articles, resulting in 30 articles. The full text of the remaining articles was then reviewed. A total of 5 articles were rejected based on inclusion and exclusion criteria, including an exclusion of review articles. A total of 25 references remained for inclusion in this review and underwent quality assessment and data synthesis.

Table 1 includes the summary descriptions of the 25 studies selected for inclusion in this systematic review and overall quality of evidence ratings based on the GRADE criteria. Of the studies included, 24 of them were observational or survey studies using cross-sectional data and 1 was a secondary analysis of randomized controlled trial data. The data sources varied significantly based on the scale of the geography that the study was set in. For example, the large datasets used were from national level data such as the US Census Bureau which utilized a nationally represented dataset of children in the United States. On the other hand, the smallest scale study involved just 71 adolescents and attempted to determine whether distance to the bariatric surgery clinic would predict post-operative follow-up compliance. Most of the studies used children as the population with several international papers in developing countries focusing on young children or infants as they related to vaccination and mortality data. A little more than half of the studies included were conducted in the United States with one from Canada and one from China and the rest from developing countries.

Of the 25 studies, 19 studies studied the role of distance relationships in relation to access to pediatric health care services, with only 6 studies that focused on actual utilization of pediatric health care services. Studies of health care access in the setting of spatial relationships utilized methodology that looked at distribution of health care systems in relation to a population with the assumption that the individuals in a population would utilize the nearest health facility. Such studies included straight line distance relationships, drive times and simple measures of being within a concentric distance from the health care facility. Studies that assessed health care utilization, in contrast, used specific individual level data from electronic medical records or survey data at the individual patient level in order to determine utilization in relation to geographic proximity. Studies of pediatric health services utilization were smaller in study sample size when compared to the sample sizes of studies that assessed health care access.

Almost all of the studies with regards to access to care and all of the utilization studies but for one concluded that distance decay effects were observed. The majority of results of the studies reviewed demonstrated that the further that patients were from a health care facility or center for the outcome of interest studied, the less access or utilization of services were achieved. Studies that looked at spatial access and spatial density of health care providers (i.e. Anesthesiologists and Trauma Centers) to population density did not assess for distance decay effects.

Risk of bias assessment using the Cochrane Risk of Bias tool were reported for each study after analysis by three reviewers. The risk of bias assessment ranged from “low” to “moderate” and “high.” A total of 10 studies were considered “low” risk of bias, 12 were rated as “moderate” risk of bias and the remaining 3 were rated as “high” risk of bias.

Table 2 includes the description of selected studies and key characteristics related to the study method and geospatial analysis. Of the 25 studies, 22 studies assessed travel distance or travel time as the primary outcome of comparison with regards to access to care and utilization. The remaining 3 studies had the primary outcome of determining the percentage of patients or population density in a given geographic region in relation to a health care provider (i.e. pediatric anesthesiologist) or health care system (i.e. pediatric trauma care). These studies were oriented toward assessing potential access to health care systems and were conducted to help guide or support health care policy and recommendations.

There were significant variations in the method by which geospatial relationships and distance were calculated in each study. Variations in distance measurement from one point to another point of interest were observed among the studies included. Of the 25 studies, 13 calculated distance relationships using Euclidean/Straight Line measurements, 2 using concentric circle distance measurements, 2 used turn by turn direction measurements, 1 utilized shortest drive distance, 3 used cost-analysis techniques of estimating travel time, 1 studied relied on self-reported distance and time estimates from study participants, 1 provided only a visual display and no actual measurement and finally 2 studies did not report distance based measurement techniques even though distance and time were reported as results.

Geocoding locations used in geospatial analysis among the studies also had significant variation. Of the 25 studies, 11 studies geocoded the actual individual address of locations (i.e. residential address and hospital center address), 7 studies used the center of a geographic block that was either existing (i.e. US Census Block, zip code) or artificially grouped (i.e. aggregation of data into distance-based neighborhoods, 6 studies used hand-held global positioning satellite (GPS) devices to determine precise latitude and longitude of locations and 1 study did not geocode due to the self-reported survey nature of the study. Use of hand-held GPS devices were in rural areas of developing countries.

Method of reporting geospatial data in the studies was also varied by scale. Some studies reported data at the country level, county level, government administrative units, district level and state level. Four of the studies did not provide a visualization of geospatial data on a map. Only two of the studies that presented geographic data on a map of patients had conducted geomasking with coordinate shifts, the process of skewing the coordinates when reporting (while maintaining the original results) in order to provide confidentiality and privacy for the study population.

Table 3*,* includes the overall quality of evidence results for the use of GIS in understanding geographic relationships with location and access to or utilization of pediatric health care services.

DICSUSSION

This systematic review is the first to synthesize the available evidence on the applications of GIS towards understanding pediatric access and utilization of health services. One of the objectives of our review was to determine the breadth and depth of how GIS is being utilized in pediatric health services research currently. While there has been increasing use of GIS in health care services research applications, within the pediatric population, the role of GIS is still limited in the literature.

Significant variation existed among the studies included in our systematic review regarding applications of GIS. For example, some studies assessed disease states, while others studied access to dental care and genetics care and other yet studies assessed geospatial relationships to specialty care centers (i.e. pediatric trauma or pediatric anesthesiologist availability). The wide variety of studies was also reflected by the large number of geographic areas that were included in the studies reviewed, variations in sample size studied and sources of data that was the foundation of the studies.

Interestingly, while there was significant variation in the type of studies conducted one major theme regarding results was consistent. The concept of distance decay was demonstrated in almost all of the studies. Increasing distance from health care services was related to decreases in a specific measured pediatric outcome in the studies reviewed. From a strength of study perspective among geographic information systems, this is akin to a dose-response relationship and provided an increase in the quality grading of some of the studies. Furthermore, this phenomenon of distance decay has also been supported by other published studies across a range of population types and health outcomes, further strengthening the quality of evidence supporting the use of geospatial analysis and understanding pediatric health care access and utilization.[25-28]

The risk of bias was assessed for each study and demonstrated that there was significant variation with the risk of bias among studies. While there was significant low and moderate risk of bias assessments there was only three studies that were identified as high risk of bias. The high risk of bias studies was limited in their study design, nature of data collection for geographic analysis and lastly did not take into account important confounding factors that could influence utilization of care. One of these studies used measurements of geospatial distance and travel time using telephone survey data of participants without other objective measurements. Another study assessed the outcome of intubations in transporting pediatric patients from one center to another but did not report the severity of patient condition necessitating transport. This was a critical source of data that could severely undermine the geospatial analysis in that study.

Risk of bias can be directly influenced by study design. The most likely reasons for the variation in assessments and moderate to high level risk could be that virtually all of the studies utilizing geographic information systems to understand pediatric health care access and utilization were observational. For example, it is unlikely at this juncture to see a GIS study that is based on a primary randomized controlled trial study design. The nature of observational research, retrospective data and database studies that is consistent across the majority of geospatial studies will lead to a variation in risk of bias analysis.

The overall quality of evidence for the role of GIS and geospatial analysis in understanding geographic barriers to access to pediatric health services was high. The overall quality of evidence for the role of GIS and geospatial analysis in understanding geographic barriers to utilization of pediatric health services was also high. While study design limitations and some data sources were limited in their data granularity to provide a lower risk of bias and a high directness assessment, the overall consistency across studies, populations, sample size and geographic location of the studies support a strong argument for the role of distance decay effects in pediatric health care services access and utilization. Overall, studies were noted to have a dose-response relationship (i.e. distance decay effect) and also took into account other confounding factors that are important to achieving access to health services including socioeconomic factors and demographic factors – a demonstration that access to care is more than just geographic but also social, cultural, financial and more.[38,39]

The overall strength of evidence for the use of geographic information systems in understanding distance decay on access and utilization of pediatric health services was good. The culmination of studies supporting this phenomenon, across populations and countries and disease states is important to consider. Observing this phenomenon in adult literature and health care access and utilization studies is also important in the overall strength of evidence consideration.

There were several limitations in our systematic review of GIS applications in pediatric health services research. There are limitations to the methodology related to quality of evidence ratings. Geographic information system research is typically non-experimental in study design and therefore not randomized controlled trials. As a result, using a rating system such as GRADE, that starts non-randomized studies at low quality evidence ratings may be skewing the systematic review results toward low quality when in fact this is standard within the research field and methodology. However, there currently is no standard for evaluating geographic research or spatial analysis methodology. In the setting of no standard, it seems plausible to continue to consider using validated and accepted frameworks of evidence grading in order to provide a structured and more likely objective measure of quality than not. We employed multiple reviewers for quality of evidence ratings as well to mitigate bias.

Another limitation in our systematic review was regarding an understanding of the methods employed to include in this review. It was not feasible to assess for specific pediatric health services research studies with similar methodologies because the current range of global pediatric health research that includes GIS is not described or well understood. We employed our methodology to identify current study design, methodology and results when GIS is applied to pediatric health services research.

Overall, there is significant heterogeneity across peer reviewed research studies assessing GIS applications in understanding access and utilization of pediatric health services. Large variation in study methodology include study size and the lack of assessing for confounding factors to access such as socioeconomic status and other demographic variables. Large variation in methodology exists as well within the scope of these studies. Large variation in geocoding levels can impact accuracy of studies although this can be mitigated with large data sets and with trend analysis and demonstration of dose-response relationships seen in distance decay phenomenon.[40] Variations in measuring distance is also important to consider across studies.[41] Depending on the use of methods to measure drive distance, for example, results can be variable. It is possible that standards need to be created to at least demonstrate that sensitivity analysis of various methods of distance and travel time estimations do not change study results. This level of comparison and sensitivity analysis would bolster the strength of analysis of studies.

Our systematic review also allowed us to identify areas for future research and development and to propose that GIS research should be directed towards given gaps in the literature and significant heterogeneity in methodology. These directions were identified as a result of reviewing the literature and conducting this systematic review with incorporation of the GRADE criteria for quality of evidence rating. Future GIS studies that assess geospatial relationships and health care access and utilization need to take into account possible confounding factors such as other barriers to health care access that has already been demonstrated in the literature besides geographic. Furthermore, reporting and publishing criteria should be created by expert consensus, however should include at the very least methodology and scale of geocoding and detailed descriptions of calculations of travel time and distance measurements. Publication of manuscripts without this data limits the quality of study and ability to reproduce the study as well. Considerations as to the incorporation of sensitivity analysis into geospatial analysis, using various methods of calculating distance, should also be considered in future work. Lastly, presentation of geospatial data and mapping in publications should be conducted with consideration of patient privacy. Geospatial data can be viewed as protected health information and in peer reviewed papers, the resolution of published patient maps can be reverse engineered to determine an approximate location.[21] Geomasking should be considered and reported when publishing data at certain scale to maintain study population confidentiality.

CONCLUSION

Research that applies of GIS in understanding access and utilization of pediatric health services vary significantly in content and methodology. While the quality of evidence was limited by the design and methodology of most studies, the overall impact of GIS allowed for a better understanding of spatial relationships with regards to pediatric health care access and utilization. Distance decay phenomenon was observed in the majority of the studies. Future research needs to focus on developing improved study designs that go beyond descriptive analysis, more standardized approaches to geospatial analysis methodology, and improved standards for reporting geographic analysis results.

Authors Contributions:
JMT wrote the protocol with input from AFS, JAG, GH, HG and AMT. JMT developed the search strategy and conducted electronic searches with support from SEM who provided librarian scientific support. JMT, AFS, JAG, GH participated in the review of articles. JMT and AMT contributed to the conception and design of this review and revised it for important intellectual content. JMT is responsible for drafting the manuscript.

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Declarations (Conflicts of Interest):
The authors have no financial and non-financial conflicts of interest related to the contents of this manuscript.

Figure 1. Study selection flow diagram from literature review to data synthesis of articles published between 1/1/2000 and 12/31/2017 on the use of geographic information system to study access and utilization of health care services for pediatric populations retrieved from PubMed and EMBASE. Articles were also filtered for full peer reviewed publications, English language and human studies only.

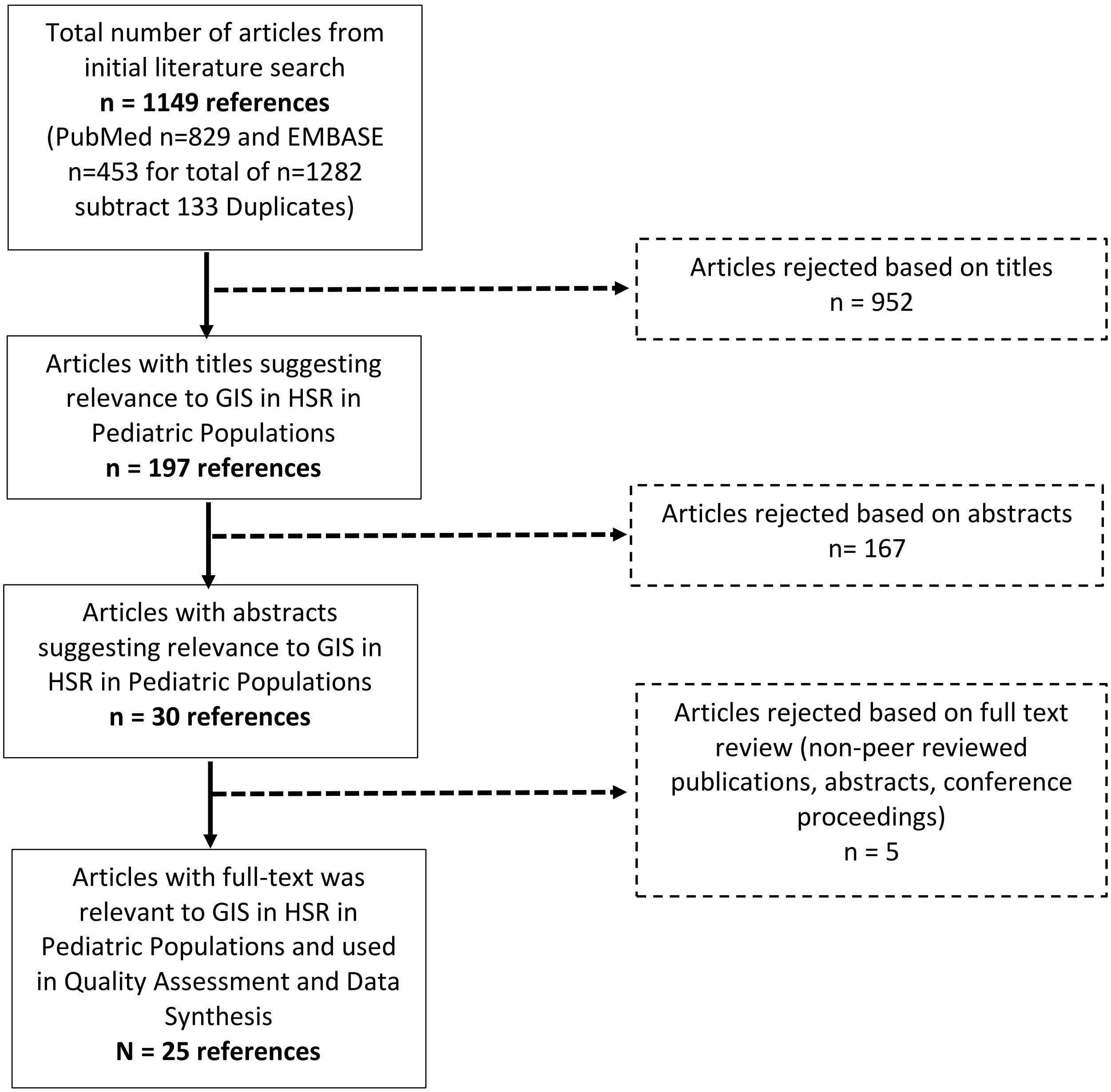

Table 1. Summary description of selected studies and quality of evidence rating using GRADE

Author (year)	Data Source	Population	Study Objectives	Sample Size (Unit of Analysis)	Geographic Region	Funding Source	Risk of Bias
Sommerhalter (2017)[42]	Population based surveillance database - State Level	Adolescents	To characterize geographic access to comprehensive cardiac care among adolescents with congenital heart defects.	2,522 Adolescents	State (New York, USA)	Grant: CDC	Low
Smith (2017)[43]	Surgeons OverSeas Assessment of Surgical Need (SOSAS) Survey	Children	To determine the geographic distribution of surgical conditions among children throughout Uganda.	2,176 Children	Country (Uganda)	Grant: Institutional / Johnson& Johnson	Moderate
Muffly (2017)[44]	US Census Bureau Data; US Department of Health and Human Services Area Health Resource File	Children	To describe the geographic distribution of pediatric anesthesiologists relative to the US pediatric population (0-17 years) and a subset of the pediatric population (0-4 years).	US Children in 2010 Census	Country (USA)	None	Low
Hansen (2016)[45]	A Single Local Emergency Medical System (EMS) database	Children	To determine if endotracheal intubation procedures are more likely to occur	7,797 EMS Runs	County (Oregon, USA)	None	High

			at greater distances from the hospital and near clusters of pediatric calls.				
Featherstone (2016)[46]	South Carolina Department of Health and Environmental Control Birth and Death Certificate records	Infants	To assess geographic access to delivery hospitals and risk of neonatal death among singleton very low birthweight infants born in South Carolina.	2,030 very low birth weight Infants	State (South Carolina, USA)	Grant: Institutional	Low
Amram (2016)[47]	Hospital administration data sets from British Columbia and Nova Scotia trauma registry	Children	To assess the impact of geographical access to pediatric trauma centers on patient outcomes, and to determine spatial access to pediatric trauma centers across Canada.	347 moderate to severe injured children in Nova Scotia and 1710 moderate to severe injured children in British Columbia	Province (British Columbia and Nova Scotia, Canada)	Primary Author Supported by Canadian Institutes of Health Research	Low
McMillan (2015)[48]	Electronic health record data from single academic pediatric hospital and US Census Bureau	Children	To investigate the importance of geographic risk factors and to confirm previously derived clinical risk factors that influence readmissions for sickle cell disease pain crisis.	501 Patients with sickle cell crisis	City (Washington, DC)	None	Low

Dumas (2015)[49]	Dental survey data from an academic primary care clinic and data from Pennsylvania Department of Public Welfare	Children (< 6 years old)	To examine dental utilization by Medicaid-insured children living in a high-resources area and characterize distance and travel-related variables to accessing care.	164 Children	City (Pittsburgh, PA)	Grant: Dental Trade Alliance Foundation; Institutional Funding; AHRQ	Moderate
Zaman (2014)[50]	Clinical Surveillance data from two large healthcare facilities	Children	To investigate whether straight-line distance from residential compounds to healthcare facilities influenced mortality, the incidence of pneumonia and vaccine efficacy against pneumonia.	6,938 Children	Rural area of Country (Gambia)	Grant: Institution; Board of the Global Alliance for Vaccines and Immunizations and the Vaccine Fund; NIH/WHO; US Agency for International Development	Moderate
Root (2014)[51]	Secondary analysis of placebo-controlled, double-blind randomized controlled trial data	Children (<2 years)	To measure the relationship between distance to the main study hospital and local-level pneumococcal vaccine efficacy.	12,194 Children	Rural province of Country (Bohol, Philippines)	None	Moderate
Delmelle (2013)[52]	Population based surveillance program - Florida Department of Transportation; Florida Birth Defects Registry; Hospital Discharge Records;	Infants	To calculate travel impedance to access medical care for infants with spina bifida and identify geographic variations in travel	612 Children	State (Florida, USA)	Grant: March of Dimes	Moderate

			impedance to access hospital care for these infants.				
Cassell (2013)[53]	Population based birth defects registry - North Carolina Birth Defects Monitoring Program; Mail/Phone Survey Instrument	Children	To determine one-way travel distance and time to receive primary cleft or craniofacial care for families of children with orofacial clefts and the extent to which taking a child to cleft and craniofacial care was perceived as a problem. To examine selected sociodemographic factors associated with travel time and distance to primary cleft care.	245 Children	State (North Carolina, USA)	Grant: National Center on Birth Defects and Developmental Disabilities, CDC	High
Okwaraji, Mulholland (2012)[54]	Surveys conducted from random selection of eligible households in the Dabat Health and Demographic Surveillance Site	Children (<5 years)	To assess whether travel time to health posts was associated with childhood vaccine coverage in a remote area of rural Ethiopia. To assess if vaccination coverage varied by household wealth status and if the effect of travel time on	775 Children	District (Dabat district, Ethiopia)	None	Moderate

			vaccine coverage was modified by household wealth.				
Okwaraji, Cousens (2012)[55]	Surveys conducted from random selection of eligible households in the Dabat Health and Demographic Surveillance Site	Children (<5 years)	To assess the effect of travel time and distance to health facilities on child mortality in this remote area of rural Ethiopia. To assess associations between household wealth and child mortality in remote areas.	2,206 Children	District (Dabat district, Ethiopia)	None	Moderate
Kashima (2012)[56]	Birth records from a nationally representative demographic and health survey	Children	To evaluate the association between proximity to a health center and early childhood mortality in Madagascar, and to assess the influence of household wealth, maternal educational attainment, and maternal health on the effects of distance.	12,345 Children	Country (Madagascar)	None	Moderate
Brantley (2012)[57]	US Census Bureau Data; National and International accrediting agencies; 2010 Homeland	Children	To describe by geographic proximity the extent to which the US pediatric population has access to pediatric	US Children in 2008	Country (USA)	None	Moderate

	Security Infrastructure Program Gold Dataset		and other specialized critical care facilities, and to highlight regional differences in population and critical resource distribution for preparedness planning and utilization during a mass public health disaster				
Schooling (2011)[58]	Prospective population representative birth cohort	Children	To examine whether childhood hospital use was associated with proximity, for both planned and unplanned admissions.	6,688 Children	City (Hong Kong, China)	Grant: Government of the Hong Kong SAR; Research Fund for the Control of Infectious Diseases in Hong Kong; Institutional	Low
Jenkins (2011)[59]	Single center cohort study - Follow-up of Adolescent Bariatric Surgery (FABS) Study	Adolescents	To determine whether the distance to the clinic, and other patient characteristics, would predict clinical follow-up compliance.	71 Adolescents	City (Cincinnati, OH)	Grant: Ethicon Endo-Surgery	High
Bersamin (2011)[60]	Longitudinal Survey Data from the National Institute of Child Health and Human Development	Adolescents	To examine the relationship between adolescent geographic access (distance, travel time, density) to Family Planning Clinics and adolescent sexual behaviors, including	921 Adolescents	Counties (California, USA)	Grant: National Institute of Child Health and Human Development	Moderate

			sexual initiation, number of partners and condom use.				
Moisi, Kabuka (2010)[61]	Population register/Epidemiologic and Demographic Surveillance System	Children	To identify predictors of the timing of immunization among infants in Kilifi District, with a focus on the effect of spatial factors such as distance to vaccine clinics.	2,169 Children	District (Kilifi District, Kenya)	None	Low
Moisi, Gatakaa (2010)[62]	Population register/Epidemiologic and Demographic Surveillance System	Children (<5 years)	To characterize spatial variations in child mortality in the Kilifi District, Kenya, and evaluate the effect of distance to health facilities on child survival in a context of increased health services density.	93,216 Children	District (Kilifi District, Kenya)	None	Low
Acosta (2010)[63]	Institutional trauma database	Children	To understand patterns of pediatric trauma patient transfers to the study trauma center as a first step in assessing the quality and efficiency of pediatric transfer within the current trauma system model.	2,798 Children	Region (Level 1 Pediatric Trauma Center, California	Grant: Agency for Healthcare Research and Policy	Low

Nance (2009)[64]	US Census Bureau Data; National associations databases	Children (<15 years)	To calculate and analyze the population's access to pediatric-specific trauma care for children younger than 15 years in the United States.	US Children in Census	Country (USA)	None	Low
Feikin (2009)[27]	Population register/Epidemiologic and Demographic Surveillance System	Children (<5 years)	To explore the impact of distance on utilization of peripheral health facilities for sick child visits in Asembo, rural western Kenya.	2,432 Children	Rural location (Asembo in Bondo District, Kenya)	None	Moderate
Case (2008)[65]	Texas Birth Defects Registry	Children	To use data from a statewide birth defects registry and geographic information system methodology to compare the spatial distribution and to summarize the distance of pediatric clinical genetic service providers in relation to residential addresses of children with selected birth defects in Texas.	22,875 Children	State (Texas, USA)	Grant: CDC	Moderate

Table 2. Description of Selected Study Method Variation for Geospatial Analysis in Selected Studies

Author (year)	Primary Outcome	Reported Method of Measurement	Geocode Method	Origin / Destination	Visualization method to protect confidentiality
Sommerhalter (2017)[42]	Drive time and public transit time	Google Maps Distance Matrix	Individual Addresses	Residential Home to Pediatric Cardiac Surgical Center	County Level
Smith (2017)[43]	Distance and Travel Time	Euclidean Distance	Geometric center of survey location and actual surgical center address	Geometric Center of Survey Location to Surgical Facility	District Level
Muffly (2017)[44]	Percentage of population living within ranges of driving distance	Proportion within concentric driving distance of service area	Block group population and City/State/Zip code of Anesthesiologist	US Census Block group population to Practice Location Address	US Census Block Groups
Hansen (2016)[45]	Distance and number of intubations	Visual display of data clusters	Individual Addresses	Incident location to hospital	County Level
Featherstone (2016)[46]	Travel time and neonatal mortality	Specific method for calculation not mentioned (only mentions ArcGIS Network Analyst Software Used	Individual Addresses	Maternal residence to delivery hospital	No map data visualization
Amram (2016)[47]	Driving time <60 min or > 60 min	Turn-by-turn calculations	Individual Addresses	Residential Address to Pediatric Trauma Center	Providence Level
McMillan (2015)[48]	30-day readmission	Euclidean Distance and subsequent categorization into distance bands determined a priori	Individual Addresses	Residential Address to Hospital Main Campus, affiliated primary care sites, emergency department and pharmacy	County Level

Dumas (2015)[49]	Driving distance	Shortest Drive Distance	Individual Addresses and tract centroid coordinates	Tract centroid coordinates and address of nearest dental clinic	City Level
Zaman (2014)[50]	Straight-line distance	Euclidean Distance and subsequent categorization into distance bands determined a priori	Hand-held global positioning system (Latitude and Longitude)	Residential compound and clinics/health care facility	Division Level
Root (2014)[51]	Distance	Euclidean Distance and subsequent categorization into distance bands	Aggregation of location into 2.5 km and 3km neighborhoods	Location of each child's house to health center	Government Administrative Units
Delmelle (2013)[52]	Travel distance and times	Driving distance using road network node modeling	Individual Addresses	Maternal home to hospital	Geomasking with coordinate shift
Cassell (2013)[53]	Maternal report of travel distance and time	Survey respondent report of travel distance and time	None	Self reported travel distance to primary craniofacial care site	No map data visualization
Okwaraji, Mulholland (2012)[54]	Travel Time	Travel time calculated using "Cost analysis" that estimates walking speed based on terrain type traversed and subsequent categorization into travel time groups	Hand-held global positioning system (Latitude and Longitude)	Residential home and health center	Kebeles - the smallest administrative unit in Ethiopia
Okwaraji, Cousens (2012)[55]	Travel time and mortality	Euclidean distance, distance traveled and travel time	Hand-held global positioning system (Latitude and Longitude)	Residential home and health center	Kebeles - the smallest administrative unit in Ethiopia
Kashima (2012)[56]	Distance	Euclidean Distance and subsequent categorization into distance bands	GPS Data	Household to nearest health center	Geomasking with coordinate shift

Brantley (2012)[57]	Percentage of population living within ranges of driving distance	Proportion within concentric driving distance of service area	Block group population and Hospital location	Grouped population to Practice Location Address	State Level
Schooling (2011)[58]	Distance and pubic hospital admissions, bed-days, and average length of stay by type of admission	Euclidean Distance and subsequent categorization into distance bands	Individual Addresses	Residential home to nearest public hospital	Neighborhood Level
Jenkins (2011)[59]	Distance and follow up at specified intervals after surgery	Great circle method using shortest straight-line distance between 2 points, accounting for curvature of the earth	Individual Addresses	Residential home to clinical center	State Level
Bersamin (2011)[60]	Distance and sexual behavior	Euclidean Distance and subsequent categorization into distance bands	Indiviudal Addresses	Residential home to clinical center	No map data visualization
Moisi, Kabuka (2010)[61]	Travel time and immunization coverage	Travel time calculated using "Cost analysis" that estimates speed based on terrain type traversed and subsequent categorization into travel time groups	Hand-held global positioning system (Latitude and Longitude)	Residential home and health center	Administrative locations within the District Level
Moisi, Gatakaa (2010)[62]	Travel time and mortality	Travel time calculated using "Cost analysis" that estimates speed based on terrain type traversed and subsequent categorization into travel time groups	Hand-held global positioning system (Latitude and Longitude)	Residential home and health center	Administrative locations within the District Level
Acosta (2010)[63]	Travel distance	Euclidean Distance	Georeferenced databased on hospitals	Transferring hospital to study center	No map data visualization

Nance (2009)[64]	Percentage of pediatric populations	Straight-line and rectilinear distance	Block group population	Block group centroid to the nearest trauma center	State Level
Feikin (2009)[27]	Distance and attendance for sick visits	Straight-line distance	Hand-held global positioning system (Latitude and Longitude)	Residential home and health center	Province Level
Case (2008)[65]	Distance	Straight-line distance	Street level address	Maternal home to nearest facility	County Level

Table 3. Overall quality of evidence assessment for applications of GIS in understanding access and utilization for pediatric health care services

Type	# of References	Risk of Bias	Consistency	Directness	Precision	Publication Bias	Dose Response Reported	Overall Assessment of Quality of Evidence
Access	19	Moderate	High	Moderate	High	Not suspected	Yes	High
Utilization	6	Moderate	High	Moderate	High	Not suspected	Yes	High

Appendix 1. Search Query for PubMed and EMBASE electronic database

PubMed Search Query:
Search (((((((gis OR geospatial OR geographic information systems OR spatial analysis)) AND ("2000/01/01"[PDat] : "2017/12/31"[PDat]))) AND (pediatric OR children OR child)) AND ("2000/01/01"[PDat] : "2017/12/31"[PDat]))) AND (health services OR utilization OR access OR accessibility) AND (("2000/01/01"[PDat] : "2017/12/31"[PDat]))

EMBASE Search Query:
((‘gis’/exp OR gis OR geographic) AND (‘information’/exp OR information) AND system OR geospatial OR ‘spatial analysis’/exp OR ‘spatial analysis’) AND (‘children’/exp OR children OR ‘child’/exp OR child OR ‘pediatric’/exp OR pediatric) AND (((‘health’/exp OR health) AND (‘care’/exp OR care) AND (‘access’/exp OR access) OR ‘health’/exp OR health) AND (‘care’/exp OR care) AND (‘utilization’/exp OR utilization) OR ‘access’/exp OR access OR ‘utilization’/exp OR utilization OR ‘health’/exp OR health) AND (‘access’/exp OR access) AND [English]/lim AND [2000-2017]/py

Appendix 2. Example table for assessing the GRADE criteria[37]

GRADE criteria	Rating (circle one)	Footnotes (explain reasons for down- or upgrading)	Quality of the evidence (Circle one)
Outcome:			
Study design	RCT (starts as high quality) Non-RCT (starts as low quality)		
Risk of Bias *(use the Cochrane Risk of Bias tables and figures)*	No serious (-1) very serious (-2)		⊕⊕⊕⊕ High
Inconsistency	No serious (-1) very serious (-2)		⊕⊕⊕◯ Moderate
Indirectness	No serious (-1) very serious (-2)		⊕⊕◯◯ Low
Imprecision	No serious (-1) very serious (-2)		⊕◯◯◯ Very Low
Publication Bias	Undetected Strongly suspected (-1)		
Other (upgrading factors, circle all that apply)	Large effect (+1 or +2) Dose response (+1 or +2) No Plausible confounding (+1 or +2)		

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