Challenging terrains: socio-spatial analysis of Primary Health Care Access Disparities in West Virginia

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Abstract

Existing measures of health care access were inadequate for guiding policy decisions in West Virginia, as they identified the entire state as having limited access. To address this, we compiled a comprehensive database of primary health care providers and facilities in the state, developed a modified E2SFCA tool to measure spatial access in the context of West Virginia’s rural and mountainous nature, and integrated this with an index of socio-economic barriers to access. The integrated index revealed that the rural areas, especially in the southern part of the state, have especially limited access to primary health care.

1. Introduction.

An emerging public health issue which has been exacerbated by the COVID-19 pandemic, is that of healthcare deserts, which are places where basic affordable health care is not accessible for residents. This problem has become worse in rural areas as rural hospitals close. In these areas, including West Virginia, scattered populations suffer from limited access to primary healthcare services. Uneven geographic and socio-economic barriers to accessing primary health care are major contributing factors to these health disparities.

West Virginia’s unique rural and mountainous settlement patterns, aging population, and economic crisis over the past two decades have resulted in unequal access to the primary healthcare services for its residents. The rural nature of the state makes it difficult to maintain medical facilities accessible to much of the population, especially as rural hospitals have been closing, such as the one in Williamson, WV (Jarvie, 2020). The mountainous terrain slows down travel across winding roads, lengthening travel times to the nearest hospital, while an aging population has increased health care needs. Lastly, an economic crisis and higher poverty rate makes West Virginians less able to pay for health care. As a result, West Virginians are confronting a health crisis. According to a recent report by the West Virginia Health Statistics Center (2019), West Virginians rank first in the country for heart attacks, have the second-highest obesity rate and prevalence of mental health prob-
lems in the country, along with the fourth-highest rate of diabetes and fifth-highest rate of cancer.

An issue faced by West Virginia’s policymakers is the limitations of tools for identifying and assessing healthcare deserts, as they are poorly suited for the unique challenges in West Virginia. Academic research has not analyzed comprehensive primary healthcare accessibility in WV, although previous studies have focused on Appalachia (e.g., Behringer & Friedell 2006; Smith & Holloman, 2011; Elnicki et al., 1995; Donohoe et al., 2015, 2016a, 2016b), and others focus on access to more specialized services (Valvi et al., 2019; Donohoe, 2016a). Existing approaches to identify the healthcare deprived areas, such as Health Professional Shortage Areas (HPSA), are not suitable for guiding West Virginia policies, because every one of the 55 counties within the state has several HPSAs, which makes prioritizing resources difficult. The lack of easily accessible, comprehensive, and up-to-date physician and healthcare facility database creates additional difficulties. Physician license datasets were found to often include inconsistent, misleading, and out-of-date information. The last limitation of the HPSA designation is that it is based on zip code areas and census tracts, which are not ideal as zip code areas lack spatial context and much covariate data, while rural census tracts are too large to capture spatial variation of access.

In this context, the WV HealthLink project was begun with joint effort with WV Rural Health Initiative (RHI) to fill gaps in research and support decision making for primary healthcare access in West Virginia. The goals of the projects are: (1) to help West Virginia’s three medical schools provide specialized professional training in rural healthcare; (2) to address health disparities by investing in clinical projects in underserved areas; and (3) to retain health professionals in WV. In 2018, to support these goals, HealthLink was invited by the RHI’s leadership to analyze disparities in primary health care access in West Virginia and develop tools for rural healthcare decision-making. These goals also create a comprehensive and up-to-date physician and facility database, new analysis tools, and new visualization tools for decision support.

The goals of this paper are to assess the spatial and social accessibility of primary health care in West Virginia, and to understand spatial and social determinants that shape this access. To achieve these goals, this paper completes the following objectives: (1) define primary healthcare and access; (2) build an extensive and up-to-date primary healthcare database; (3) develop an assessment framework for WV; and (4) visualize the results for policy makers and practitioners. The structure of this paper is as follows. First, we describe three methodological problems encountered as we define primary health care access. Second, we present the methods used to resolve these problems, and conclude by presenting our modified enhanced two-step floating catchment area (E2FCA hereafter) approach and its results for WV. Our foci in this modification were improving the accuracy of the analysis regarding measuring distance, considering distance decay effect, and more precisely representing the location of supply and demand.
Background

The West Virginia Context

West Virginia is a rural state with mountainous terrain, which pose unique challenges to making health care accessible. Additionally, its population is aging and impoverished, both of which can make traveling longer distances challenging. Together, these conditions pose unique obstacles to providing adequate primary healthcare service for all West Virginians.

The rural nature of the state means that many locations with lower population densities are left behind in the provision of primary health care, and those residents must rely upon remote facilities. Small towns throughout WV do not have a sufficient population to sustain health care facilities, as evidenced by recent closures of hospitals and birthing centers. There are few cities in the state large enough to provide many facilities (Charleston, Huntington, Morgantown), and only a small number of cities in neighboring states that would attract West Virginians seeking primary health care services (Marietta, OH; Steubenville, OH; Cumberland, MD; Hagerstown, MD; Winchester, VA). None of these cities has a population exceeding 50,000, reinforcing the rural nature of the state. Compounding this is an aging population, with the 3rd highest proportion of the population over the age of 65. (ACS, 2017) This increases the potential demands upon the health care system, which in turn raises the economic burden facing rural health care facilities. This burden is exacerbated by the poverty situation within West Virginia, where the median income is the 3rd lowest, and the percent of residents living in poverty (17.8%) is the 7th highest in the United States. (2017 ACS) Mountainous terrain and frequent landslides make road maintenance harder, especially in adverse weather conditions. Meandering mountain roads increase travel time because drivers slow down for curves, which create additional barriers to accessing health care. Lastly, the difficulties in transportation are made worse by limited public transportation within WV, especially in rural areas that already have limited health care access. This ensures that residents must have access to private vehicles to access health care. These barriers of an aging population, alongside an impoverished economy and a rural population in a mountainous state, all combine to create a unique set of challenges to accessing health care in WV.

Primary Healthcare and Accessibility

Responding to the unique challenges posed by the state’s rural geography, the RHI provides funding to support the three medical schools to address the goals listed above. Like many initiatives seeking to address rural health disparities, the RHI inherited a limited definition of “the rural” via HPSAs which made it difficult to prioritize funding, establish eligibility criteria, evaluate their impact, or make policy recommendations. To provide the RHI with a more useful measure of health care deserts, we created indices that provide as much spatial detail as possible by using the smallest spatial units for which the data is available.

To better assess the primary healthcare accessibility, understanding the social and spatial determinants of health, we first precisely defined primary health care and
access or accessibility. For the former, we adopted World Health Organization standards as a basic or general health care facility, emphasizing its role as where the patient first enters the medical care system. This includes family practice physicians, general practice physicians, general internists, obstetricians, pediatricians, psychiatrists, and mid-level providers. This study employs a slightly different definition based upon our survey research, which included providers and sites defined as family medicine, internal medicine, internal medicine/pediatrics, obstetrics and gynecology, behavioral, and pediatrics, because these are potential entry points into the health care system in WV.

Building upon this definition of primary health care, we then defined primary health care access in terms of the ability to travel to and acquire an appropriate and affordable level of the potential healthcare service. The dimension of access to healthcare service can be classified by spatial and non-spatial factors (Khan, 1992). To assess disparity to primary healthcare service, both spatial and aspatial factors impacting accessibility need to be measured (Langford et al., 2016; Luo & Qi, 2009). Spatial accessibility is defined as the amount of healthcare facilities, considering both the range of services provided and the proximity of services to the demand locations (McGrail, 2012). Socio-economic accessibility is the capability to access adequate healthcare service without financial or social difficulties (Wang & Luo, 2005). This may include access to public transportation or a private vehicle to reflect the ability to travel. The integration of both aspatial and spatial factors is critical to measuring potential accessibility (Langford et al., 2016; Luo & Qi, 2009; Hege et al., 2018).

**Measuring spatial and Socio-economic accessibility**

Penchansky and Thomas (1981)’s criteria were used as the basis of choosing variables to assess spatial and socio-economic accessibility: availability, accessibility (travel-wise), accommodation, affordability, and acceptability of health care. Based on these factors, several approaches have derived spatial and socio-economic accessibility to various healthcare services.

In terms of spatial accessibility, Two-Step Floating Catchment Area analysis (2SFCA) is a widely-accepted approach for healthcare services (e.g., Luo & Qi 2009, Donohoe et al., 2016b). It was initially developed by Radke & Mu (2000) and has been improved since then, with several variants. Enhanced 2SFCA was developed by Luo & Wang (2003a, 2003b) to measure spatial accessibility using the size of the population (demand) and the volume and distance of nearby service locations (supply), based on the gravity model. However, two major deficiencies of the E2SFCA have been identified: lack of distance decay effect and fixed catchment area size (McGrail, 2012). Both limitations reflect a population’s behaviors for travel to healthcare sites. To tackle the distance decay effect in which a person’s willingness to travel decreases gradually with increased distance, several functions have been introduced in E2SFCA studies, sometimes considering multi-modal transportation (McGrail, 2012; Wang, 2012) summarized six types of distance decay functions used in healthcare access research: gravity model, binary discrete, multiple discrete, Gaussian function, kernel function, and three-zone hybrid function. However, empirical evidence about people’s behavior has not been provided for specifying distance
decay functions (Acury et al., 2005; McGrail 2012). Techniques to vary the size of the catchment area, or the maximum distance a person may travel, based on population size and urban/rural distinction have been developed (McGrail, 2012).

There has also been a lack of consensus in selecting socio-economic variables to measure the ability to afford and access healthcare service. Variables that represent economic barriers, such as household poverty, home ownership, income, employment status, social class, demographics of household head, and level of education (Chateau et al., 2012; Daly et al., 2019; Shah et al., 2015; Field & Briggs, 2001; Meade & Emch, 2010; Morris & Carstairs, 1991), transportation issues, such as car ownership and public transportation (Asanin & Wilson, 2008; Paez et al., 2010; Wang & Luo, 2005), and urban/rural distinction (Bascuñán & Quezada, 2016; Domnich et al., 2016) are used in different combinations and weights. However, to date, only a few attempts have been made to integrate spatial and socio-economic factors into a single accessibility measurement (Bissonnette et al., 2012; Wang & Luo, 2005). No consensus exists for the means to integrate spatial with aspatial accessibility.

Data Issues

Three datasets are commonly required to derive the spatial accessibility using the E2SFCA variants: location of healthcare sites, location of demand, and the proximity from a demand location to a supply site. Licensing boards maintain databases of locations of healthcare sites. However, such lists are often incomplete or inaccurate, with out-of-date information and incorrect practice addresses (Wang & Luo, 2005). Previous research used the centroids of zip code areas or other enumeration units as surrogate locations sites with incomplete or inaccurate data (Luo & Qi, 2009; Luo & Whippo, 2012; McGrail & Humphreys, 2009; Wang & Luo, 2005). However, this reduction of spatial precision inevitably increases errors in measuring accessibility. More recently, geocoded locations of physician addresses have been used (Langford et al., 2016; Luo & Whippo, 2012; Tao et al., 2018; Wan et al., 2012). However, verification and error correction must be conducted because of inaccuracies from listing P.O. Box addresses as the practice location, and outdated databases. Simple tactics such as requiring a street address instead of a P.O. Box address (Wan et al., 2012), will reduce, but not eliminate errors in the spatial accessibility measures.

For the second dataset, the location of demand, aggregated units are used to ensure patient privacy (Cudnik et al., 2012). Centroids of census units or rasterized population distribution are used to represent demand locations. The spatial resolution of demand units should be made as fine as possible, ideally to census blocks in the United States, to best capture and measure spatial variance of accessibility in sparsely populated rural areas. Most previous research, however, relied on census tracts or equivalent units (Luo & Whippo, 2012; Wang & Luo, 2005).

The last required data is a means of measuring the proximity of the sites in the first dataset to the demand units in the second dataset. Travel time via road network is the most common proximity measure, using assumed travel speeds (Langford et al., 2016; Luo & Qi, 2009; Wan et al., 2012; Wang & Luo, 2005). Recently, to reflect actual traffic and road conditions, travel time estimated by an online map service
(e.g., Google Maps) have been employed (Cheng et al., 2016; Gu et al., 2010; Tao et al., 2018; Wang & Xu, 2011), but not within the United States.

To support the goals of the RHI as outlined in the introduction, a new approach to measuring health care accessibility is required, in order to overcome the limitations of the studies cited above: ensuring the database of primary health care sites is complete and up-to-date, using as fine as possible a resolution for the location of the population who can need to access health care, and measuring the impact of distance and socioeconomic variables as reliably as possible. We choose to use the most spatial detail that is available for the spatial and aspatial indices even though this means that the spatial index is computed at a finer spatial resolution than the aspatial index, and we use the finer resolution when creating the integrated index. The next section describes how we carry out our study to accomplish this in the context of WV.

Methods

Study Area and Data

For our state-wide accessibility analysis, data on physicians, primary healthcare sites, and socio-economic variables were collected for the entire state of West Virginia. Figure 1 presents the study area with the locations of 602 identified primary health care sites overlaid with a digital elevation model to illustrate the challenges of topography, and Fig. 2 presents the estimated population density of census blocks. For demographic and socio-economic analysis, we used American Community Survey 2016, a five-year estimate between 2012 and 2015 (U.S. Census Bureau 2018), which is based on census block groups. For spatial accessibility, we used census block units used in the 2010 Census. To estimate the socio-economic data for the census blocks, variables were treated as identical for all blocks in a block group.

Next, we developed classification criteria for healthcare sites based on funding sources and types of service provided (Tables 1 and 2). Most of these sites and services are available to everyone, and thus are useful in evaluating primary care access. Correctional facilities, school-based clinics, and Veterans Affairs hospitals provide primary care but limit the populations served. Site designations based on funding can indicate the level and types of service that they provide. Both the funding source and service types of each site were incorporated into the evaluation of health care access. Primary Care sites were identified if they fell under the site designations in Table 1 which are available to everyone, and they offered services in Table 2 including family and internal medicine, obstetrics and gynecology, pediatrics, and other sites that practitioners self-identified as where they offer primary care.

Regarding healthcare sites and physician datasets, clearing house portals such as the WV Rural Health Association, federal data on the geographic location of primary care sites, and other datasets that used county or census tract scale proxy locations for primary care were all insufficient. Furthermore, there was no systematic data collection technique that geo-referenced the accurate location of primary health care sites, categorized the services provided, and tracked where or when health care professionals provided care in those sites. While proxies are critical to building spatial
decision-making tools, we found many health care maps were building proxies based on proxies; the underlying data was either not available or ground-truthed. Although we could access practitioner data from boards of medicine, nursing, and physician assistants, these databases primarily contained the home addresses of health professionals, not their workplace, nor hours of work. In sum, a key barrier to assessing health disparities was that the RHI, and West Virginians, lacked an accurate and integrated healthcare GIS database containing primary health care location data.

To solve this data deficiency, we developed a simple but effective data collection and validation procedure to build an exhaustive spatial database on primary health care sites and practitioners in West Virginia. This procedure involves initial license data collection, address standardization, address error correction, geocoding, location validation, service validation, and physician workplace validation. The 2017 physician (MDs and DOs) license datasets were acquired from their respective licensing boards, the WV Board of Medicine, the WV Board of Osteopathic Medicine, and the WV Board of Nursing. Their datasets, which were stored in simple spreadsheet format, have two types of address fields, mailing address and workplace address, which is the street address of healthcare site. The address fields were not standardized, and sometimes only include P.O. Box address which cannot be geocoded to the facility site. We utilized text parsing and processing functionality of Python to standardize the address field for geocoding. Out-of-state workplaces were removed. These data
quality issues, such as the absence of standard data format, out-of-date site locations and practitioner lists, and inconsistency in address reveal the difficulty researching health care access for an entire state.

Our team then manually validated and corrected locations of primary care sites and practitioners using multiple resources, including health insurance provider lists, targeted Google searches, health system websites, and publicly available databases. During this step, we acquired additional healthcare site locations that were not in the licensing data. We used systematic Google searches to identify workplace locations for physicians with P.O. Box addresses. With standardized and verified address, the addresses were geocoded using Google Maps Geocoding API. Those 731 geocoded locations were then manually evaluated and corrected using Google Maps and Google Street photos to construct an up-to-date database. Then the list of services was confirmed and updated by collecting all available supplementary information. Based on our classification criteria (Table 2), we classified 602 of 731 locations as primary healthcare sites. Finally, we validated physician worksites of physicians with unverified workplace addresses. However, even after multi-staged validation and correction procedure, we were unable to identify practitioners in 11 locations out of 602 verified primary healthcare sites (1.8%). Having confirmed the existence and operation of these sites, we assumed the presence of at least one physician for each site.

To improve the accuracy of accessibility in WV considering its rural and mountainous nature, we measured real world travel time between supply and demand locations instead of approximating travel times by distance. The travel time, precise distance,
and average speed of travel between each census block to each site was measured using Google Maps API, in the middle of a weekday, assuming moderate traffic. Considering the number of census blocks in WV (135,218) and possible combinatorial pairs between the blocks and the 602 sites (81,401,236), we applied several methods to reduce the number of Origin-Destination pairs. First, we grouped both supply and demand locations based on their proximity to each other. We grouped some census blocks within their respective block group, by imposing a five-kilometer grid

| Site Designation                        | Definition                                                                                                                                 |
|-----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Federally Qualified Health Centers (FQHCs) | Health centers that provide primary care to an underserved area or population, offer a sliding fee scale, provide comprehensive services, have an ongoing quality assurance program, and have a governing board of directors. All organizations receiving grants under Health Center Program Sect. 330 of the Public Health Service Act are FQHCs. |
| Critical Access Hospitals               | Rural hospitals designated for benefits such as cost-based reimbursement for Medicare services. CAH sites are usually 35+ miles from another hospital, provide 24/7 emergency care, have 25 or fewer acute care inpatient beds, and maintain an average length of stay of <96 h for acute care patients. |
| FQHC Look-A-Likes (LALs)                | LALS are community-based health care providers that meet the requirements of the HRSA Health Center Program, but do not receive Health Center Program funding. |
| Certified Rural Health Clinics (RHCs)   | Outpatient clinics located in non-urbanized areas that are certified as RHCs and meet NHSC Site requirements including accepting Medicaid, CHIP, and providing services on a sliding fee scale. |
| Veterans Affairs Sites                  | Clinics and hospitals that exclusively available for persons who are former or active military. VAs receive federal funding to provide primary care but access to these sites is limited to a subset of the population. |
| School Based Health Centers             | SBHCs are clinics housed in public schools that are sponsored and managed by Community Health Centers. They provide immediate and preventive care during school hours. Care is limited to students enrolled in the respective schools. |
| Correctional Facilities                 | Medium to maximum security federal and state correctional institutions and youth detention facilities with a shortage of health providers |
| State Mental Hospitals                  | State or county hospitals with a shortage of psychiatric professionals (mental health designations only) |
| Other Facilities (OFAC)                 | Public or non-profit private medical facilities serving a population or geographic area designated as a HPSA with a shortage of health providers |
over each census block group to aggregate census blocks, assuming consistent access within these grid cells. The centroid of each grid cell was used as a surrogate location in the Google Maps API for all blocks within the grid cell/block group intersection. Similarly, primary care sites located within 500 m of each other were grouped, using their centroids as representative locations. Second, from each primary care site, blocks only within 30 miles are evaluated for travel time. The maximum travel time threshold for spatial accessibility in this study is 30 min, so a 30 mile straight-line distance is a reasonable heuristic for limiting computational costs, especially considering the complex topography of WV and the associated recognition that road distances can greatly exceed 30 miles within a 30 mile buffer. As a result, we derived travel times for 224,286 pairs of blocks and facilities, or their surrogate locations.

### Spatial accessibility Assessment: enhanced two step floating Catchment Area

In this research, we measured two potential accessibilities to primary healthcare service in WV, spatial and aspatial, or socio-economic, accessibility. For assessing spatial accessibility to the primary healthcare service, we used the E2SFCA model developed by (Luo & Qi, 2009). However, we modified it regarding the distance
decay function and catchment area size to reflect the local spatial context of West Virginia.

In the first step, the E2SFCA derives physician-to-population ratio for each primary care site based on demand locations within the catchment area of the given site. The impact of each demand area to the ratio is determined based on the size of demand population and distance, while a distance decay function governs the influence of the distance. \( R_j \), the physician-to-population ratio of a primary healthcare site \( j \) is computed as follows:

\[
R_j = \frac{S_j}{\sum_{i \in \{d_{ij} \in T\}} P_i w_{ij}}
\]

where \( S_j \) is the number of physicians at site \( j \), \( P_i \) is population of demand location \( i \), and \( w_{ij} \) represents the distance decay weight for travel between locations. In the second step, physician-to-population ratios of the healthcare sites within the catchment area of a demand location are summed up to compute an accessibility index \( A^F_i \) for the given demand location as follows:

\[
A^F_i = \sum_{j \in \{d_{ij} \in T\}} R_j w_{ij}
\]

For the distance decay function, we have adopted three-zone hybrid function (McGrail & Humphreys, 2009). Like other distance decay functions in the previous potential access assessment studies, our design of distance decay function relied on assumptions. First, we assumed that the customers would not differentiate facilities within 10-minute driving distance, so the distance decay starts after 10 min. Second, we assumed that a given resident’s willingness of travel would depend on the travel time to a healthcare facility and the ease of travel. While the ease of travel is a function of road characteristics, such as the number of lanes, speed limits, traffic, sinuosity, and surface conditions, we used the average travel speed as an indirect measurement of this, as ease of travel is related to these characteristics. Applying this to the basic distance decay function, our distance decay weight between a demand and a facility, \( w_{ij} \), is derived as following:

\[
w_{ij} = \frac{1}{d_{ij}} \quad \text{where} k = \frac{1}{v_{ij} \times s}
\]

where \( d_{ij} \) is travel time distance between location \( i \) and \( j \), \( v_{ij} \) is estimated travel speed along the specific route between locations, and \( s \) is scaling factor for each estimated speed range: (1) up to 25 mph, 0.7; (2) between 25 and 45 mph, 0.85; and (3) faster than 45 mph, 1. The first speed range represents residential or business areas, as well as poor road conditions that hamper easy travel. The second speed range assumes local routes in moderate or good conditions. The last range represents local or state routes in non-residential areas in good conditions or divided highways. In
short, we assumed residents will travel longer if road conditions are better, as represented by the estimated speed.

We used an adaptive catchment area size based upon the ease of travel, based upon the idea that faster speeds also represent less friction for travel. Therefore, the size of the catchment is dependent upon the speed of travel, with a 30-minute catchment area for the first and second speed ranges defined above. However, we expanded the catchment area to 40-minute for the third speed range, faster than 45 mph for the total trip. We also assumed a single mode of travel, private vehicles, because there is little public transportation in WV, especially rural areas. Although several urban areas have limited public transportation, such as Morgantown and Charleston, detailed route and schedule data were not available, and these areas also have more healthcare facilities. Therefore, public transportation is not relevant for identifying areas of limited access.

Spatial affordability Assessment

Spatial accessibility is important, but spatial barriers are not the only barriers to accessing health care (Penchansky & Thomas 1981). Socioeconomic and demographic barriers can impede access to health care, even if there is spatial proximity. However, while many studies have examined non-spatial barriers to access (e.g., Chateau et al., 2012; Paez et al., 2010; Shah et al., 2015), there is little consensus regarding which variables are best to use. Below, we explain our choices of variables, most of which have been used in existing studies, although they have not been used together in this combination.

We estimated two aspects of socio-economic accessibility, the ability to afford health care and the ability to access health care, using census block group level data from the 2016 American Community Survey. To measure the barriers socioeconomic and demographic factors can impose upon the ability to access primary care services, four variables were chosen that indicate the overall economic capability of the population in a given block group (Table 3). The percent of households in poverty was used to indicate a possible economic impediment to afford the service. (Shah et al., 2010, Daly et al., 2019) Even if a person has health insurance, there are frequently co-pays and out-of-pocket expenses which can render health care inaccessible. The percent of the population without a high school diploma was used to consider the influence of the education level on access (Chateau et al., 2012; Shah et al., 2015; Bascuñan and Quezada, 2016; Daly et al., 2019). While education is related to income, it has been demonstrated to have additional impacts upon access. The percent of households with a female head of the household was used as female headed households may often be single-parent households, with lower typically lower wages or salaries in the United States, as well as additional time burdens that impede access health care. (Paez et al., 2010; Chateau et al., 2012; Gao et al., 2017) We recognize that this variable may not be as relevant in places with better gender equity than the study area. Lastly, the percent of households that do not own their dwelling was included as an indirect indicator of economic status, as well as a recognition that renters tend to be more transitory, and thus less likely to have a local primary care physician. (Gao et al., 2017)
To estimate the ability to access primary healthcare service in West Virginia, two additional variables were selected (Table 3). The percentage of households without a vehicle suggests transportation barriers beyond the travel time of the spatial index. (Paez et al., 2010, Bascuñan and Quezada 2016) As mentioned above, this is especially critical for West Virginia as public transportation is minimal throughout much of the state. Lastly, the percent of households without health insurance was selected because this imposes extra costs that would limit a person’s ability to use healthcare facilities. This has not been used as extensively in other studies, although it is important in West Virginia, perhaps because many studies are situated in other countries where health insurance is nearly, or entirely, universal. While the Affordable Care Act provided health insurance to many West Virginians, there remain many households without insurance, who would find it especially difficult to afford health care services. Lastly, as the goal of the research is assessing and identifying the disparity in healthcare access, indices were visualized based on the percentile of each analysis unit, census block for the spatial accessibility and census block group for socio-economic accessibility. We classified the resulting values into five classes, from the top 20% to the bottom 20%.

### Integration: calculating the socio-spatial primary health care accessibility index

To assess comprehensive socio-spatial accessibility to primary healthcare, considering both spatial and socio-economic variables, we integrated the two accessibility indices. As mentioned above, there is no consensus regarding the appropriate means of combining spatial accessibility and non-spatial accessibility into a single index. In this research, we give equal weight to both spatial and socio-economic accessibility indices and add them to create a combined index. We chose equal weights because we lack an a priori reason to believe one is of greater importance than the other within the context of West Virginia. To convert the socio-economic accessibility indices to the same spatial units as the spatial accessibility index while maintaining a proper level of analysis resolution, the socio-economic index for a block group is assigned to all census blocks within that block group, treating the socio-economic conditions as homogenous within the block group. As the two indices were measured in different scales, they were normalized, then added, to compute the comprehensive index. Like the other two indices, the comprehensive index is also presented using the percentile classification.
Results

We derived a total of five indices to assess the accessibility to the primary healthcare service in WV: ability to afford, ability to access, combined aspatial access, spatial access, and comprehensive access. The socioeconomic indices are calculated for census block group units, while the spatial accessibility index is presented for census block units, and county boundaries are included for presentation purposes. Figure 3 presents the socioeconomic index, Fig. 4 presents the spatial index, and Fig. 5 presents the combined index. Because all indices are normalized and unitless, they are presented in five quantiles to compare the top 20%, the second highest 20%, etc. Collectively, these reveal the spatial patterns of disparity across the state. Table 4 shows the population distribution for each index.

The two socio-economic indices reveal a similar, scattered pattern, while the spatial index shows a more concentrated pattern of access to primary healthcare facilities at the populated areas. This can also be inferred from observing that 28.9% of the population lives in the 20% of census blocks with the greatest accessibility, decreasing steadily to where 12.8% of the population lives in the quintile of census blocks with the lowest accessibility to health care. Even so, Table 4 shows that roughly 30% of West Virginia residents live in areas of low or medium-low access. These 30% of residents with low access are mapped in Fig. 6. This shows that the areas with the greatest populations in need of access are in the southwestern part of the state, just south of Charleston and Huntington, and east of Beckley, in the areas of the
state hardest hit by the decline in coal mining. An area in the northeast also appears, near the Cumberland, MD, metropolitan area, which may provide services for these residents.

To guide decisions about the placement of facilities, and highlight areas that are uniquely vulnerable to the closure of healthcare facilities, we identified the areas with only zero, one, or two primary healthcare facilities within 30 min driving distance, ignoring distance decay (Fig. 7). About 1.4% of the residents of WV do not have any primary healthcare facility within 30-min driving range, and 2.9% of the entire population only have a single facility, making them highly susceptible to a lack of access if that facility closes.

**Conclusion & discussion**

We defined primary healthcare service in the context of West Virginia, then built an extensive database for primary healthcare facilities. We then developed a locally informed assessment framework based on E2SFCA approach. An assessment of accessibility was followed. Our analysis revealed spatial pattern of disparity in primary healthcare access across WV. By using data at the block group and census block unit, we provided a more detailed map of areas facing barriers to accessing health

![Fig. 4 Spatial index](image-url)
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The integrated index map in Fig. 5 shows that many counties feature areas with high levels of access and low levels of access. Therefore, county-scale measures of health care access will obscure these variations within counties, and having this more precise map can guide policymakers seeking to ameliorate gaps in health care access.

As anticipated, healthcare services are less accessible with mountainous terrain and rural populations. The Appalachian mountain range and plateau are major contributors for the meandering road network that slows travel, while poor road conditions add difficulties in travel. Scattered populations in rural areas are insufficient to maintain a healthcare facility in small towns, which leaves 30% of West Virginians with medium-low or low access to primary healthcare service. Furthermore, a vulnerability analysis revealed that about 34.2% of the state’s area has two or fewer health-

|        | Social index | Spatial index | Comprehensive index |
|--------|--------------|---------------|---------------------|
| High   | 21.1%        | 28.5%         | 28.9%               |
| Medium high | 20.9%    | 22.1%         | 22.7%               |
| Medium | 20.6%        | 21.1%         | 18.8%               |
| Medium low | 19.9%    | 17.4%         | 16.8%               |
| Low    | 17.6%        | 10.8%         | 12.8%               |

Table 4 Population distribution for each index

Fig. 5 Integrated socio-spatial index
care facilities within thirty minutes, making the residents of those regions vulnerable to changes in service like facility closure or reduced hours of operation. We also modified the E2SFCA procedure to have a distance decay function to recognize spatial access is not binary and thereby provide a better measure of spatial accessibility.

Our applied geographic research yielded significant results for our project partners. Our intention was that this would be used as a decision supporting tool in the context of exploratory analysis. Since completing this work and providing our analysis to RHI, they have begun integrating our findings into support for projects addressing health disparities in targeted communities and training future health care professionals on the spatial and socio-economic barriers to patients seeking care. Our extensive data collection effort enabled us to analyze the primary healthcare accessibility in WV with a high level of accuracy and in fine-scale detail.

Nevertheless, there are limitations to our study. First, the socio-economic index and the spatial index are measured at different scales, and combined by assuming that the socio-economic conditions are homogenous within the census block group. As the map in Fig. 3 shows, this is not the case for counties, and it is unlikely to be the case for block groups. Therefore, our procedure for measuring healthcare access can still smooth differences from one area to another. Also, under the current design, the most important variable is the spatial access index derived from E2SFCA which contributes 50% of the integrated socio-spatial index. The individual socio-economic

![Spatial distribution of population with low or medium low access](image)

**Fig. 6** Spatial distribution of population with low or medium low access

[Image of spatial distribution map]
variables in the integrated socio-spatial index individually contribute less as they are combined into social index which is collectively the other 50% of the integrated index. This is the result of our initial assumption that spatial barriers to access are equally important to non-spatial barriers to accessibility within the healthcare service, even though there are more factors involved with non-spatial barriers. Indeed, the spatial pattern of the integrated socio-spatial index is very similar to the spatial index, though it showed distinctive patterns in western part and eastern panhandle portion of the WV.

To improve the accuracy of the current accessibility analysis, a few improvements will be made. First, data on realized travels to the healthcare sites from various locations of West Virginia need to be collected. This dataset will be crucial to update the functions to determine distance decay weights and the size of the catchment area to improve the accuracy of the analysis. However, caution needs to be taken when varying weights and catchment area sizes, because the wrong distance decay function or catchment size could imply a misleadingly high tolerance to the longer travel that results from low spatial accessibility, and thereby overestimate accessibility. Further, even if the residents of low accessibility areas by necessity travel more to receive healthcare, the time and money spent in traveling to and from facilities will still have

Fig. 7 Spatial distribution of areas of greatest vulnerability, with zero to two facilities within thirty minutes
impacts, with expenses in gasoline and, for many families, the expenses of lost wages due to travel time and arranging child care while a parent is traveling. This has potentially adverse impacts on their health, as they may seek treatment less frequently, or delay treatment until they have enough time to make the trip, although the travel time is not an absolute barrier. Second, we would adjust the weights of each variable in the socio-economic index based on their actual contribution for the accessibility in WV. This will require additional research to more precisely identify the barriers individuals face. Furthermore, we also intend to shift attention from a focus on primary health care sites to specific services, e.g., dental, behavioral, and pharmacy. By deepening our research, we intend to gain a greater understanding of the complete landscape of health care accessibility in West Virginia, going beyond the location of clinical infrastructure and incorporating all the socio-spatial barriers to access of essential services and the health care professionals that provide them.

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