Assessment of disparities in spatial accessibility to vaccination sites in Florida

Kyusik Kim, Mahyar Ghorbanzadeh, Mark W. Horner and Eren Erman Ozguven

ABSTRACT

Community-wide vaccinations would be the most effective way to end the COVID-19 pandemic, and accessing vaccination sites would be central in this nexus. Given that the number of COVID-19 vaccines was limited to certain groups of people in the early phases of vaccine distribution, age-based prioritization may have overlooked differences in income levels and the races/ethnicities among older populations. In this vein, using two spatial accessibility measures based on spatially disaggregated hexagons, this paper assesses the disparities in spatial accessibility to vaccination sites with consideration of older populations’ (65+) income levels and their races/ethnicities at the state and the county level. To evaluate the disparities and identify counties with the greatest disparities, a non-parametric two-sample Kolmogorov–Smirnov test at the state level and the Gτ statistic at the county level are implemented. The findings of this study indicate that older blacks, older Hispanics, and older populations below the poverty level had better access compared to older whites, older non-Hispanics, and older populations above the poverty level, respectively, at the state level, whereas access disparities varied at counties and geographic locales. We thus conclude that policymakers should take into account older populations’ income levels and races/ethnicities for vaccine prioritization and should pay attention to counties with relatively high disparities in spatial access to vaccines.

1. Introduction

Coronavirus disease 2019 (COVID-19) has drastically affected global society and led to a significant number of deaths worldwide. Practicing social distancing and wearing masks have been recommended by the World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC) in order to prevent the spread of the virus. Although these are effective ways to slow down the rate of COVID-19 deaths and cases, they are not enough to fully control the COVID-19 pandemic. As of 22 February 2021, the number of COVID-19 deaths surpassed 500,000 in the United States (CDC 2021). The State of Florida ranked third among the U.S. states after California and Texas given the number of positive cases (CDC 2021). As Wouters et al. (2021) noted, community-wide (mass) vaccination and equal access to vaccine distribution sites are the most effective ways to mitigate the spread of COVID-19.

As of 1 March 2021, the population aged 65 and older accounts for 83% of the deaths due to COVID-19 in Florida (Florida Department of Health 2021a). Florida prioritizes persons 65 years and older, health care personnel with direct patient contact, residents and staff of long-term care facilities, and persons deemed to be extremely vulnerable to COVID-19 by hospital providers (Florida Department of Health 2021b) in the early vaccination distribution stage. However, questions about age-based prioritization have been raised given the fact that the COVID-19 pandemic has disproportionately impacted socially disadvantaged population groups such as racial/ethnic disadvantaged population groups; in particular, those people who are near or below the federal poverty line (Mein 2020), and Zhang and Schwartz (2020) also reported that the portion of older populations and population below poverty are associated with deaths of COVID-19. These are consistent with previous pandemics, such as the 1918 Spanish influenza pandemic and the H1N1 influenza pandemic in 2009, in which minority groups were affected by pandemics compared to non-minority groups (CDC 2010; Hutchins et al. 2009). Thus, to reduce racial/ethnic and economic disparities during the COVID-19 pandemic, avoiding purely age-based prioritization in vaccination has been suggested (Persad, Peek, and Emanuel 2020).

Scanning the literature, numerous efforts have studied spatial accessibility to healthcare services and its social and spatial disparities while using geographic
information systems (GIS). To measure spatial accessibility, the shortest travel distance/time, the number of services within a given spatial threshold and a two-step floating catchment area (2SFCA) method have all been widely applied. Using one of the methods depends on an assumption on people’s travel choices of reaching to services or facilities. For example, if having only one facility nearby is enough, the shortest travel distance/time would be a reasonably accessibility measure (Horner et al. 2015). Accordingly, the shortest travel distance/time was applied to different types of healthcare services such as biomedical therapeutic trial sites (Khazanchi et al. 2021), immunizing health facilities (Joseph et al. 2020), pharmacies (Ikram, Hu, and Wang 2015), and potential vaccination sites (Cochran et al. 2021). In particular, with respect to vaccination, it was reported that a long travel time to vaccination sites could be a barrier (Cochran et al. 2021; Joseph et al. 2020).

Although the shortest travel distance/time to the nearest vaccination site can be easily calculated and intuitively interpreted, another measure should be considered when the nearest vaccination site is unavailable due to vaccine shortages. In this case, a cumulative opportunities measure that indicates the degree of accessibility based on the number of facilities within a threshold (Scott and Horner 2008) can be an alternative. This is because if there are more vaccination sites that can be accessed in a given zone than other zones, a person living in the zone is more likely to have opportunities to reserve vaccines. Using the cumulative opportunities measure, Paez et al. (2010) revealed large disparities in accessibility to healthcare facilities between urban and suburban older adults in Montreal Island, while Horner et al. (2015) demonstrated different levels of accessibility to pharmacies, hospitals, and health facilities by transportation modes and age groups.

The 2SFCA method is also one of the widely used accessibility measures and has been applied to intensive care unit (ICU) beds (e.g. Ghorbanzadeh et al. 2021; Kang et al. 2020; Kim et al. 2021; Pereira et al. 2021) and testing sites (e.g. Tao et al. 2020) in terms of the COVID-19 pandemic situation. In particular, as described in a case study in Florida, Tao et al. (2020) revealed that the older population (65+) had some difficulties accessing testing sites, while black and low-income residents had comparatively better accessibility, and Kim et al. (2021) reported that Hispanic communities and rural residents are likely to have lower accessibility to ICU beds in Florida.

As widespread vaccinations will lead to reducing the burden of illness and the health care system (Grohskopf, Liburd, and Redfield 2020) and a vaccine is limited to a certain age group during the early period due to the number of vaccines, allocating vaccine distribution sites should be efficient and equitable. Nonetheless, previous studies reported that socially disadvantaged populations, such as the older population (Tao et al. 2020), Hispanic communities in Florida (Kim et al. 2021), black and low-income communities in Brazil (Pereira et al. 2021), and vulnerable population groups including ethnic minorities in Illinois (Kang et al. 2020), tend to have lower accessibility to ICU beds compared with other population groups during the COVID-19 pandemic. Furthermore, given evidence that the older population 65+ tend to be more vulnerable to COVID-19 (Blackburn et al. 2020), access to vaccines for those potentially vulnerable and disadvantaged population groups should be given greater attention. Although there is much variation, one view is that the level of spatial access to vaccinations will vary by racial/ethnic and income minorities because residential area settlement patterns may vary between blacks, non-Hispanic whites, and Hispanics (Baicker, Chandra, and Skinner 2005), which may influence healthcare disparities (White, Haas, and Williams 2012). This assumption can also be applied to age and income. In this regard, we can postulate that access to vaccination sites can also be different by race/ethnicity, age, and income level.

Focusing on people’s spatial accessibility to vaccination sites, this study aims to evaluate and identify disparities among older population groups in need of the COVID-19 vaccine based on their income levels and races/ethnicities at the state level as the overall state and at the county level in Florida. To achieve these goals, the present paper based on GIS uses hexagons, a highly disaggregate spatial unit, to calculate more spatially disaggregated accessibility, followed by a weighted-mean accessibility approach, which is utilized to compare population groups’ accessibility based on the shortest travel time to the closest facility and cumulative opportunities measure. The older population groups in this study consist of combinations of races/ethnicities (i.e. white, black or African American, Hispanic or Latino, and non-Hispanic white) and income levels (i.e. income level above the poverty level and below the poverty level), and the comparison will be split by race and ethnicity.

2. Study overview

2.1. Data

As of 18 March 2021, there were 1,112 sites that provided the COVID-19 vaccine to Florida residents, such as facilities associated with the Department of Health,
pharmacies (in Publix, Walmart, CVS, Navarro Discount Pharmacy, and Winn-Dixie), community centres, parks, churches, colleges and universities. Since the addresses of vaccination sites have been maintained by the Florida Department of Health (https://floridahealthcovid19.gov/vaccines/vaccine-locator/), we collected the vaccination locations by geocoding the addresses. In Figure 1, readers can quickly notice that the vaccination sites are concentrated in urbanized counties, such as Duval, Orange, Polk, Hillsborough, Sarasota, Palm Beach, Broward, and Miami-Dade counties, but there are few vaccination sites in North Florida. Based on a designation of ‘rural’ determined by the Florida Department of Transportation – Office of Policy Planning (Florida Department of Transportation Office of Policy Planning 2018), many rural counties are concentrated in North Florida, which means they are more likely to have fewer vaccination sites as compared with urban counties.

In this early vaccination stage, the COVID-19 vaccine has been prioritized for older people (65 and older) in the state of Florida (Florida Department of Health 2021c); however, it has also been suggested that income and racial/ethnic characteristics could be considered (Persad, Peek, and Emanuel 2020). We thus considered eight older subpopulation groups based on two races with two income levels and two ethnicities with two income levels. Here, white alone (hereafter whites) and black or African American (hereafter blacks), non-Hispanic white (hereafter non-Hispanic) and Hispanic or Latino (hereafter Hispanics), and income in the past 12 months above the poverty level (hereafter APL) and income in the past 12 months below the poverty level (hereafter BPL) were considered as race, ethnicity, and income levels, respectively. This population information was collected at the census tract level from the 2015–2019 American Community Survey 5-year estimates data. While there are more detailed spatial units such as census block groups and blocks, the most disaggregated unit with the population information is the census tract.

2.2. Methodology

2.2.1. Measuring spatial accessibility

This paper sought to calculate more spatially disaggregated accessibility by considering the geographical distribution of the population. As Lucas, van Wee, and Maat...
(2016) noted, there are differences in accessibility within a zone, thus calculating accessibility can be problematic when the large areas are analysed. Acknowledging this potential problem, we attempted to calculate hexagon-based spatial accessibility. The hexagons were derived from the global H3 geospatial indexing system, which has been developed by Uber’s Hexagonal Hierarchical Spatial Index (https://eng.uber.com/h3/) at resolution 9 (≈0.1053 km² and ≈0.041 mi²) (https://h3geo.org/docs/core-library/restable). The size of the hexagon is even smaller than the census block. Applying smaller hexagon than census block, we computed highly disaggregated spatial accessibility while avoiding less detailed accessibility calculations from the census tract’s centroid. While the size of the census tract in an urban area may be small enough to show disaggregated spatial accessibility, some census tracts in a rural area could be too big to exhibit sufficiently disaggregated population variance. Moreover, large parts of Florida are covered by forests, wetlands, and lakes, which are uninhabitable. For example, most parts of Collier, Monroe, and Miami-Dade counties in South Florida are uninhabitable since these counties are covered by Big Cypress National Preserve and Everglade National Park. In order to calculate accessibility based on habitable areas, urban and built-up areas were filtered from a Statewide Land Use and Land Cover dataset1 provided by the Florida Department of Environmental Protection. We thus computed spatial accessibility based on hexagons intersected with urban and built-up areas.

Our accessibility values are aggregated with procedures illustrated in Figure 2 that represents a concept of aggregating accessibility from hexagons to the county through the census tract. In the first instance, accessibility in hexagons is averaged onto the census tract. Accessibility in the census tract is then aggregated into the county. Calculating weighted-mean accessibility by county was conducted as part of the second procedure.

GIS-based two spatial accessibility measures were used to capture different aspects of spatial access to vaccination sites: travel time to the nearest facility and cumulative opportunities. The travel time to the nearest facility is an accessibility measure assuming that access to one facility is sufficient, which was termed as a ‘nearest opportunity’ measure (Horner et al. 2015). Since the nearest opportunity measure is calculated as travel time or distance, the measure can be easily interpretable in units, such as miles or minutes, thus has benefits to help communicate with policymakers (Neutens 2015; Yin et al. 2018). Moreover, given that minorities and older adults communities are the population groups significantly affected by transportation barriers to healthcare services (Syed, Gerber, and Sharp 2013), the nearest opportunity metric can be viewed as a relevant accessibility measure.

\[ A_i^N = \min_j(d_{ij}) \]

where, \( A_i^N \) is the nearest opportunity measure calculated by travel time to the nearest vaccination site \( j \) (Equation (1)), which means that \( A_i^N \) is the minimum travel time between demand location \( i \) and supply location \( j \) through the shortest path of a road network.

Another measure used in this analysis is cumulative opportunities. This measure counts the number of facilities reaching out within a given threshold travel time. A larger value of the measure indicates the number of options that the population can reach, this thus means better access to opportunity (Horner et al. 2015). This measure also has the advantage that it is comparable and interpretable in absolute units with the number of

![Figure 2](image-url). Illustration for the concept of aggregation from hexagon level to county level.
opportunities but has a downside that a threshold is arbitrarily decided (Neutens 2015). Nonetheless, cumulative opportunities were recommended to evaluate equity because it can explain travel-time fluctuations without a priori assumption (Neutens et al. 2010).

\[ A^C_i = \sum_j O(t_j), \]

where

\[ O(t_j) = \begin{cases} 1, & \text{if} \; d_{ij} \leq S \\ 0, & \text{otherwise} \end{cases} \]

where, \( A^C_i \) is the cumulative opportunities at origin \( i \) within a time threshold \( S \). If the travel time, \( d_{ij} \), from origin \( i \) to destination \( j \) is within \( S \), this counts the number of opportunities. In this analysis, based on a result of separate analysis using the National Household Travel Survey 2017 data (https://nhts.ornl.gov) that 80% of adults aged 65+ in Florida make at least one trip of 15 minutes, we selected 15 minutes as a reasonable threshold for the cumulative opportunities.

These two accessibility measures were calculated based on the hexagons, then were aggregated into census tracts using a population-weighted average method. This method can be thought of as an average accessibility level of a given subpopulation group in a county, and the population-weighted average accessibility is computed as follows:

\[
\text{Population-weighted average accessibility} = \frac{\sum_i A_i \times \text{Population}^k_i}{\sum_i \text{Population}^k_i}
\]

where, \( A_i \) can be either the nearest opportunity or cumulative opportunities of census tract \( i \) in a given county, and \( \text{Population}^k_i \) is a corresponding population group \( k \) living in a census tract \( i \). This is a form of the weighted mean of nearest opportunity (\( A^1_i \)) and cumulative opportunities (\( A^C_i \)) based on a certain subpopulation group. These accessibility metrics were calculated by using travel time between a hexagon and a vaccination site. This analysis used Open Source Routing Machine (OSRM) that is an open-source C++ routing engine for shortest paths in road networks (Project OSRM 2021) to calculate the approximate travel time by car, \( d_{ij} \). There are alternatives for road network sources, whereas OSRM has an advantage for calculating travel time and a more detailed road network with speed limits based on OpenStreetMap.

### 2.2.2. Comparative assessment of spatial accessibility between older subpopulation groups

Using the two accessibility measures, we evaluated disparities between older subpopulation groups based on their races, ethnicities, and income levels, and Figure 3 illustrates how the comparison is implemented. First, in terms of the income level, older subpopulations were compared within the same race and ethnicity category; for instance, a comparison between older blacks APL and older blacks BPL, and a comparison between older non-Hispanics APL and older non-Hispanics BPL. Second, older subpopulations between whites and blacks were compared within the same income level; for example, a comparison between older whites APL and older blacks APL, and a comparison between older whites BPL and older blacks BPL. Lastly, older subpopulations of non-Hispanics and Hispanics were compared within the same income level; for instance, a comparison between older non-Hispanics APL and older Hispanics APL, and a comparison between older non-Hispanics BPL and older Hispanics BPL. Since this paper sought to determine potential disparities controlling for either races/ethnicities or income levels, a comparison between older, different racial/ethnic populations with different income levels was not considered.

### 2.2.3. Analytic strategy for identifying disparities in spatial accessibility

The disparities in the two spatial accessibility measures computed on hexagonal grids among the older subpopulation groups were assessed on a couple of

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**Figure 3.** Illustration of various comparisons used in this study. A comparison with a horizontal axis refers to a comparison between income levels within the same race/ethnicity, and a comparison with a vertical axis indicates a comparison between races/ethnicities within the same income level.
scales and in several ways. The spatial accessibility based on hexagonal grids would be reasonable compared to centroids of census tracts, as hexagonal grids include only inhabitable areas. By aggregating the spatial accessibility from the small units to large units, subpopulation group-weighted average accessibility at different scales helps to assess disparities in the spatial accessibility.

At the state level, a cumulative percentage distribution plot was used to compare the levels of accessibility aggregated by the census tract level among the subpopulation groups. The plot has been utilized to assess disparities and inequalities among population groups elsewhere (e.g. Grengs 2010). Based on the cumulative percentage distribution, differences among the population groups were statistically evaluated through a non-parametric two-sample Kolmogorov–Smirnov (KS) test. This is a method for testing if the distribution functions of two samples are identical or not. Unlike the non-parametric Mann–Whitney test or the parametric t-test, which captures the differences in means between two groups well enough but has limitations in terms of identifying other kinds of differences such as variance, the KS test has advantages as it detects any type of differences between the two groups (e.g. mean, median, or variance) (Conover 1999, 456).

At the county level in Florida, disparities were assessed by identifying counties with substantial differences in accessibility between subpopulation groups, using Getis-Ord’s $G^*_i$ statistic that is a method for spatial hotspot analysis (see Getis and Ord 1992; Ord and Getis 1995). In other words, a county where a difference in accessibility between two groups is significant would be distinguished as a hot or cold spot and classified as a county with disparity. The simple form of $G^*_i$ is equation (4) (Getis and Ord 1992).

$$G^*_i = \frac{\sum_{j=1}^{n} w_{ij} x_j}{\sum_{j=1}^{n} x_j}$$

where, $G^*_i$ is the statistic, $x_j$ is a size of the difference in accessibility between two groups at location $j$ over all $n$ ($j$ may equal $i$), and $w_{ij}$ is the spatial weight value between $i$ and $j$.

Figure 4. Access to vaccination sites at hexagon level. To illustrate better access in the figures, we reversed the colour scheme from travel time to cumulative opportunities. The bright yellow presents better access. (a) Nearest opportunity. (b) Cumulative opportunities within 15 minutes.
3. Results

3.1. Accessibility at hexagon level

As previously stated, the whole of Florida was divided into hexagons. The total number of hexagons was 1,542,729, and 490,010 hexagons were filtered as habitable hexagons (Figure 4). Of 490,010 hexagons, hexagons accessible to a vaccination site within 5, 15, 30, and 60 minutes were 20.83%, 63.34%, 90.29%, and 99.69%, respectively, but 0.31% of hexagons were still located beyond 60 minutes (Figure 4a). Most hexagons in urban areas have a vaccination site within five minutes (yellow-coloured) of them, but vaccination sites tend to be located more distantly from the other hexagons in rural areas (purple-coloured). In terms of cumulative opportunities (Figure 4b), hexagons located around Orange, Pinellas, and Broward counties had a larger number of opportunities relative to other hexagons (yellow-coloured). The hexagons located in these counties have more than 20 vaccination sites within 15 minutes. In contrast, again considering the travel times to the nearest vaccination site, hexagons in rural areas and North Florida have less than or equal to two vaccine sites within 15 minutes (purple-coloured) on average.

3.2. Comparison of spatial accessibility between subpopulation groups at the state level

Table 1 shows the average accessibility of the older subpopulation groups, which was calculated by population-weighted accessibility at the state level. On average, older blacks were closer to the nearest vaccination site than older whites regardless of income levels, and older Hispanics had better access than older non-Hispanics regardless of income levels. However, the overall population groups were able to access the nearest vaccination site within 7 minutes. Like the nearest opportunity, older blacks had more of the number of vaccination sites within 15 minutes compared to older whites. In particular, older blacks BPL had 14.6 of vaccination sites, while older whites APL had 9.1 of vaccination sites. For the ethnicity, older Hispanics BPL were closer to the nearest vaccination site compared to others. On average, older Hispanics were able to reach the nearest vaccination site within about 5 minutes, whereas older non-Hispanics took 7.2 minutes to the nearest vaccination site. Regarding the number of vaccination sites within 15 minutes, like the nearest opportunity, older Hispanics had more sites than older non-Hispanics.

We present the cumulative percentage distribution plots of spatial accessibility in Figures 5 and 6 to compare how many percentages of each subpopulation group could access a vaccination site or have opportunities within a 15-minute threshold. Figure 5a shows the cumulative percentage distribution of the nearest opportunity for older whites and older blacks. Since a smaller value means better access, locating the left side from the other lines indicates better access. According to the lines, almost 90% of older blacks groups (solid blue and dashed purple lines) were able to access the nearest vaccination site within 10 minutes. In contrast, less than 90% of older whites (solid red and dashed green lines) were able to access the nearest vaccination site within 10 minutes. Across all population groups, almost 95% of populations were able to access the nearest vaccination site within 20 minutes. Furthermore, the two-sample KS test confirmed that all differences between races and income levels were not statistically significant at the 95% significance level.

For the cumulative opportunities, the right side of the other lines indicates better access (Figure 5b). Figure 5b indicates that older blacks (solid blue and dashed purple lines) had better access compared to older whites (solid red and dashed green lines). Interpreting horizontally, these graphs can help to understand the plots more than vertically. For example, 50% of older blacks APL (solid blue line) had about 12 vaccination sites within 15 minutes, while the same percentage of older whites APL (solid red line) had about seven vaccination sites within 15 minutes. This means that older blacks APL had more opportunities relative to older whites APL in the same threshold. Nevertheless, the KS test showed that disparities in both accessibility measures were not statistically significant.

The comparison between non-Hispanics and Hispanics is shown in Figure 6. For the nearest opportunity (Figure 6a), over 90% of older Hispanics (solid blue and dashed purple lines) were able to access the nearest vaccination site within 10 minutes, but only 80% of older non-Hispanics (solid red and dashed green lines) were able to access the nearest vaccination site within 10 minutes. Nevertheless, almost 95% of all population groups were able to access the nearest vaccination site within
20 minutes. Although older Hispanics had better access than older non-Hispanics, the KS test did not show statistical significance at the 95% level.

Moreover, as a result of the nearest opportunity, the outcomes of the cumulative opportunities (Figure 6b) show that older Hispanics had better access than older non-Hispanics. For example, 50% of older Hispanics BPL (dashed purple line) were able to access 16 vaccination sites within 15 minutes, but the same proportion of older non-Hispanics BPL (dashed green line) were able to access about eight vaccination sites (Figure 6b). As the figures illustrate, differences between income levels with the same ethnicity (i.e. solid lines vs. dashed lines) do not seem large, and there was no statistically significant difference.

3.3. Comparison of spatial accessibility between subpopulation groups at the county level

Although disparities in spatial accessibility to vaccination sites were not statistically identified at the state level for both accessibility measures, it does not necessarily mean there would be no disparities at the county level as well. In this section, levels of spatial accessibility between older subpopulation groups were compared between different income levels and between different races/ethnicities by using $G^i_r$ statistic based on a difference in accessibility between subpopulation groups.

Hot spots and cold spots from the $G^i_r$ analysis depict spatial clusters of high values and those of low values, respectively. In this sense, the $G^i_r$ analysis is used to identify a county where the difference in accessibility between two given subpopulation groups is significant. For example, if the accessibility of older whites APL is larger than older whites BPL (i.e. older whites APL – older whites BPL > 0), a county will be identified as a hot spot that is called ‘worse for older whites BPL’. On the other hand, if the accessibility of older whites APL is smaller than older whites BPL (i.e. older whites APL – older whites BPL < 0), a county will be identified as a cold spot that is called ‘worse for older whites APL’ (see Table 2).

Figure 7 shows the result of $G^i_r$ statistic of a difference between the different income levels within the same racial subpopulation group. First, for the nearest
opportunity for older whites (Figure 7a), older whites APL need to travel longer than older whites BPL to access the nearest vaccination site in Gulf County. On the other hand, older whites BPL travel longer than older whites APL in Leon County. Except for these counties, older whites between two income groups have no significant difference in terms of the nearest opportunity in other counties of Florida. However, for the cumulative opportunities of older whites (Figure 7b), older whites APL have a smaller number of vaccination sites within 15 minutes compared to older whites BPL in Pinellas, Polk, Seminole, and Brevard counties. Older blacks BPL tend to travel longer than older blacks APL to access the nearest vaccination site in Lee, Collier, Monroe, and Broward counties in Southern Florida (Figure 7c). Figure 7d shows that in terms of cumulative opportunities, older blacks BPL have fewer opportunities than older black APL in Southern Florida, while older blacks APL have fewer opportunities than older blacks BPL in counties in Central Florida. Notably, older blacks BPL may struggle to access vaccination sites in Lee, Broward, and Monroe counties of South Florida compared to older blacks APL, given that these counties are worse for older blacks BPL due to longer travel time to the nearest vaccination site and a smaller number of vaccination sites within 15 minutes.

Figure 8 presents counties with large disparities between the different income levels within the same ethnic population group. For the nearest opportunity of older non-Hispanics (Figure 8a), large disparities were found around North Florida, especially in counties such as Okaloosa, Holmes, Bay, and Leon, which are worse for older non-Hispanics BPL. In terms of cumulative opportunities (Figure 8b), Seminole County is worse for older non-Hispanics APL. Regarding older Hispanics populations, it was found that Highlands and St. Lucie counties are worse for older Hispanics APL and Gilchrist County is worse for older Hispanics BPL for the nearest opportunity (Figure 8c). For cumulative opportunities (Figure 8d), older Hispanics BPL and older Hispanics APL have fewer opportunities in North-Central Florida and Central Florida.

Table 2. A way of using $G^*_i$ for comparison between subpopulation groups.

| Comparison (Subtraction) | Hot spot | Cold spot |
|--------------------------|----------|-----------|
| APL – BPL                |          |           |
| Older whites – Older blacks |            |          |
| Older non-Hispanic – Older Hispanics |        |          |

|                |          |           |

Figure 7. Hot and cold spots from comparisons between income levels within racial subpopulation groups at the county level. The green colour indicates the APL group has better access than the BPL group, and the brown colour means the APL group has lower access than the BPL group.
respectively, when compared to another. Of these identified counties, Gilchrist County is worse for older Hispanics BPL for both accessibility measures, which may lead to older Hispanics BPL in Gilchrist County needing to travel longer and having fewer vaccination sites within 15 minutes compared to older Hispanics APL.

Figure 9 depicts counties with disparities between races within the same income level. First, within APL, older whites need to travel longer than older blacks in North Florida, while older blacks are necessary to travel longer than older whites in South Florida (Figure 9a). In contrast, for cumulative opportunities (Figure 9b), older whites have fewer opportunities in Collier County than older blacks, and older blacks have fewer opportunities in Hernando County than older whites. Next, within BPL, older blacks are farther to the nearest vaccination site compared to older whites in South Florida (Figure 9c). When it comes to cumulative opportunities (Figure 9d), older blacks have fewer opportunities in Hernando, Lee, and Broward counties, and older whites have fewer opportunities in Putnam and Collier counties. For both accessibility measures, older blacks BPL need to travel longer to the nearest vaccination site and have fewer opportunities in Lee and Broward counties compared to older whites BPL.

Lastly, a comparison between ethnic population groups within the same income level is presented in Figure 10. In terms of APL, older non-Hispanics in Calhoun, Liberty, Franklin, and Leon counties of North Florida need to travel longer to the nearest vaccination site than older Hispanics, whereas older Hispanics in Columbia and Suwannee counties of North Florida and Glades, St. Lucie, and Palm Beach counties of South Florida are farther to the nearest vaccination site than older non-Hispanics (Figure 10a). For cumulative opportunities, older non-Hispanics have fewer opportunities than older Hispanics only in Pasco and Pinellas counties (Figure 10b). Regarding BPL, there are disparities in the nearest opportunity in the two counties, Lee and Broward, worse for older Hispanics. On the other hand, older Hispanics and older non-Hispanics have fewer opportunities in North Florida and Central Florida (e.g. Tampa Bay area), respectively, when compared to another population group (Figure 10d).

3.4. Disparities with geographic locales

Unsurprisingly, as our maps illustrate, vaccination sites in Florida are disproportionately distributed across urban and rural areas. People living in urban areas are more

![Figure 8](image-url) Figure 8. Hot and cold spots from comparisons between income levels within ethnic subpopulation groups at the county level. The green colour indicates the APL group has better access than the BPL group, and the brown colour means the APL group has lower access than the BPL group.
likely to be able to access a vaccination site with a short travel time and have more vaccination sites within 15 minutes than their counterparts in rural areas. Despite these clear divides, disparities between income groups or racial/ethnic groups may differently appear, acting independently of their geographic characteristics. In this regard, we count the number of identified counties with disparities based on the urban-rural classification (see Figure 1) to examine an association between population disparities and geographic locales.

Table 3 shows the number of counties based on groups for comparison, accessibility measures, and geographic locales, which combines the results of Figures 7–10 and Figure 1. There are several notable observations. First, older whites APL have few opportunities compared to older whites BPL in four of the urban counties. By contrast, older blacks BPL tend to travel longer (four urban counties) and have few opportunities (four urban counties) than older blacks APL in urban counties. Second, older non-Hispanics BPL travel longer than older non-Hispanics APL in three urban counties, whereas older Hispanics BPL have few opportunities compared to older Hispanics APL in six rural counties. Third, within the APL group, older whites tend to travel longer than older blacks in four rural counties, but within the BPL group, older blacks travel longer (four urban counties) and have fewer opportunities (three urban counties) than older whites in urban counties. Lastly, within the APL group, there are urban and rural counties favourable to non-Hispanics and Hispanics, respectively. In contrast, within the BPL group, older non-Hispanics have few opportunities compared to older Hispanics in four urban counties, and older Hispanics are more likely to travel longer in two urban counties and have fewer opportunities in four rural counties than older non-Hispanics. In sum, the disparities between urban and rural counties are inconsistent, and their variance depends on income and racial/ethnic groups.

4. Discussion
This paper assessed disparities in spatial accessibility among older subpopulation groups based on races, ethnicities, and income levels in Florida, using very spatially disaggregated accessibility approaches based on
hexagonal grids. To capture different aspects of accessibility in terms of how fast people can reach the closest vaccination sites and how many total vaccination opportunities people can have within a given threshold, we calculated the nearest opportunity and cumulative opportunities metrics, respectively. Each subpopulation-weighted spatial accessibility based on the two spatial accessibility measures was used for comparison among the older subpopulation groups at the state and county levels.

Findings revealed that regardless of income levels, older blacks are closer to the nearest vaccination site than older whites at the state level, as the study by Ikram, Hu, and Wang (2015) found African-Americans are closer to the

**Table 3.** The number of counties with disparity according to the urban and rural classification.

| Group       | Disparity       | Urban Nearest | Urban Cumulative | Rural Nearest | Rural Cumulative |
|-------------|-----------------|---------------|------------------|---------------|------------------|
| White       | Worse for APL   | -             | 4                | 1             | -                |
| Black       | Worse for BPL   | 1             | -                | -             | -                |
| Black       | Worse for APL   | 1             | -                | -             | -                |
| Non-Hispanics | Worse for BPL | 4             | 4                | -             | -                |
| Hispanics   | Worse for APL   | 1             | 2                | 1             | 1                |
| APL         | Worse for White | -             | 1                | 4             | -                |
| APL         | Worse for Black | 2             | 1                | 1             | -                |
| BPL         | Worse for White | -             | 1                | -             | -                |
| BPL         | Worse for Black | 4             | 3                | 1             | -                |
| APL         | Worse for Non-Hispanics | 1             | 2                | 3             | -                |
| APL         | Worse for Hispanics | 2             | -                | 3             | -                |
| BPL         | Worse for Non-Hispanics | -             | 4                | -             | 1                |
| BPL         | Worse for Hispanics | -             | -                | -             | -                |

**Figure 10.** Hot and cold spots from comparison between racial subpopulation groups within the same income level at the county level. The green colour indicates the older non-Hispanics group has better access than the older Hispanics group, and the brown colour means the older non-Hispanics group has lower access than the older Hispanics group.
nearest pharmacy in Baton Rouge, Louisiana, while there are no statistically significant disparities between the subpopulation groups. While the type of facility is dissimilar from the study by Tao et al. (2020) that analysed spatial accessibility to COVID-19 testing sites, our result is comparable to the research given that older blacks, older Hispanics, and low-income residents had relatively better accessibility to COVID-19 healthcare opportunity.

When focusing on counties that have disparities in both two accessibility measures, we were able to identify that in terms of income levels, older blacks BPL travel longer and have fewer accessible vaccination sites within 15 minutes than older blacks APL in Lee, Broward, and Monroe counties in South Florida, and older Hispanics BPL travel longer and have fewer opportunities than older Hispanics APL in Gilchrist County. In addition, regarding races, older blacks travel longer and have fewer vaccination sites than older whites in Lee and Broward counties.

These findings from the state and county levels can be supported by the study by Baicker, Chandra, and Skinner (2005) noting that racial/ethnic disparities were a local phenomenon in the sense that disparities that were not identified at the state level were found at the county level. In addition to racial/ethnic disparities, our finding also suggests that disparities according to income level are a local phenomenon as well.

One may wonder why the disparities identified in this study occurred. One of the possible explanations is that the disparities likely have resulted from unequal allocation/distribution of the vaccination sites, racial/ethnic segregation among older populations, residential choices, and transportation networks connecting older subpopulations with vaccination sites. In particular, the idea that APL groups have fewer opportunities in some urban counties may stem from the residential choices of high-income households that own a car and prefer to be away from dense areas. On the other hand, the low accessibility of BPL groups in rural counties with few vaccination sites may ultimately lead to significant health issues, given that travelling longer and fewer opportunities may have people defer to get vaccinated. In addition, the finding that older Hispanics BPL have low accessibility in urban and rural counties may amplify their vulnerability to COVID-19, and this is unfortunately consistent with the result that Hispanic populations are more likely to have low accessibility to intensive care unit beds during the COVID-19 pandemic (Kim et al. 2021). In addition, the fact that COVID-19 cases and mortality rates have increased in nonmetropolitan counties (Zhang and Schwartz 2020) may serve to highlight the potential challenges going forward for rural counties in Florida. In this regard, planning for and allocating vaccination resources should be specifically handled with special attention to older subpopulation groups, who tend to have disproportionately low accessibility to vaccination sites, especially in rural counties. Such disparities may have detrimental influences on the individuals’ or communities’ health issues (White, Haas, and Williams 2012).

Consequently, this paper argues that granular prioritization for vaccination among older populations would be needed and allocating vaccination sites should recognize spatial accessibility of different older subpopulation groups in a given county with consideration of their income level and race/ethnicity. If differences among older subpopulation groups were not accounted for by age-based prioritization ignoring income and racial/ethnic characteristics, an urgent demand from minorities and low-income population groups that are disproportionately influenced by COVID-19 would be neglected. Furthermore, when local disparities not identified at a state level were not considered, healthcare burdens by the COVID-19 would be worsened in local communities.

There are at least several limitations in this study. First, this study did not focus on the causes of disparities; it simply tried to identify them. If the reasons came up within our analysis, policymakers would possibly make a decision to reduce the disparities. This limitation would bring future research questions. Why does a certain population group have less access than others in a given county? Which factors drive the disparities? With spatial accessibility based on the spatially disaggregated hexagons, possible factors that lead to disparities may be figured out in future research. Second, since we chose specific spatial accessibility measures and used a given set of data, changing either of these would potentially lead to different findings. For instance, when additional vaccination sites would be added, the level of spatial accessibility of each subpopulation group may be different from our results. Lastly, we did not consider auto ownership and other factors that might affect an individual’s ability to reach a vaccination site. For example, if a person does not have a car, it may not matter how a facility is close by. Since we did not take into account different auto ownership rates or the availability of public transit, our results should be understood with these limitations.

5. Conclusions

This paper assessed the level of spatial accessibility of older subpopulation groups selected based on income levels and races/ethnicities (i.e., older whites APL and BPL, older blacks APL and BPL, older non-Hispanics APL and BPL, and older Hispanics APL and BPL) to vaccination sites in Florida. Spatially disaggregated nearest opportunity and cumulative opportunities were calculated based
on hexagonal grids, and subpopulation-weighted spatial accessibility was compared with different methods, such as cumulative percentage distribution plots and KS test at the state level and $G^*_c$ statistic at the county level.

This paper showed that the extent of disparities in spatial accessibility may be able to differ at the state level and the county level and the illustrated counties to which are needed to be paid attention from policymakers. With these outcomes, we conclude that the disparities in spatial accessibility among the subpopulation groups were not substantial at the state level, but some disparities were found at the county level in Florida. Policymakers thus would need to focus on county-level disparities as well as state-level disparities and consider both travel time to the nearest vaccination site and the number of vaccination sites within a given travel time threshold in order to avoid some population groups in need of vaccines having disproportionately less access to vaccination sites than others.

In future work, spatial accessibility to vaccination sites with different transport modes, such as walking, biking, public transit, and a private car, can be assessed among older subpopulations with different income levels and races/ethnicities. This future research can help differentiate each older subpopulation group’s accessibility to vaccination sites in terms of a certain transport mode.

Note

1. The types of land use are classified as Urban and Built-Up, Rangeland, Agriculture, Upland Forest, Wetlands, Water, Transportation, Communication, and Utilities, and Barren Land in the Statewide Land Use and Land Cover dataset.

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ORCID

Kyuisk Kim http://orcid.org/0000-0003-3753-3196
Mahyar Ghorbanzadeh http://orcid.org/0000-0002-5651-7573

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