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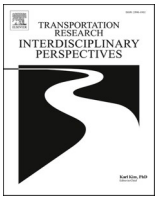

Measuring spatial accessibility of public libraries using floating catchment area methods: A comparative case study in Calhoun County, Florida

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ABSTRACT

Public libraries are critical facilities that provide a variety of essential services to the public such as providing access to information, resources, sheltering and gathering space during natural disasters such as hurricanes, especially in rural areas. Although several researchers have focused on accessibility to libraries, these works only consider the travel time or distance between communities and libraries, which may be an inadequate way of analyzing their accessibility. To provide a more realistic analysis, this paper uses the Enhanced Two-Step Floating Catchment Area (E2SFCA), and Three-Step Floating Catchment Area (3SFCA) methods to measure the accessibility of U.S. Census block groups to public libraries within Calhoun County, Florida, a rural county hit hard by Hurricane Michael in 2018. These methods define the service areas of libraries by a threshold travel time while accounting for their availability by the demand surrounding these facilities. Findings indicate there are disparities in accessibility among census block groups. The ones with higher population densities have lower accessibility to libraries which indicates that accessibility does not depend only on travel time as determined by other research works but also on the capacity of the service area. To improve the accessibility of public libraries in rural counties, this study recommends the creation of service areas for libraries in order to provide better service to the public, including vulnerable populations such as older adults.

Introduction

Social amenities such as libraries, hospitals, and shelters are parts of the social infrastructure system that are provided to improve the quality of life. Therefore, it is imperative to understand the accessibility of communities to these facilities. Central and local governments propose social infrastructure plans for these facilities and many other social infrastructures where communities are warranted to be adequately served. This infrastructure should be fairly distributed and effectively set up for service providers to satisfy locally varied community needs (Yhee et al., 2021). For infrastructure planning, population and accessibility should be considered as primary factors in accordance with land use planning. For example, the siting of public facilities such as libraries and their accessibility should be important in land use planning. Access to these public facilities becomes more convenient when the distribution of these facilities is carefully planned by considering the spatial distribution of the population, and taking vulnerable populations (e.g., elderly, families with children, and disabled) into consideration (Tao, 2022). Most communities in northwest Florida are in rural areas and comprise many vulnerable populations. Prior research has concentrated on the inequalities in access to some public facilities, like shelters and hospitals (Bryant & Delamater, 2019).

This inequality problem becomes even more complicated during natural disasters such as hurricanes. During hurricanes, these rural public libraries not only serve as a source of information and communication but they are also utilized as shelters if needed. As such, there is a need for these rural communities to have better access to these facilities. The time taken to travel to these facilities and the cost involved becomes a critical problem for many residents and this especially takes a toll on vulnerable populations. An evenly distributed accessibility is regarded as a reliable indicator of "equality of opportunity" (Oliver & Mossialos, 2004). Equality in service of these social amenities is one central policy that governments and local policymakers should consider. Planning to position libraries is crucial for libraries and librarians' role in emergency

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preparedness and natural disasters (Ghorbanzadeh et al., 2021). Concerning emergency preparedness and disaster recovery, the services delivered differ by disaster and community. Thus, it is frequently up to rural public libraries to find and offer services such as providing shelter, information, and social capital that other governmental agencies do not supply (Jaeger et al., 2007).

Many coastal and inland areas in Florida are prone to natural disasters, such as hurricanes and tropical storms. (CoreLogic, 2020). Some rural areas in northwest Florida have been severely impacted by Hurricane Michael in 2018, indicating the urge to focus on the needs of rural communities in this area. One such need is accessing resources before, during, and after natural disasters. With a focus on Calhoun County in northwest Florida, this study examines the spatial accessibility of vulnerable populations to libraries, where the population above sixty-five years (65 +) is assumed to be a representative subset of vulnerable populations. The aim is to identify the critical issues and gaps due to overestimation of accessibility which is related to the methodological variations, facility congestion (i.e., the demand above service capacity), and travel time considering total and vulnerable (65 +) populations residing in rural communities through a comparative analysis using two widely used spatial accessibility measurement methods: the Enhanced Two-Step Floating Catchment Area (E2SFCA), and the Three-Step Floating Catchment Area (3SFCA).

Literature review

Public libraries in disaster planning and response

In small towns around U.S., public libraries are regularly present (Johnson & Griffis, 2014). In all phases of disasters and towards addressing urgent community needs during these times, public libraries play a crucial role (Ghorbanzadeh et al., 2021). They generally have close ties to their communities and are a crucial component of local identity (Boyer, 2008). Libraries and librarians take on several different responsibilities during natural disasters, including disaster response and emergency preparedness. This responsibility of libraries and the roles librarians play during such an extreme event makes them an integral part of the disaster planning and response phase.

Most libraries are more durable than most community buildings since they are constructed from the ground up with stacks and large populations in mind (Mabe & Ashley, 2017). These libraries make room to accommodate residents in their local communities who have been affected by natural disasters, assist people in many ways, including health support, and educate their communities about health issues, treatments, and other resources. In addition, public libraries offer free access to reliable and high-quality information (Kosciejew, 2020). Public libraries significantly aid many U.S. communities. Public librarians also extend regular hours, help evacuees, offer improvised on-demand services, and assure library service continuity and restoration during disasters. They often serve as delivery locations for aid and information (Tenney et al., 2021). They serve as solid community hubs offering access to services the public cannot get anywhere else during natural disasters and fostering social integration while building a connection to opportunities and community engagement (Scott, 2011). People in the communities rely on public libraries for an Internet connection so they can apply for assistance, look up missing relatives and friends, submit to the Federal Emergency Management Agency (FEMA) their missing relatives, and file insurance claims (Bishop & Veil, 2013). People seek answers to questions regarding the nature of the threats that natural disasters pose on their communities and how to respond to them during times of crisis from libraries since they view libraries as credible sources of information (Zach, 2011). As a result, libraries leverage this as an opportunity to serve the residents within the communities in which they operate by ensuring they have the necessary information and resources available.

Between 2000 and 2022, Florida has been hit by 79 hurricanes or other severe storms, causing more than $123 billion in damage and 339 fatalities (*List of Florida Hurricanes*, 2022). Over the last two decades, this sad picture has alerted many federal, state, and local organizations at multiple scales. Libraries are one of the locally organized institutions that played and will continue to play an instrumental role in disaster planning and response over many decades by leveraging the resources at their disposal to serve residents in their communities.

Rural communities and public library accessibility

A quarter of the population of the United States lives in rural areas according to the Rural Policy Research Institute's 2007 report (Landgraf, 2016b). Rural communities usually have limited social amenities like libraries, hospitals, and schools. Public libraries have been one instrument for the dissemination of information and acquisition of knowledge and having access to such a facility is fundamental for many communities. Physical access to libraries is a crucial component of comfort and information for rural communities.

However, residents of many rural communities still must travel miles to access the closest library facility. This especially takes a major toll on vulnerable populations such as families with children, disabled, and aging populations who may have specific needs to access these facilities. Thus, travel distance is an essential factor, considered in previous accessibility analyses for public libraries, but often represented by straight lines creating underestimation problems (Park, 2012). Therefore, this study used network-based travel time to measure public library accessibility.

However, rural communities' distance and travel time as well as the misrepresentation of them are not the only factors for library accessibility. Limited capacities of rural libraries during demand peaks is one form of discouragement to residents in these communities (Johnson and Griffis, 2014). Library capacity is considered as a supply-side variable in this research. A rural community's susceptibility can be evaluated by assessing how easily its members can access social, economic, physical, and intellectual amenities like health care, information, transportation, and food (Ghorbanzadeh et al., 2021). Public libraries have a critical role here in providing many of these services. They have been helping low-income residents in rural areas and providing them with information; however, the actual transportation accessibility of the libraries is still a significant problem.

Accessibility of library services by aged populations

The vulnerability of older people is well-known, and hurricanes consistently have a disproportionately negative effect on them (Ghorbanzadeh et al., 2021). They also typically endure physiological changes brought on by aging and are more prone to certain illnesses. To further complicate the problem, the proportion of older people in the world's population is growing significantly (Kaminow et al., 1999). Therefore, the issues raised in the previous section are especially critical for the elderly, who use the services of libraries the most. Only in the U.S., 10,000 people reach retirement age every day. This will result in a significant demographic shift and a corresponding surge in demand for library services to older persons over the course of the following 15 years (Landgraf, 2016a).

Public libraries have been known to offer crucial services for helping older people find and use information (Glusker, 2014). The disaster preparedness training offered at libraries helps the older population gather hurricane information, prepare for them, and plan for measures to put in place during such natural disasters. The upcoming demographic change that public libraries will go through as a result of this aging population has lately been discussed by library experts (Landgraf, 2016a). The way public libraries view senior persons and the tools available to them must adapt and expand in response to the rise in aging populations as well as hurricane occurrences (Horton, 2019). These adaptations and expansions in library resources would improve their

accessibility.

Florida is known to host a significant number of older populations who are vulnerable to disasters. Aged populations are generally considered as those above the age of 65 and classified as vulnerable populations with children and people with disabilities. As such, this paper will also focus on the 65 + population as a case study because it is often considered the threshold age for retirement and eligibility for certain benefits and services as established by the United States (OECD Labour Force Statistics 2022, 2023) and many countries. The needs of older individuals are catered for by various services and initiatives. Healthcare services, elder housing, neighborhood amenities, senior discounts, and other advantages can be among them. Using 65 as the cutoff point enables targeted resource and service allocation for this demographic. By designating those 65 and older as "elderly," policymakers, healthcare professionals, and researchers can concentrate on the special requirements and difficulties this age group faces, such as age-related illnesses, geriatric care, and social support.

Application of GIS in library siting

Many studies have used GIS as a decision support tool in planning where to place facilities such as shelters, healthcare facilities, and industrial facilities (Eldrandaly, 2013). The applications of accessibility for libraries are not wide, but several researches have focused on this problem. A recent study used GIS to investigate, measure, and analyze library services and resources (Mandel et al., 2020). The study discovered increased GIS-enabled library research during the previous ten years. To estimate accessibility to libraries, a GIS-based statistical and descriptive analysis was used (Park, 2012) along with a roadway network-based distance measure. This study showed that access to libraries was significantly impacted by distance.

Kinikin (2004) used GIS to examine patron distribution in relation to the primary library systems and assess the demand for new Weber County library branches. The analysis revealed that the southeast region of the county needed more branches (Kinikin, 2004), where most libraries were relocated and closed due to poor and unsuitable locations. This challenged vulnerable populations that relied on the library services. The opening of a replacement facility closer to a person's home or place of employment can even be advantageous to some users (Koontz et al., 2009). GIS was also used in conjunction with multi-attribute decision-making (MADM) to choose an appropriate location for the construction of public libraries in Tehran using a spatial criterion (Shorabeh et al., 2020). According to the centrality criterion, 42 % of the research area was classified as being appropriate for library construction (Shorabeh et al., 2020). Additionally, GIS provides public libraries with data on neighborhood demographics, population trends, and other relevant topics so they can appropriately plan where to position their libraries (Bishop et al., 2011).

Although several researchers have focused on accessibility to libraries, these works only consider the travel time or distance between communities and libraries. To provide a more comprehensive and realistic analysis, this paper uses the Three-Step Floating Catchment Area (3SFCA), and the Enhanced Two-Step Floating Catchment Area (E2SFCA) methods to measure the accessibility of U.S. Census block groups to public libraries within Calhoun County, Florida, a rural county hit hard by Hurricane Michael in 2018.

Methodology

Floating catchment area (FCA) methods

The floating catchment area method is used in various fields to analyze and measure spatial accessibility to facilities, including healthcare (e.g., hospitals), education (e.g., schools), and services (e.g., jobs) (Luo, 2004; Luo & Qi, 2009; Luo & Wang, 2003a, 2003b; Saxon & Snow, 2020; Wan et al., 2012; Wang & Minor, 2002). Accessibility is influenced by many factors, such as travel impedance (e.g., time, distance, and cost), willingness to travel, and choice of transportation mode. Several methods have been employed considering these factors in spatial accessibility. One widely used methodology is the floating catchment area method (FCA), which measures accessibility using the supply-to-demand ratio. In the Chicago area, the FCA method was used to define the service area of physicians by a threshold travel time while accounting for their availability to the surrounding demand (Luo & Wang, 2003b). However, this research did not account for several elements, such as mode of transportation, socioeconomic characteristics, income, and population segmentation, such as minority populations. The two-step floating catchment area (2SFCA) method, which is a measure of accessibility by using the supply-to-demand ratio based on a given travel time, as well as the summation of these ratios (Luo & Wang, 2003b), was utilized to examine how various population groups are vulnerable to severe injuries considering crash locations. In another study, based on roadway network distances and a socioeconomic characteristics-based weighting method, an empirical-Gaussian 2SFCA method was employed (Kocatepe et al., 2017). The enhanced two-step floating catchment area (E2FCA) method is an improved version of the 2SFCA that gives less weight to suppliers farther from the origins but those that are still within the distance threshold (Luo & Qi, 2009). In addition to E2SFCA, the three-step floating catchment area (3SFCA) method is a more advanced method with a selection weight or populations' willingness to travel within a buffer distance in addition to the travel impedance weight.

The 3SFCA method works better compared to other gravity models, i.e., 2SFCA and E2SFCA methods since they disregard the selection weights even though E2SFCA uses a stepwise decay function similar to the 3SFCA. For the E2SFCA method, the first step is to establish a 30-minute catchment area for each service site. The catchment is then divided into three sub-zones based on 10, 20, and 30-minute intervals. Capacity-to-population ratio, R_j, for each library facility j is calculated using equation (1).

$$R_j = \frac{S_j}{\sum_{r=1,2,3}\sum_{k\in D_r} P_k W_r} \tag{1}$$

where S_j is the total supply (i.e., number of libraries) available inside a distance or time-based buffer centered at provider location j, W_r is the travel time weight (e.g., impedance) for the travel time of each sub-zone D_r defined using a stepwise decay function; P_k is the total population or demand inside a buffer centered at location k and r is the various sub-zones (zone 1, zone 2, and zone 3) within the catchment area.

$$Ai^{e2sfca} = \sum_{r=1,2,3}\sum_{j\in D_r} R_j W_r \tag{2}$$

where A_i^{e2sfca} is the spatial accessibility index of location i, W_r is the travel time weight (impedance) for the travel time of each sub-zone. D_r defined using a stepwise decay function function, and R_j is the library-to-population ratio. E2SFCA takes into account the distance impedance within the catchment area, resulting in a decrease in people's access to a library as travel time increases (Wan et al., 2012).

These methods have been applied to healthcare and other areas, but there are limited applications to library accessibility. To determine how well public libraries are situated to serve rural populations in Northwest Florida, a geographic information system (GIS)-based methodology was used previously (Ghorbanzadeh et al., 2021). However, this research did employ floating catchment area methods, but only focused on the travel time-based accessibility.

This paper uses the 3SFCA and E2SFCA methods to measure the spatial accessibility of libraries within rural communities in Calhoun County in northwest Florida. In this method, it is assumed that the accessibility of other facilities will impact how much a population requests from a particular facility (Wan et al., 2012). The steps are as follows:

Step 1: Based on a 30-minute driving radius around the population

area, determine the population area's catchment. Each catchment is then split into multiple travel time zones (e.g., 10, 20, and 30 min) and it is dependent on the travel time. A selection weight (G), which is a stepwise decay function, is then assigned to the travel time weight (W) of each library location based on the zone in which they lie (e.g., zone 1, zone 2, and zone 3 if there are three zones) since every zone within the buffer is not equally accessible. The selection weight between the demand location i and supplier location j is calculated using equations (3), (4), and (5).

$$G_{ij} = \frac{W(t_{ij})}{\Sigma W(t_{ik})} \quad k \in \{TravelTime(i,k) < t0\} \tag{3}$$

where G_{ij} is the selection weight between origin i and library site j; where, $W(t_{ij})$ is the travel time or impedance weight for each (i,j) pair calculated using a stepwise decay function, and the corresponding stepwise decay function for j and k are t_{ij} and t_{ik}, respectively; *Travel Time* (i, k) is the travel time (impedance) in minutes from any service site i to any site k inside the catchment, and t_0 is the size of the catchment (i.e., 30 min driving time used for the purpose of this research).

Step 2: Using the same method as step 1, calculate the 30-minute catchment area of each facility site j and divide the catchment into three zones. Find every location in the catchment, then calculate the ratio (R) of the library to the population of location j by

$$R_j = \frac{S_j}{\sum_{r=1,2,3}\sum_{k\in D_r} G_{kj}P_k W_r} \tag{4}$$

where S_j is the total supply (libraries) available inside a distance or time-based buffer centered at provider location j, W_r is the travel time weight (impedance) for the travel time of each sub-zone r defined using a stepwise decay function; G_{kj} is the selection weight between j and population site k derived from a stepwise decay function and P_k is the total population or demand inside a buffer centered at position k and r is the various sub-zones (zone 1, zone 2, and zone 3) within the catchment area (Wan et al., 2012).

Step 3:

$$A_i^{3fca} = \sum_{r=1,2,3}\sum_{j\in D_r} G_{ij}R_j W_r \tag{5}$$

where A_i^{3fca} is the spatial accessibility of population site i, G_{ij} is the selection weight between origin i and library site j derived from a stepwise decay function, and W_r is the travel time weight (impedance) for the travel time of each sub-zone, and D_r defined using a stepwise decay function.

For the 3SFCA method, when there is only one library facility, then the selection weight becomes static as the population can only access one location. However, if there are multiple library locations within the catchment area, the population can now decide through the selection weight, which is based on the travel time weight (i.e., the facility near the origin of the population). The methodology has a clear assumption: If there are multiple library facilities in the catchment area, the population's demand for a library facility around them is influenced by the impedance (e.g., travel cost) of that facility as well as the impedance of another facility within the same catchment area with different costs. The selection weight in the 3SFCA method considers that a population's demand for a particular facility could decrease with the increasing availability of other library facilities with the selection weight (G). With the multiplication of the $G_{ij} \times P_i \times W_{ij}$, the adjusted population demand of origin i on a library at location j can be determined.

Case study and data

This study employs the E2SFCA and 3SFCA methods in measuring the spatial accessibility to library facilities within Calhoun County in the northwest Florida region. Calhoun County is one of many rural counties in Florida with a population of around 14,000 people with 29.5 % being 65 and older (Calhoun County, Florida Population 2022, 2022). Calhoun County has an area of 574 mi^2 with six public libraries (See Fig. 1). Overall, the county has limited access to emergency facilities and was drastically impacted by Hurricane Michael in 2018 (Ghorbanzadeh et al., 2021), where some roadways, such as state roadway 20 (SR 20), were closed. The road closures made already limited facilities even more inaccessible.

The population data is at the census block group level (total population and 65 and older population). There are ten census block groups within Calhoun County. The total population, total population density, aged (65 +) population, and 65 + population density maps are shown in Fig. 2. Block groups 4 and 6 have the highest population for total population and block group 3 has the least total population. The population density for block group 6 is the highest whereas block group 3 has the lowest population density. On the other hand, block group 4 has the highest aged population and block groups 3 and 7 have the lowest. The population density for the aged population is highest in block groups 4, 6, 8, and 9 and lowest in block group 3. Library capacities are estimated for both total and aged populations by dividing the surface area of each facility by the space requirement of respective population segment. For the total population 20 sq ft, and for the aged population 60 sq. ft. are the assumed space requirements of each individual (Scott & Maul, 2018).

Evaluation procedure

This paper examined the E2SFCA and 3SFCA methods for spatial accessibility to libraries, where the spatial patterns of the accessibility scores and the areas with lower accessibility were identified. The following describes how these two methods were used specifically, along with the comparison process.

The census block groups are represented by their geographic centroids, and a block group's population (total population and aged population in two different scenarios) was considered the demand of that block group. Travel time is a good measure of accessibility (Wang & Minor, 2002). The Origin-Destination Cost Matrix feature of ArcGIS Pro 3.1 was used to calculate the congested travel times between block group centroids and library locations. This feature generates a matrix showing the congested travel times between all origin (census block group centroids) and destination (libraries) pairs within a travel-time threshold.

The first phase of this application involved determining the travel time for each census block group and library pair to acquire the selection weight, which was used to demonstrate how the populations in those block groups can access libraries. The second phase was to determine the capacity-to-demand ratios used in the final step to calculate the accessibility of each block group. After generating the travel times to assign zones to the various facilities and obtaining the distance and selection weights, the weighted sum of G, P, and W represents the adjusted accessibility score of each census block group. In the E2SFCA method, the stepwise decay function was used and capacity-to-demand ratios were calculated, but selection weights were not considered.

Results

Findings of applying the E2SFCA and 3SFCA methods in measuring the spatial accessibility of libraries within Calhoun County are shown in Table 1. The obtained accessibility indices were based on two weights (i.e., selection and distance weights), and the supply-to-demand ratios of the various library facilities within the area.

In Fig. 3, k-means clustering was used to cluster and depict accessibility scores. For both 3SFCA and E2SFCA methods, several k values were used to check the clustering of the accessibility scores, and the lowest error (0.05) yielding clustering was obtained when $k = 8$. The accessibility maps were prepared according to the k-means clustering

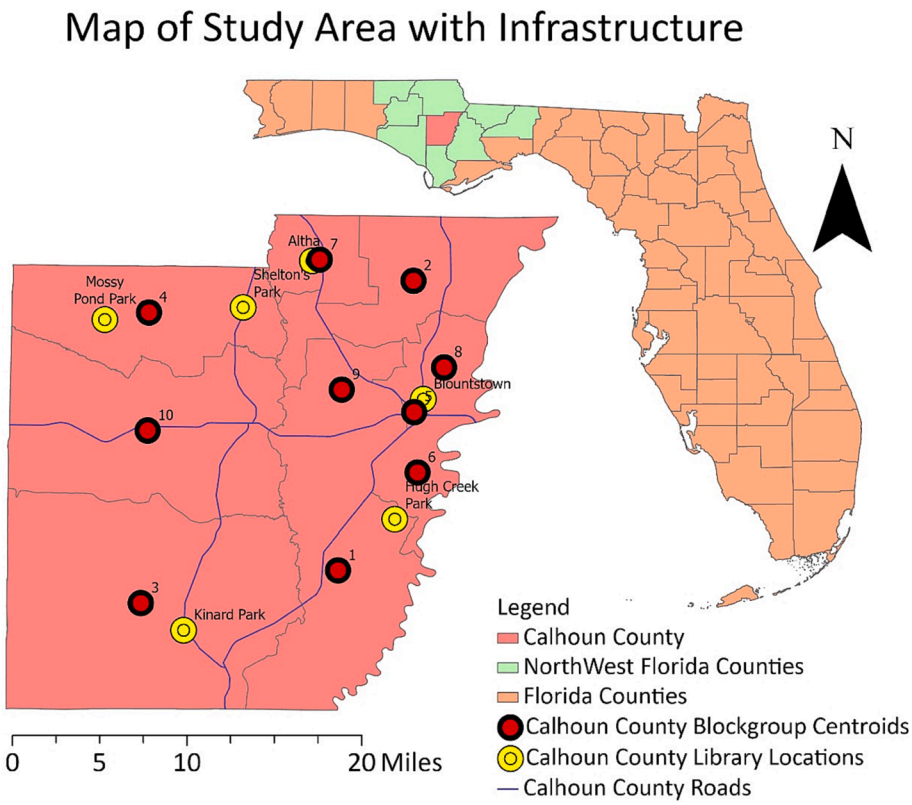


Fig. 1. Study Area.

results and the accessibility scores presented in Table 1. Incorporating k-means clustering with 3SFCA or E2SFCA models made it possible to identify spatial patterns and classify locations according to the ten block groups. It assisted in clustering block groups with similar accessibility profiles.

Fig. 4 shows the spatial accessibility scores for the total and 65 + population. One advantage of using the 3SFCA method for measuring spatial accessibility is the opportunity for one demand point to choose which facility to use. According to Fig. 4a, when the 3SFCA method was applied, there is a clear indication that the block group with a higher accessibility index (block group 3) had access to multiple library facilities with minimum travel times. This is the only case where 3SFCA overestimates the accessibility compared to the E2FSCA. In all other cases, we observe that E2FSCA has the problem of yielding overestimated accessibility scores.

As shown in Fig. 4, block groups 1, 7, 9, and 10 had higher accessibility scores using E2SFCA for both total and aged populations; however, their accessibility scores are reduced in the 3SFCA due to the selection weight. This indicates overestimation in the E2SFCA since most block groups had more facilities but were not accessible, considering several other factors such as travel time, choice, and population distribution. Also, in the 3SFCA (see Fig. 4**a**), block group 4 has access to multiple facilities compared to block groups 1, 2, 3, 9, and 10 (see Table 1). These block groups have fewer close facilities, but block groups 1, 3, and 9 have better accessibility scores than block group 4. This is because a few libraries with higher capacity and accessibility are located in less populated areas.

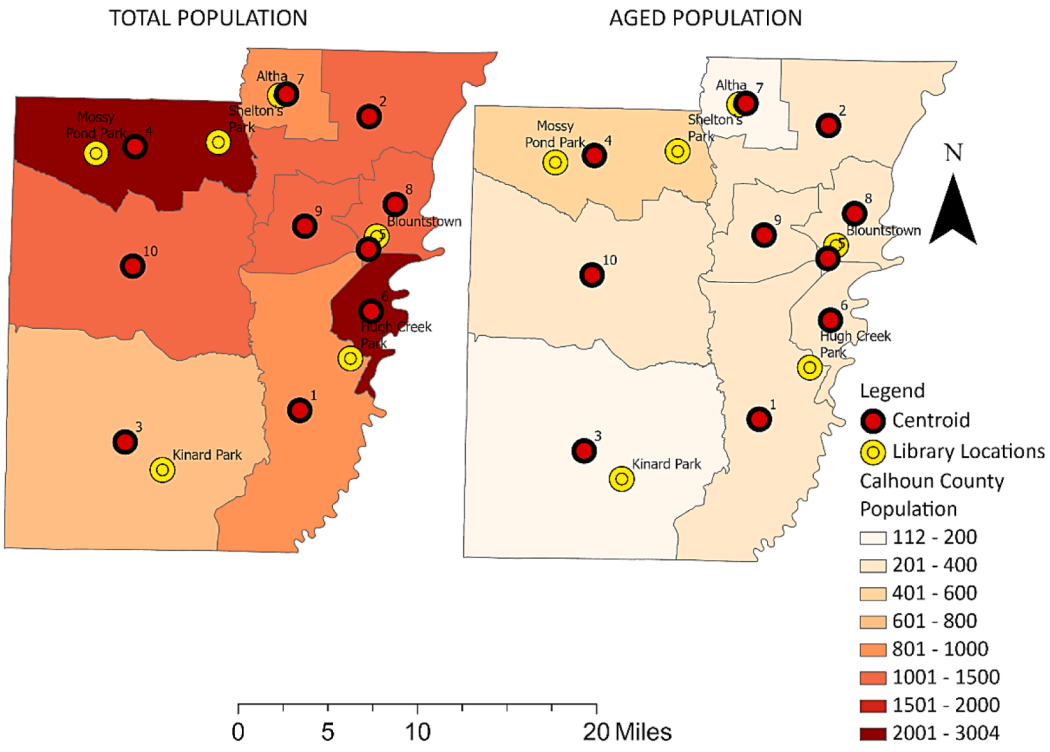
Fig. 5 compares the accessibility scores calculated by the 3SFCA and E2SFCA methods. Most block groups with high accessibility scores were presented in the E2SFCA portion of the chart. The E2SFCA does not consider the selection weight, which residents may have regarded as the travel time to the closest facilities. However, in the case of emergency management, where the residents must choose between facilities to use, there are several factors other than the capacity of a facility or demand, such as travel cost and proximity. Therefore, residents can choose based on which factor is essential for them. The 3SFCA scores are lower than those for E2SFCA since it considers a selection weight that gives options and choices to demand points by not limiting important factors to demand only.

Based on the findings, the demand of block group 4 supersedes the available supply within the region. According to Fig. 2, places with lower population density have higher accessibility scores in Fig. 4 for the total and aged population. In contrast, areas that have higher population density have lower accessibility scores for both the total population and the aging population. The same pattern is observed in Fig. 5. Note that these results depend on the capacity, demand, and travel time to the facilities. Some block groups also had higher accessibility for the aged population than the total population within the same models due to having a lower aging population than the entire population within the area.

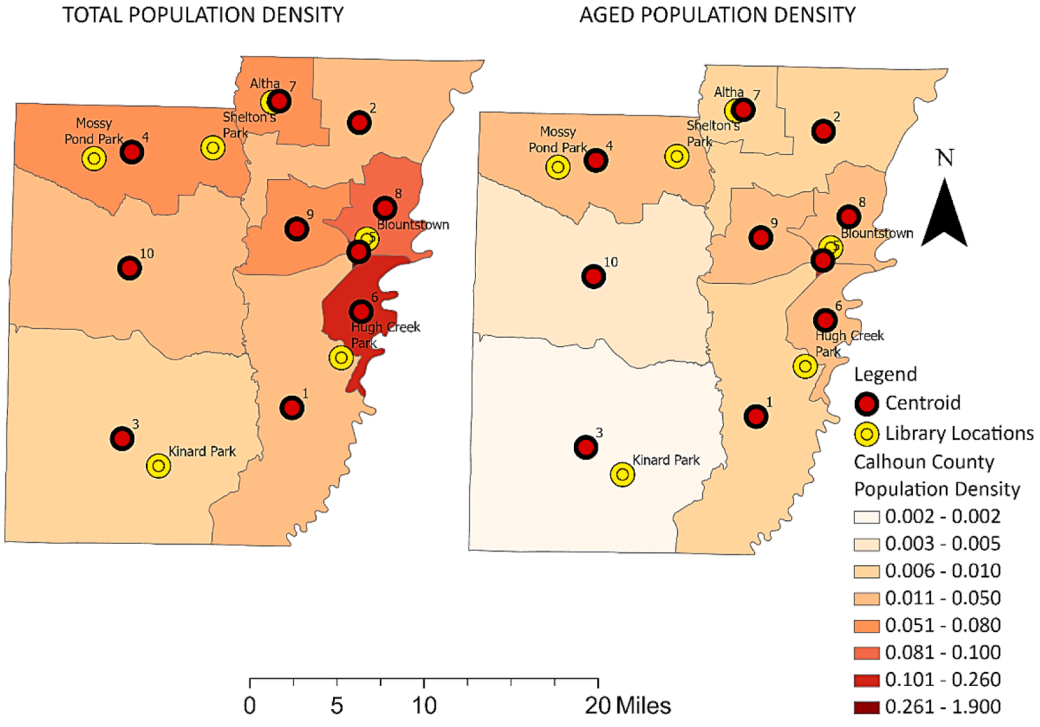
Findings indicate a clear sign of overestimation in the case of the E2SFCA. This is because, within this method, residents consider not only the facility's capacity but also how fast and early they can access these facilities. Therefore, if several facilities have the same or similar holding capacity, the 3SFCA method helps measure which facility is more accessible. Libraries are less accessible for the areas with lower accessibility scores in both models. For locations where the population is clustered densely, it may be easier to see how E2SFCA overestimated the accessibility scores for libraries.

Discussion

This study addressed a knowledge gap in the transportation accessibility field by studying the accessibility to libraries by defining service areas for them using a threshold travel time and accounting for their availability by the public demand. To provide a more comprehensive and realistic analysis, this paper uses the Enhanced Two-Step Floating Catchment Area (E2SFCA) and Three-Step Floating Catchment Area



(a)



(b)

Fig. 2. Population distribution of Calhoun County (a) Population (b) Population density.

Table 1
3SFCA and E2SFCA scores for the block groups within Calhoun County

BLOCK GROUP ID	3SFCA SCORE		E2SFCA SCORE	
	TOTAL POP.	AGED POP.	TOTAL POP.	AGED POP.
1	0.1208	0.2044	0.1263	0.2176
2	0.1020	0.1851	0.1002	0.1767
3	0.1595	0.2585	0.1230	0.2097
4	0.1127	0.1878	0.1123	0.1912
5	0.1116	0.1973	0.1307	0.2275
6	0.1229	0.2192	0.1091	0.1919
7	0.1011	0.1737	0.1245	0.2147
8	0.1239	0.2207	0.1099	0.1933
9	0.1157	0.2042	0.1293	0.2250
10	0.1048	0.1799	0.1206	0.2078

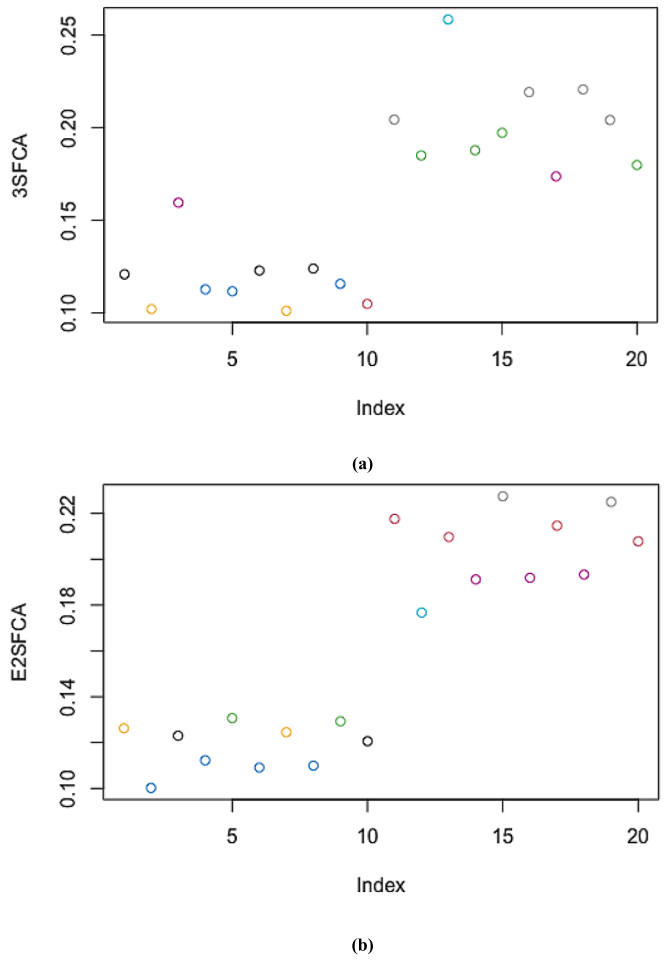


Fig. 3. K-means clustering for (a) 3sfca method, and (b) e2sfca method.

(3SFCA) methods to measure the accessibility of U.S. Census block groups to public libraries within Calhoun County, Florida, a rural county hit hard by Hurricane Michael in 2018.

Note that libraries are critical community facilities where communities access information and get support during natural disasters such as hurricanes. Disparities in access to those facilities, which may result in poor accessibility, a lack of library services, and a concentration of library resources in one location, would exacerbate social and educational differences. Besides, the ease of access is critical during hurricanes and other natural disasters when those facilities are used as shelters. During natural disasters, residents living within communities with lower accessibility will have difficulty getting timely help and support from librarians due to long distances and travel times.

It is important to identify those areas with low accessibility to libraries because this information may have policy implications for better library plans or continuity of operations documents. As such, problematic areas can be identified so that agencies can leverage this information to alleviate the accessibility problems of those locations, and policymakers can better allocate resources, ensuring that libraries are positioned to serve best the communities in need, whether for regular access or in times of need. Of course, providing accessibility to all these locations would be ideal from a transportation point of view, but it would not be feasible and practically possible. One solution would be to provide mobile library services to those communities to offer assistance and information, especially in underserved communities.

Understanding library accessibility can be crucial to broader community initiatives to improve resilience. Communities can better endure and recover from disasters by ensuring libraries are widely dispersed and accessible. This will lead to better information dissemination during disasters, which heavily depend on libraries, especially in rural areas. Accurate accessibility measurements can help ensure that libraries are situated where the public can successfully access them. Administrators can also adjust their services, especially while facing disasters such as hurricanes, to match the unique needs of communities by recognizing the genuine accessibility of their libraries. For instance, libraries in less accessible locations could concentrate on serving as emergency gathering places for the local population.

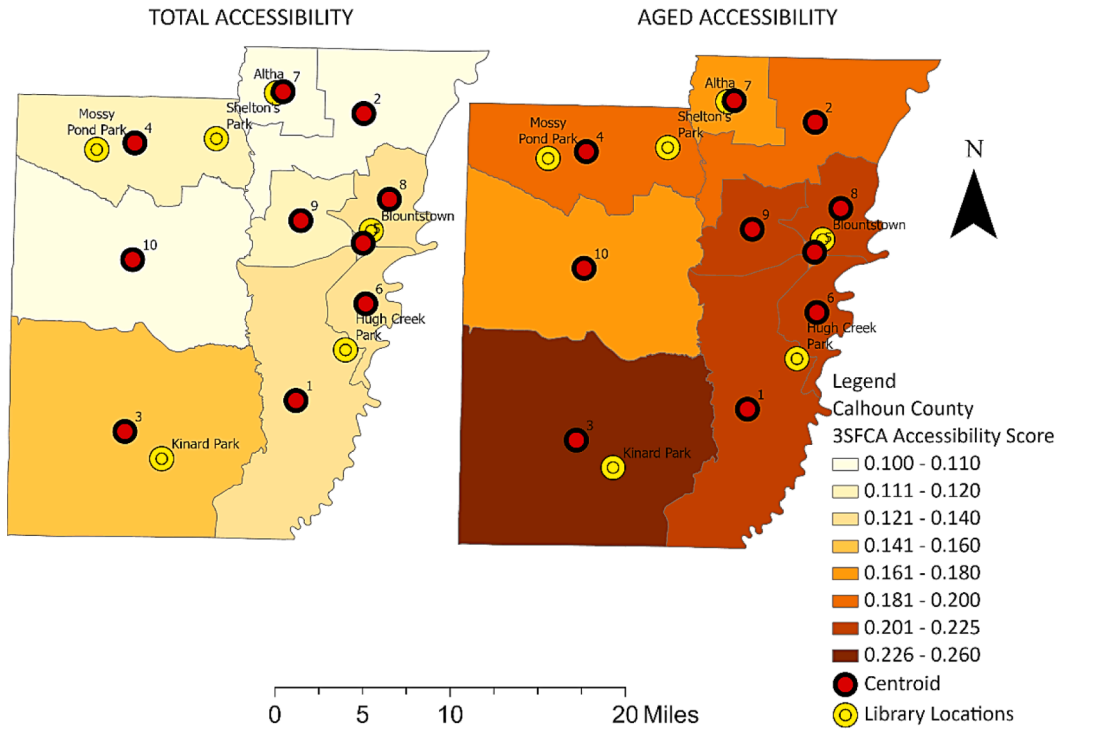
This study has the potential to raise awareness among users about the importance of library accessibility and its influence on their communities towards better advocating for the maintenance and enhancement of library services. Appropriately allocating resources to communities with less accessibility would be critical in how libraries can serve them more effectively.

We are aware of other possible approaches that can be adopted to assess the accessibility to libraries and optimize the possible future locations of these facilities. For example, one approach would be to identify the residence of individuals using libraries and their services and perform statistical analysis using demographic and socioeconomic variables of residence as proxy information of their identity. Although this is a valid approach, it is challenging due to data scarcity and strong assumptions about using these variables as a proxy for a person or household. On the other hand, our approach does not require such data sets and is a practical way of estimating the accessibility of libraries to surrounding communities.

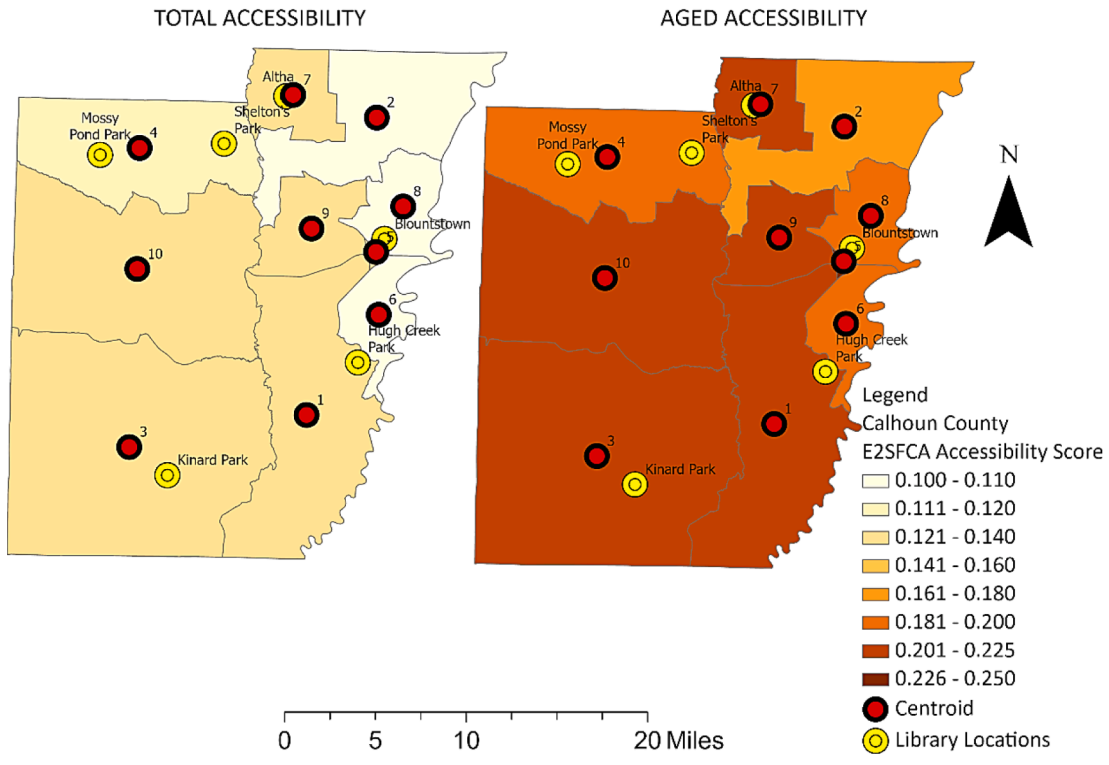
To sum up, the presented approach to transportation accessibility is worth studying. This paper is a first step towards investigating the accessibility of libraries from a service area standpoint, which would be a promising aspect that would add to the transportation and library science knowledge bodies.

Conclusions, Limitations, and future work

This study was conducted to understand the library siting and populations' accessibility to public libraries in a better way compared to the existing literature. As such, the E2FSCA and 3SFCA methods have been selected to measure and analyze the spatial accessibility of block groups to libraries in Calhoun County based on the comparative analysis provided. The methodology used in this paper considers potential interaction between residents within proximity to library facilities. According to the results, there are disparities in accessibility among census block groups. The ones with higher population densities have lower accessibility to libraries, which indicates that accessibility does not depend only on travel time as determined by other research works but also on the capacity of the service area. This should be taken into consideration in future planning efforts. Some block groups without many library facilities but near other block groups with high-capacity library facilities have better access due to their lower population. Better accessibility levels could be achieved by situating additional library facilities in the areas with lower accessibility scores or by increasing the libraries'



(a)



(b)

Fig. 4. Accessibility scores using (a) 3SFCA Method and (b) E2SFCA Method.

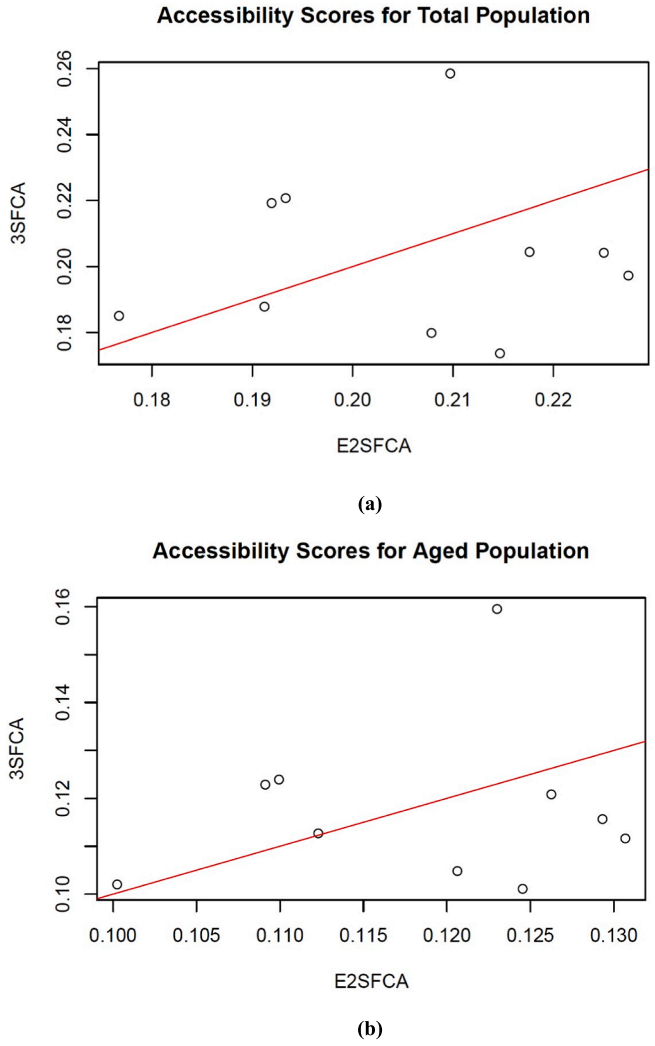


Fig. 5. Comparison of accessibility scores of 3SFCA and E2SFCA methods (a) Total population (b) Aged population.

capacities that could serve more populations. However, more in-depth research on the spatial accessibility of rural areas to libraries is required, emphasizing alternative potential accessibility models to deal with the issue of overestimation when measuring spatial accessibility.

It was also revealed that in areas with multiple facilities, accessibility can be higher when the facilities can serve a larger group. The 3SFCA method made it available for residents to choose which facility to access. However, when all facilities within the catchment area cannot serve the population, residents must travel long distances to access other library facilities. However, when a facility has a higher accessibility score, it would be more convenient for residents to choose which library is best accessible without considering traveling a long distance to other facilities. The service competition structure of the 3SFCA method could cause its moderating effect (Wan et al., 2012). For instance, more service capacity will be "assigned" to remote and sparsely populated locations due to the selection weight's tendency to "allocate" a lesser proportion of services to densely populated areas with many libraries. The spatial accessibility for less populous block groups will then increase.

Some limitations in this study include the following: Sample size (i.e., number of libraries) can be increased with data on libraries from other counties to support and validate the findings. Capacities for the libraries were estimated based on space; however, this can be improved with more realistic data on their usage. Different catchment areas can also be utilized to provide sensitivity analyses. This study has studied older adults as the vulnerable population group. In future work, sites for constructing new libraries can be identified based on those locations with low spatial accessibility index, with higher significant weights. Also, other population segments can be studied regarding their accessibility to libraries. The mode of transportation can also significantly impact the accessibility, and therefore, should be an excellent direction for future work. Other socioeconomic factors such as income, education, and age can also influence accessibility, which can be added to the proposed approach.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Author contributions statement

The following authors confirm their contribution to the paper with regards to Study conception and design: Samuel Takyi, Richard B. Antwi, Onur Alisan, Mahyar Ghorbanzadeh, and Eren Erman Ozguven; Data collection: Samuel Takyi, Richard B. Antwi, Onur Alisan, Mahyar Ghorbanzadeh, Eren Erman Ozguven, Marcia Mardis, and Faye Jones; Analysis and interpretation of results; Manuscript preparation: Samuel Takyi, Richard B. Antwi, Onur Alisan, Mahyar Ghorbanzadeh, Eren Erman Ozguven, Marcia Mardis, and Faye Jones. All authors reviewed the results and approved the final version of the manuscript.

References

Bishop, B.W., Mandel, L.H., McClure, C.R., 2011. Geographic information systems (gis) in public library assessment. Libres 21 (1). https://doi.org/10.32655/libres.2011.1.1.

Bishop, B.W., Veil, S.R., 2013. Public libraries as post-crisis information hubs. Public Library Quarterly 32 (1), 33–45. https://doi.org/10.1080/01616846.2013.760390.

Boyer, J.P., 2008. Local Library Global Passport: The Evolution of a Carnegie Library. Blue Butterfly, pp. 341–342.

Bryant, J., Delamater, P.L., 2019. Examination of spatial accessibility at micro- and macro-levels using the enhanced two-step floating catchment area (E2SFCA) method. Ann. GIS 25 (3), 219–229. https://doi.org/10.1080/19475683.2019.1641553.

CoreLogic. (2020). *Storm surge report.* https://www.corelogic.com/wp-content/uploads/sites/4/downloadable-docs/storm-surge-report-20200528-screen-2.pdf.

County, C., 2022. Florida Population 2022. https://worldpopulationreview.com/us-counties/fl/calhoun-county-population.

Eldrandaly, K., 2013. Developing a GIS-based MCE site selection tool in ArcGIS using COM technology. Internat. Arab J. Inform. Technol. 10 (3), 276–282.

Ghorbanzadeh, M., Ozguven, E.E., Tenney, C.S., Leonarczyk, Z., Jones, F.R., Mardis, M. A., 2021. Natural disaster accessibility of small and rural libraries in Northwest Florida. Public Library Quarterly 40 (4), 310–329. https://doi.org/10.1080/01616846.2020.1772027.

Glusker, A., 2014. Public libraries could better serve older adults with more programming specifically directed toward them. Evid Based Libr Inf Pract 9 (4), 70–72. https://doi.org/10.1080/01616846.2013.818814.

Horton, J., 2019. Senior Citizens in the Twenty-First-Century Public Library. Public Library Quarterly 38 (2), 179–192. https://doi.org/10.1080/01616846.2018.1554176.

Jaeger, P.T., Langa, L.A., McClure, C.R., Bertot, J.C., 2007. The 2004 and 2005 Gulf Coast Hurricanes: Evolving roles and lessons learned for public libraries in disaster preparedness and community services. Public Library Quarterly 25 (3–4), 199–214. https://doi.org/10.1300/J118v25n03_17.

Johnson, C.A., Griffis, M.R., 2014. The effect of public library use on the social capital of rural communities. J. Librariansh. Inf. Sci. 46 (3), 179–190. https://doi.org/10.1177/0961000612470278.

Kaminow, S., Kleiman, A., Lang, R. J., Martin, J., Mayo, K., Miller, A., Parker, S., Pellusch, J., Rubin, R., Schaffer, C., & Smart, E. (1999). *Guidelines for Library Services to Older Adults*.

Kinikin, J.N., 2004. Applying geographic information systems to the Weber County Library System. Inf. Technol. Libr. 23 (3), 102–107.

Kocatepe, A., Ulak, M.B., Ozguven, E.E., Horner, M.W., Arghandeh, R., 2017. Socioeconomic characteristics and crash injury exposure: A case study in Florida using two-step floating catchment area method. Appl. Geogr. 87, 207–221. https://doi.org/10.1016/j.apgeog.2017.08.005.

Koontz, C.M., Jue, D.K., Bishop, B.W., 2009. Public library facility closure: An investigation of reasons for closure and effects on geographic market areas. Libr. Inf. Sci. Res. 31 (2), 84–91. https://doi.org/10.1016/j.lisr.2008.12.002.

Kosciejew, M., 2020. Public libraries and the UN 2030 Agenda for Sustainable Development. IFLA J. 46 (4), 328–346. https://doi.org/10.1177/0340035219898708.

Landgraf, G., 2016a. An aging population reshapes library services: Growth rate of older adults produces demographic shift. Am. Libr. 22–23.

Luo, W., 2004. Using a GIS-based floating catchment method to assess areas with shortage of physicians. Health Place 10 (1), 1–11. https://doi.org/10.1016/S1353-8292(02)00067-9.

Luo, W., Qi, Y., 2009. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. Health Place 15 (4), 1100–1107. https://doi.org/10.1016/j.healthplace.2009.06.002.

Luo, W., Wang, F., 2003a. Measures of spatial accessibility to health care in a GIS environment: Synthesis and a case study in the Chicago region. Environ. Plann. B. Plann. Des. 30 (6), 865–884. https://doi.org/10.1068/b29120.

Luo, W., Wang, F., 2003b. Measures of spatial accessibility to health care in a GIS environment: Synthesis and a case study in the Chicago region. Environ. Plann. B. Plann. Des. 30 (6), 865–884. https://doi.org/10.1068/b29120.

Mabe, M., & Ashley, E. A. (2017). The Developing Role of Public Libraries in Emergency Management: Emerging Research and Opportunities. In *Advances in Library and Information Science*. IGI Global. 10.4018/978-1-5225-2196-9.

Mandel, L.H., Bishop, B.W., Orehek, A.M., 2020. A new decade of uses for geographic information systems (GIS) as a tool to research, measure and analyze library services. Library Hi Tech. https://doi.org/10.1108/LHT-03-2020-0052.

OECD Labour Force Statistics 2022. (2023). OECD. 10.1787/dc0c92f0-en.

Oliver, A., Mossialos, E., 2004. Equity of access to health care: Outlining the foundations for action. J. Epidemiol. Community Health 58 (8), 655–658. https://doi.org/10.1136/jech.2003.017731.

Park, S.J., 2012. Measuring public library accessibility: A case study using GIS. Libr. Inf. Sci. Res. 34 (1), 13–21. https://doi.org/10.1016/j.lisr.2011.07.007.

Saxon, J., Snow, D., 2020. A rational agent model for the spatial accessibility of primary health care. Ann. Am. Assoc. Geogr. 110 (1), 205–222. https://doi.org/10.1080/24694452.2019.1629870.

Scott, R., 2011. The role of public libraries in community building. Public Library Quarterly 30 (3), 191–227. https://doi.org/10.1080/01616846.2011.599283.

Scott, R., & Maul, W. (2018). Statewide Emergency Shelter Plan 2018.

Shorabeh, S.N., Varnaseri, A., Firozjaei, M.K., Nickravesh, F., Samany, N.N., 2020. Spatial modeling of areas suitable for public libraries construction by integration of GIS and multi-attribute decision making: Case study Tehran, Iran. Lib. Inform. Sci. Res. 42 (2) https://doi.org/10.1016/j.lisr.2020.101017.

Tao, Z. (2022). Facility or Transport Inequality ? Decomposing Healthcare Accessibility Inequality in Shenzhen , China.

Tenney, C., Leonarczyk, Z., Ghorbanzadeh, M., Jones, F., & Mardis, M. (2021). A GIS-Based Analysis for Transportation Accessibility, Disaster Preparedness, and Rural Libraries' Roles in Community Resilience. *Alise 2021*.

Wan, N., Zou, B., Sternberg, T., 2012. A three-step floating catchment area method for analyzing spatial access to health services. Int. J. Geogr. Inf. Sci. 26 (6), 1073–1089. https://doi.org/10.1080/13658816.2011.624987.

Wang, F., Minor, W.W., 2002. Where the jobs are: Employment access and crime patterns in Cleveland. Ann. Assoc. Am. Geogr. 92 (3), 435–450. https://doi.org/10.1111/1467-8306.00298.

Yhee, H., Kim, S., & Kang, S. (2021). Gis-based evaluation method for accessibility of social infrastructure facilities. *Applied Sciences (Switzerland)*, *11*(12). 10.3390/app11125581Zach, L. (2011). What do I do in an emergency? The role of public libraries in providing information during times of crisis. *Science and Technology Libraries*, *30*(4), 404–413. 10.1080/0194262X.2011.626341.