Assessing Geographical Inaccessibility to Health Care: Using GIS Network Based Methods

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Abstract Disparities in the geographic accessibility to health care may be due to the location/distribution of the population and the characteristics of the transportation infrastructure relative to spatial arrangement of the health care delivery system within a region. Access to health care is a complicated concept and is largely dependent on the characteristics of the population in need of services. The most significant features affecting the health status and health outcomes involve distance between the population's geographic regions and health care facilities and the travel time taken to reach the health care delivery system. Because of Mississippi's rural nature and uneven distribution of physicians, geographic disparities exist in access to primary care services leaving women, children, elderly and general populations in underserved health care regions. The purpose of the research is to identify hot spots of vulnerable population burdened due to geographical accessibility to right kind of health services. This research investigates these features by using network-based GIS methods in ten counties with urban-rural settings. The methodology assesses the geographic accessibility of three types of critical health care facilities: obstetrician/gynaecology (Women in child bearing age); paediatrics (children) and Trauma/Burn Centers (general population). To examine, using network analyst GIS functionalities, these facilities are geocoded, and optimal travel-time based service areas were generated and pertinent vulnerable population data layers were developed. The results identified hot spots of vulnerable populations residing outside the optimal service areas, with rural regions and pregnant women bearing most of the health burden due to geographic inaccessibility. This GIS methodology equip health administrators and policy makers in providing comprehensive view of the health systems from a territorial perspective while assisting them in making conscious policy decisions.

Keywords Geographic Accessibility, Network Based Methods, Health Care, GIS

1. Introduction

Healthy people make health economy. Health care is the basic care provided to the populations at community level and targets better health outcomes and greater equity in health. Primary health care is the key in shaping healthy communities, improving and maintaining health of people. The health care quality is better described as a gulf for certain segments of the population, such as racial and ethnic minority groups, given the gap between actual care received and ideal or best care quality [1]. These health care disparities arise due to hitches in optimal health care functionalities such as availability, accessibility and affordability [2]. Disparities in geographic access to health care result from the configuration of facilities, population distribution, and the transportation infrastructure [3]. Geographic accessibility is considered as a critical

determinant of human health around the globe (World Health Organization) than any of the vectors and significant factor contributing towards health disparities.

Access to health care is a complicated concept and is largely dependent on the characteristics of the population in need of services. The most significant features affecting the health status and health outcomes involve distance between the population's geographic regions and health care facilities and the travel time taken to reach the health care delivery system.

1.1. Geographic Accessibility: Location and Health

Location and Health have been prominent features in determining accessibility rates among communities; and "location" was long considered more a determinant of health than pathogens [4]. One of the most significant factors that controls health status and largely contributes to health disparities is 'the distance to health care facilities'. The issue of equality to health care access has become a research priority in many countries [5].

The United States Department of Agriculture (USDA) has expressed concern over growing health disparities

between urban and rural communities in the dimension of infant mortality, age-standardized mortality and pregnancy related mortality rates [6].

The quality of health care in rural areas with predominantly low income and minority populations largely depend on geographical access and the distance to health care facility is highly sensitive in making health care choices. Geographical accessibility is defined as the ability of obtaining health care resources that meet the health demands of the population. It infers that a community has health care accessibility if the resources meet specific characteristics such as geographic location, affordability that fit with patient's needs [7].

Geographical accessibility centres on the concept of the presence of the right type of health care service with in the optimum travel time. The concept develops from the spatial arrangement of how people/communities, facilities and transportation network are connected or configured. Analyzing this spatial configuration serves as a measurement to expose the health disparities due to lack of the 'right' health care facilities that meets the needs of local people and difficulties with increased travel times, referred as 'burden of travel', to the facilities.

1.2. Critical Health Care Services: Optimal Distances

Availability and accessibility to specialty health care facilities and trauma centers are the key component to US health care system because they have shown to decrease morbidity and mortality rates with their location being in optimal distances to patients needs. The issue of geographical inaccessibility to health care facilities often affects approximately 20% of nation's population in Rural America, those who live in non-metropolitan counties. The health disparities are very large, especially in terms of geographical accessibility, with sparse distribution of general hospitals and few specialty health care systems [8].

Many studies by World health researchers have exposed health disparities related to limited/timely access to required health care facilities in these under served areas [9]. A large body of literature has documented the level of geographical accessibility to three critical health care services: Obstetrician / Gynecology, Pediatrics and Trauma Centers services as primary drivers of mortality and morbidity rates and consequent health disparities [10]. Pregnant women, Children and general populations may experience greater difficulties navigating the critical health care services within designated optimal times with poor geographical accessibility. Assessing the geographical accessibility to these three critical health care services within optimal times projects the status of health care system in the region in addition to revealing the needs of medical services required by the community.

1.3. Mississippi's Health Care System Status

The poor status of Mississippi's health care system can be revealed from the fact that all of Mississippi's 82 counties contain Designated Medically Underserved Areas as defined by the federal Health Resources and Services Administration (HRSA) [11]. Over a half of Mississippian's (54.3%) live in designated primary health professional shortage area [12]. The foundation reports that the state's burden of high mortality and morbidity rates are exacerbated due to limited geographical access to health care facilities and outpacing the national averages in the number of deaths.

The high disparity scores, related to pregnancy, child birth and prenatal care among the women in Mississippi ranks the state 47th of 50 states in births to females 15-17 years of age, 49th in child death, and 50th in low birth weight, infant mortality [10]. While the infant mortality goal for US stands at 6.0, the rate for Mississippi stands at 9.6, attributing primary cause to issues in access to health care [13]. The University of Mississippi Medical Center (UMMC), located in the state capital is the only Level 1 Trauma facility, the only burn center and the only Level III neonatal intensive care nursery in the state.

Because of Mississippi's rural nature and uneven distribution of physicians, geographic disparities exist in access to primary care services leaving women, children, elderly and general populations in underserved health care regions.

To understand and present a clear setting of health disparities due to geographical accessibility, this study, using GIS based network analyst functionalities, identifies hot spots of vulnerable populations (in need of a specialty care) residing outside the service areas of three critical health care facilities (Obstetrician/Gynecology; Trauma Centers; Pediatrics) and equip health administrators and policy makers in providing comprehensive view of the health systems from a territorial perspective while assisting them in making conscious policy decisions.

1.4. GIS Network Based Methods for Measuring Geographic Accessibility

According to the literature, these studies on mortality rates indicate an apparent evidence of geographic effects on health and geospatial researchers have identified these patterns as an important national policy problem in public health [14] [15]. The regional variations of mortality rates confirm the significance of spatial methods in measuring the accessibility patterns [16] and further supports the necessity to analyze geographical accessibility from a spatial perspective so as to reduce health disparities.

The availability of detailed spatial data coupled with the ability of Geographic Information System (GIS) to simulate real world scenarios conveys crucial information aiding the analysis with visualization reports [17] [18]. Geospatial methods offer wide range of analytical possibilities to understand the overall picture of health disparities due to geographical accessibility. The computational power of network based GIS methods integrating transportation networks, along with their attribute information such as

distances, speed limits and restrictions, provides a framework to assess geographical accessibility by estimating the physical distance or travel time between a right type of health care facility and the patient in need of the service. Even though, distance and time are both important factors of accessibility, World Health Organization (WHO) recommends using travel time, rather than distance, to assess geographical accessibility.

2. Creating Network Based Service Areas for Critical Health Care Facilities

Defined travel time based service areas are suitable measurements for healthcare accessibility and utilization [19] [20]. This research utilizes GIS Network Analyst tools to model geographical access to specific health care service scenarios in central Mississippi 10 county region, which is characterized with urban and rural regions. Network Analyst tools provide potential for greater use of estimations of travel time that can easily calculate service areas (buffers) and include or exclude populations that exist within the defined boundaries. Creating service areas requires accurate road network data with associated information on speed limits and restrictions. The availability of populations (with demographical profiles) at a finest geographical unit (census block level) will enhance examining the geographical accessibility of services.

The framework for measuring geographical accessibility centers on two components

1. Defining optimal travel time service area for each of the three critical health care facilities by building network dataset of transportation routes in GIS
2. Identifying pertinent vulnerable populations at a census block level, outside the optimal service area for the needed critical health care.

2.1. Datasets: Road Network, Specialty Health Care and Population Data

The road network dataset collected from Census Bureau, 2010 provides high quality, detailed road network data for all the state of Mississippi in vector GIS format and provides information on speed limits and restriction for each and every edge and node which is critical to model real time service areas based on travel time estimates. The three critical specialty healthcare facilities: Obstetrician/ Gynecology, Pediatrics and Trauma Centers are collected from Mississippi Primary Health Care Association and are geocoded, based on their physical addresses, to a point layer as a part of dataset. Block level demographic census data obtained from U.S. Census bureau was used in this research to model access to health care facilities. The demographic profiles were categorized as women in childbearing age, children under age of 12 and general population.

2.2. Assumptions

When representing real world scenarios, a number of assumptions are required for modeling. Centered on numerous population-based studies [21], to model travel time, this research makes assumptions on potential unpredictable factors that influence travel and the lack of geo-referenced data. Therefore, the GIS-based scenarios created for the three critical facilities presents an average situation. This research adopts assumptions that the travel conditions are similar through out the study region and therefore the variable factors influencing the travel conditions such as weather, traffic patterns etc. are kept constant. The research is limited to data availability and data processing capabilities.

2.3. Defining Optimal Travel time Based Service Areas for Health Care with Specialty

Defining travel-time based service areas cannot be generalized (as 30 minutes or 1 hour) as every health need has an optimal time to access specialty health care for lower mortality rates. Numerous health and mortality related studies have provided the following optimal travel times appropriate for each of the three critical health care facilities that define the health care system status of any region (Table 1).

Table 1. Defining optimal travel time for critical health care facilities

Critical Health care	Optimal Travel time studies	Optimal travel time used for this research
Obstetrician/ Gynecology	An optimal time from home to a needed health care of 20 minutes or more is associated with an increased risk of mortality and adverse outcomes for pregnant women [22].	20 minutes
Pediatrics	For any child health care or primary medical care, an area is designated as HPSA if no care is accessible with in 30 minutes of travel time [23].	30 minutes
Trauma Centers	In case of emergencies and access to trauma centers, an increase in optimal travel time of more than 30 minutes is associated with 1% increase in the mortality rates [24].	30 minutes

2.4. Modelling Accessibility Using Optimal Travel time Service Area

To create travel time based services areas for each of the critical facilities in the study region, ArcGIS Network Analyst was employed. Prior to creating services areas, the major task was to convert the road network dataset into a geospatial network dataset. Each line segment was assigned

a travel time cost attributes using the line segment's length (distance), speed limit and travel impedance factors. The converted network dataset assigns travel time along a line segment based on the distance and speed limit with additional cost in minutes calculated for turn delays. The generated network dataset was loaded into Arc GIS (10.0) along with health care locations and census block level demographic data layers.

The travel-time based service areas defined for each of the critical facilities were created as polygons using 'Service area' function: a 20-minute service area for obstetrician/Gynecology, 30-minute service areas for pediatrics and 30-minute service area for all the trauma centers were generated.

To assess the level of health care access to population, each service area is clipped to the demographic spatial distribution at a census block level. The underserved census blocks are identified by inversing the selected clipped areas of the 20-minute, 30-minute service areas through out the study region. To create population data layer for each health care, a block's population was assigned to the underserved area only when the centroid fell within the bounds of underserved area polygon. This framework involves considering: 1) Obstetrician/Gynecology: women in child bearing age (CBA) (18-55 years), 2) Pediatrics: children under 12 years, 3) trauma/burn centers: General populations for creating these population data layers.

3. Results and Discussion

Initial examination of the results indicates that there are few significant gaps in accessibility to some of the health care service. The travel time approach adopted by this study identifies population to have varied level of access to needed health services along the transportation routes. A clear distinction in geographic access to three critical health care emerged between urban and rural populations within the study region. To illustrate the hotspots, the highly populated census blocks outside the optimal travel times are categorized under various levels.

The results are presented under the following sections to discuss the geographical accessibility of population to the critical care facilities.

3.1. Geographical Access to Obstetrician/Gynecology

Figure 1 shows the spatial distribution of obstetrician/ Gynecology health care facilities and the proximity area that can be accessed with in 20-minute to the facility by road.

There are 26 OBS/GYN facilities, with uneven geographical distribution, mostly concentrated in Hinds, Rankin and Madison counties (Figure 1). The population data layer shows that around 30% of the total women in

childbearing age are residing outside the optimal travel times, with rural counties taking most (80%) of the burden (Figure 2). Claiborne County designated as a Rural County according to Census, bears the block with maximum number (>275) of women in childbearing age with limited geographical accessibility to Obstetrician/Gynecology centers (Figure 3).

The low mortality rates associated with optimal travel times makes these rural areas vulnerable. With the underserved rural population clearly exceeding the urban population numbers, the rural women often take the burden of low mortality and high infant death rates with poor geographic access. A total of 10% of the childbearing age women is identified to be located in hot spots, with high populations concentrations and low geographical accessibility (Figure 3 and Table 2).This geographical inaccessibility, to a large extent, affects how rural residents view the long-term sustainability of their communities.

Table 2. Urban and Rural concentrations of population outside optimal service areas

Total number of OBS/GYN Clinics	Total Women CBA outside 20min		Blocks with women in CBA outside 20-minute optimal service area	
	Urban	Rural	Urban	Rural
26	4897	21788	1215	1720

3.2. Geographic Access to Pediatrics

Figure 4 shows the spatial distribution of pediatric health centers and a service area of optimal 30-minutes travel time from each facility (Figure 4).

There are 48 Pediatric specialized clinics. The study area has an even spatial distribution of the facilities covering majority of the population both in urban and rural regions. The results reveal that more than 90% of the children are living within the optimal 30-minute travel times (Figure 5). However, the population data layer illustrated some hotspots outside optimal travel times showing blocks with high children population concentrations and poor accessibility to health care (Figure 6). Interestingly, most of these hot spots are found in urban counties presenting information to alert health officials in decision-making process (Table 3).

Table 3. Urban and Rural concentrations of population outside optimal service areas

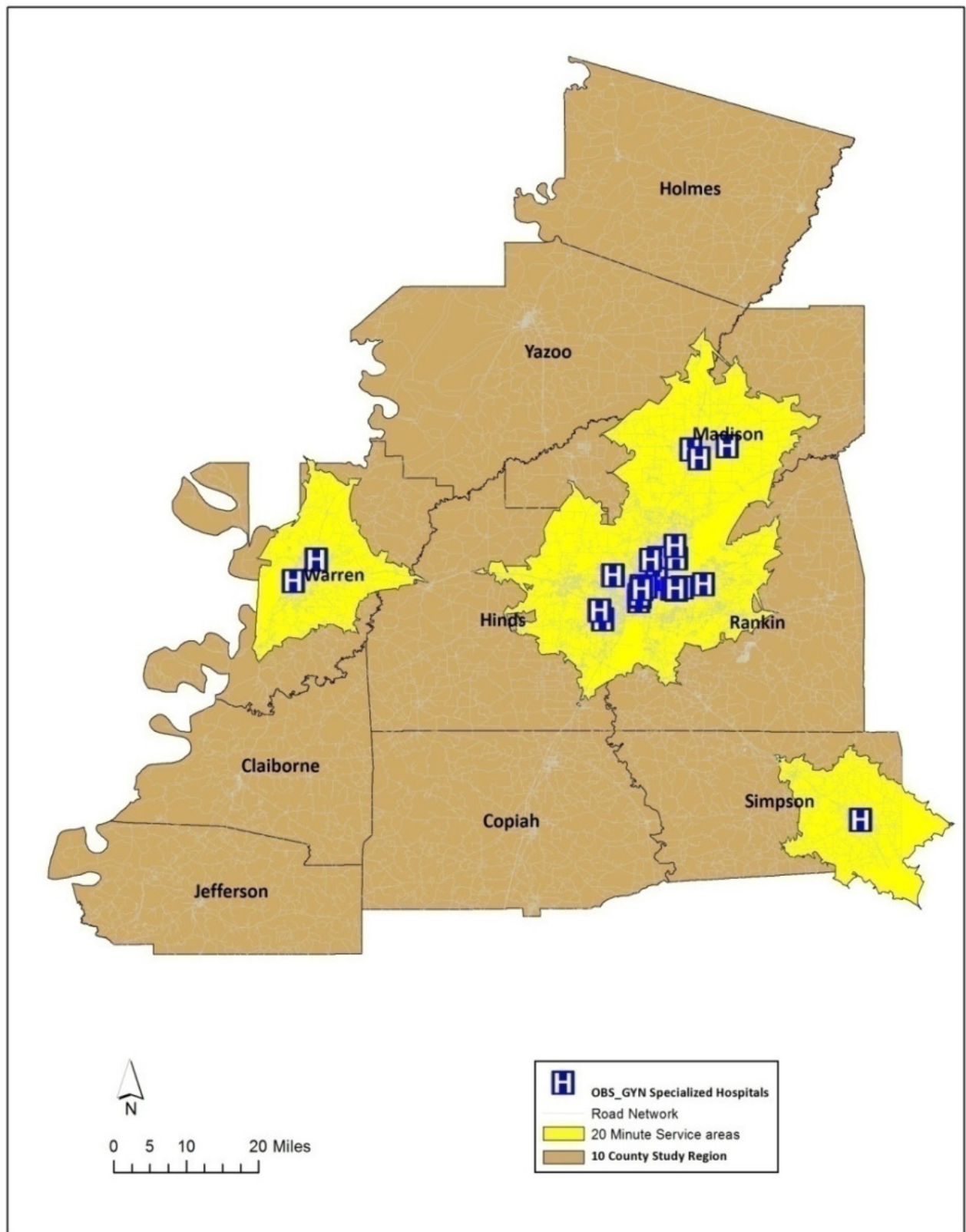| Total number of Pediatric Clinics	Total Children outside 30min 10660		Block groups with Children and outside optimal 30 min service area	
	Urban	Rural	Urban	Rural
48	2965	7695	1500	900

Figure 1. Spatial distribution of obstetrician/gynecology health facilities
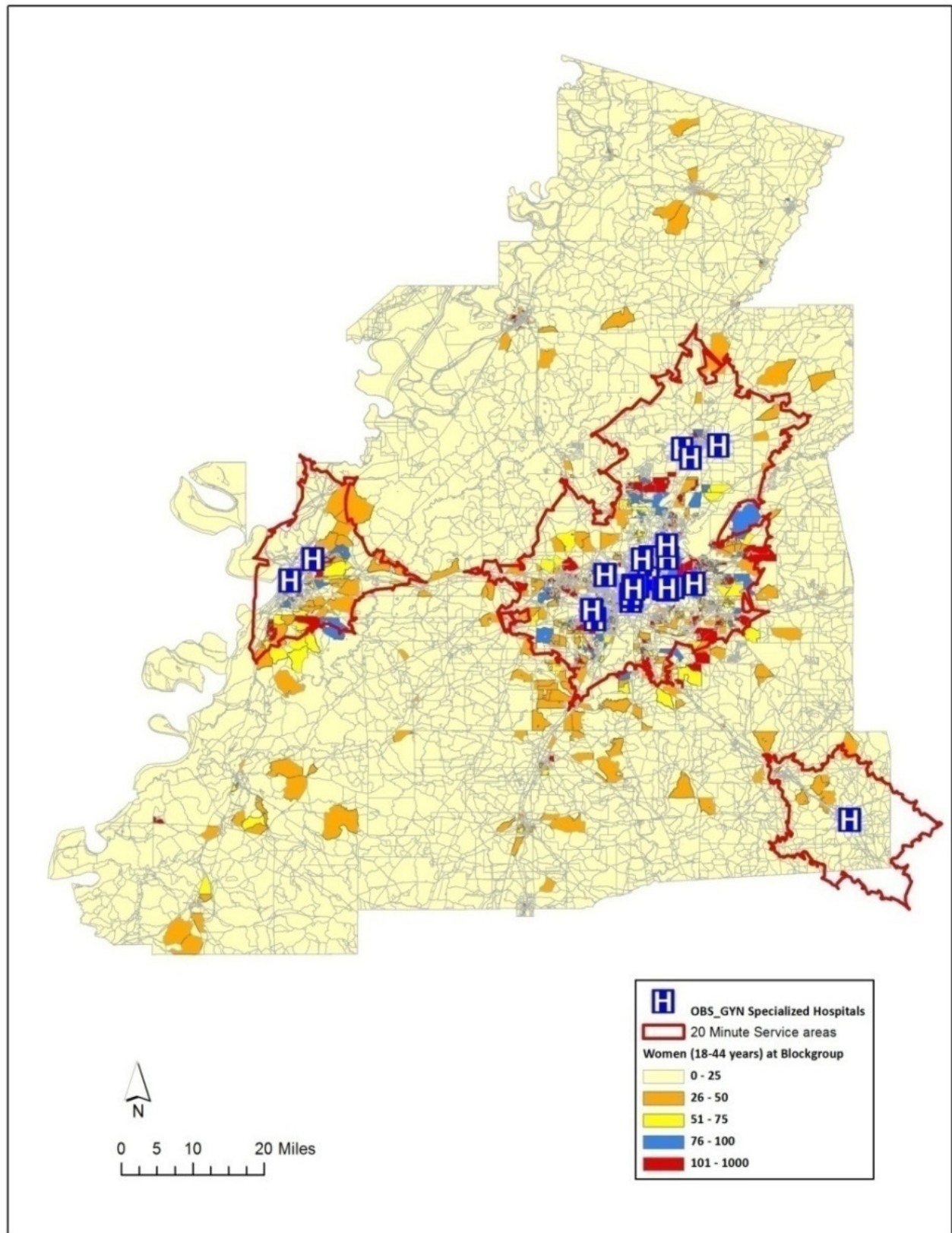
Figure 2.   Optimal 20-minute health service areas and spatial distribution of women in childbearing age
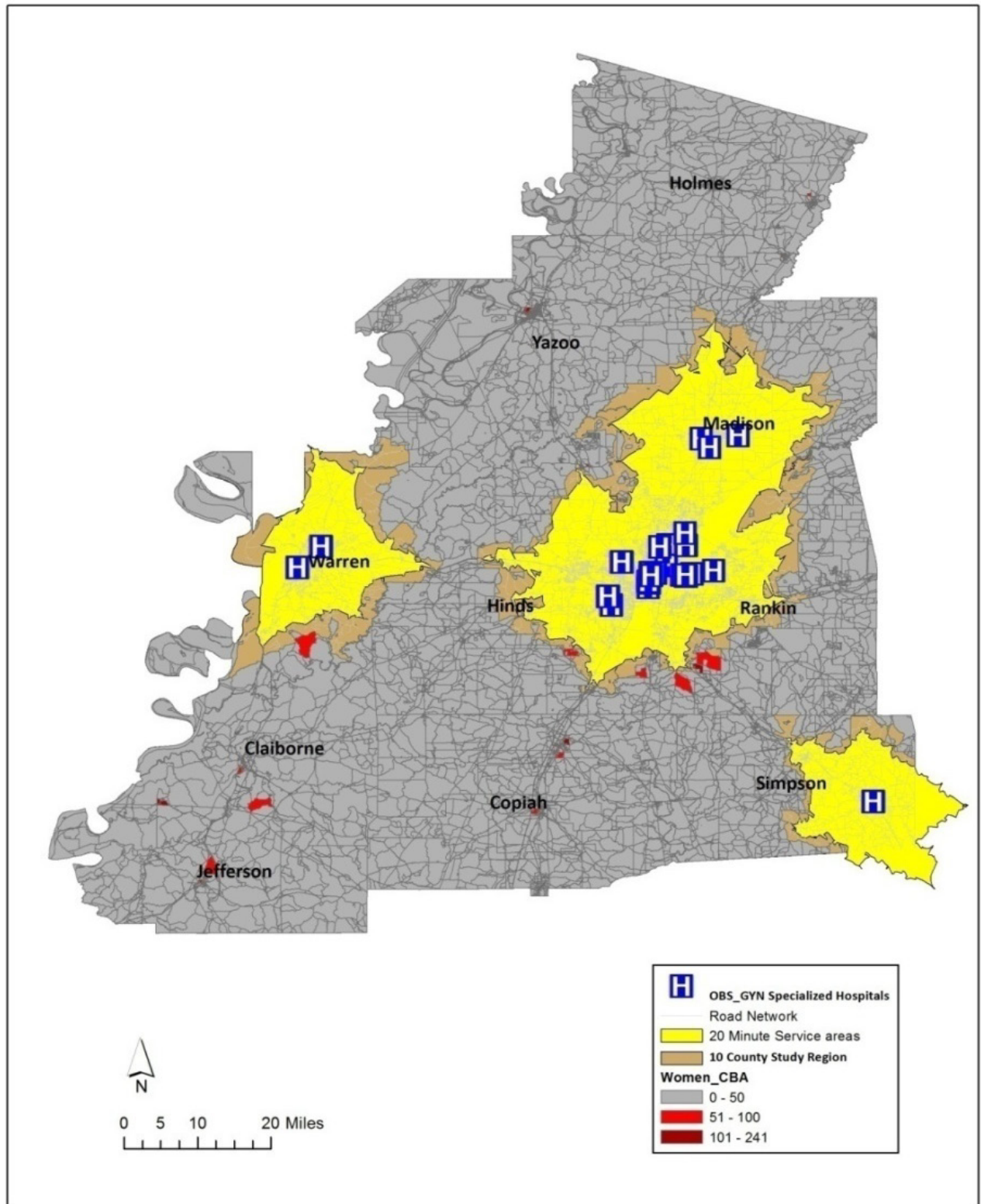
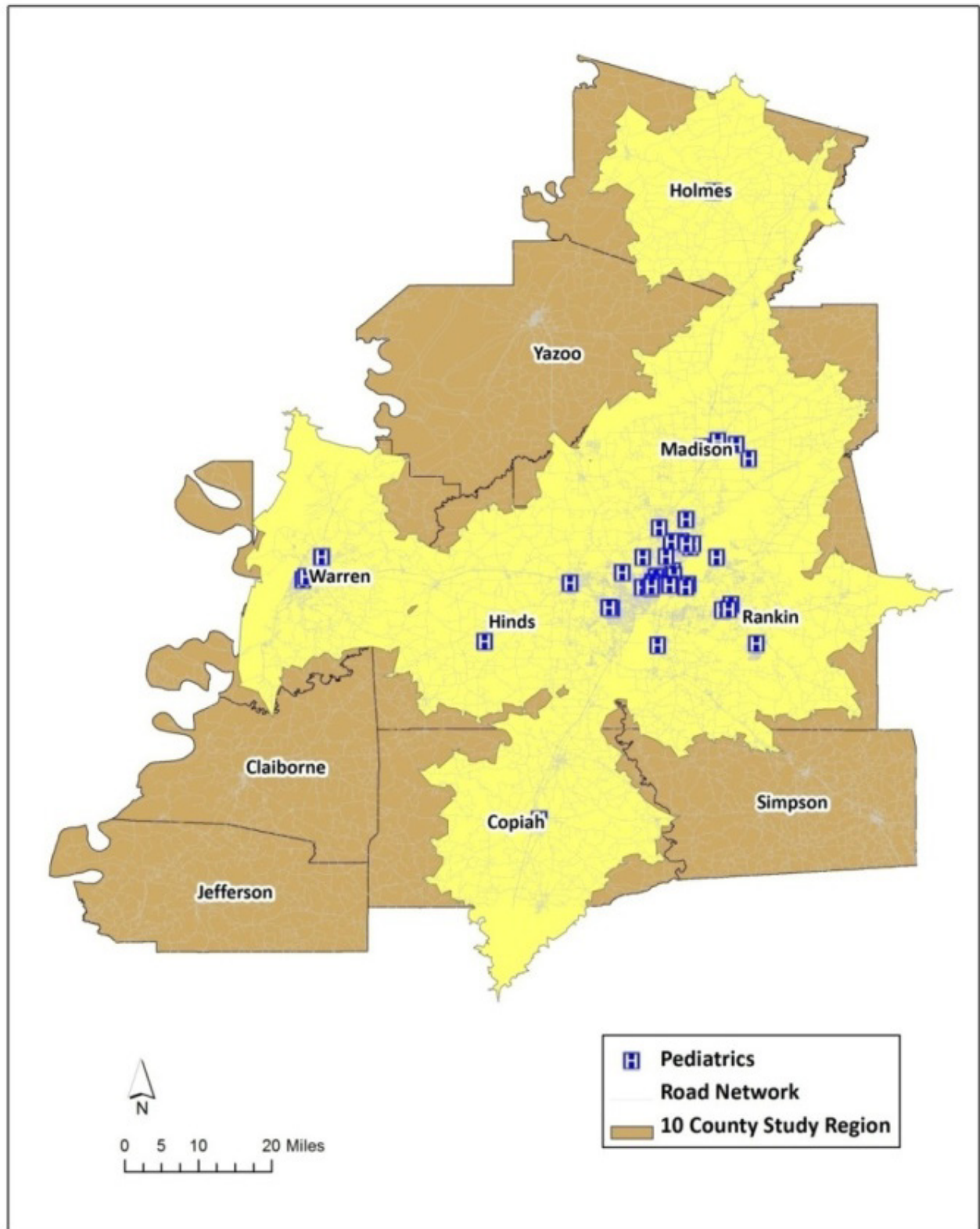**Figure 3.** Hotspots of concentrations of women in childbearing age outside the optimal service regions

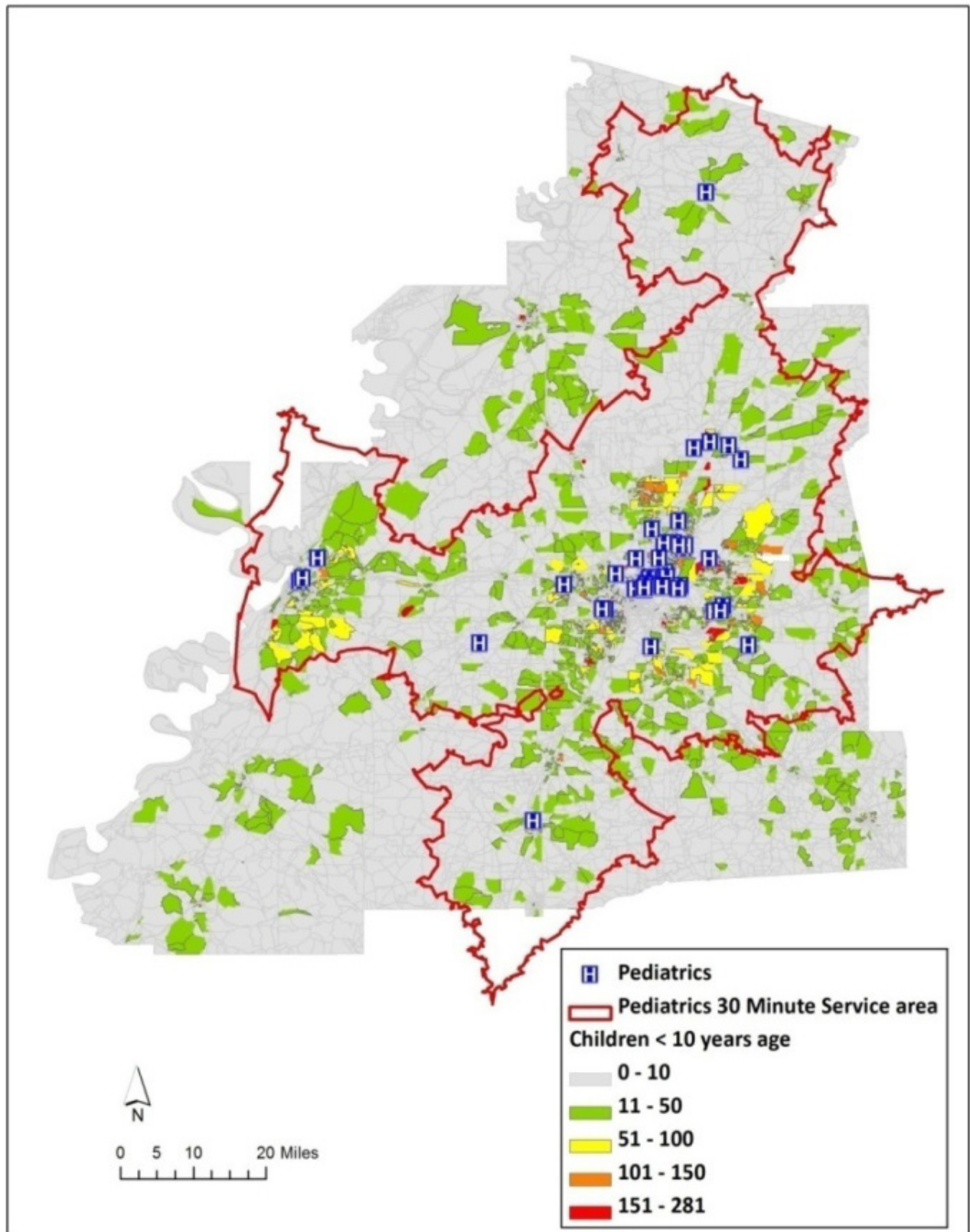**Figure 4.**   Spatial distribution of Pediatric health facilities

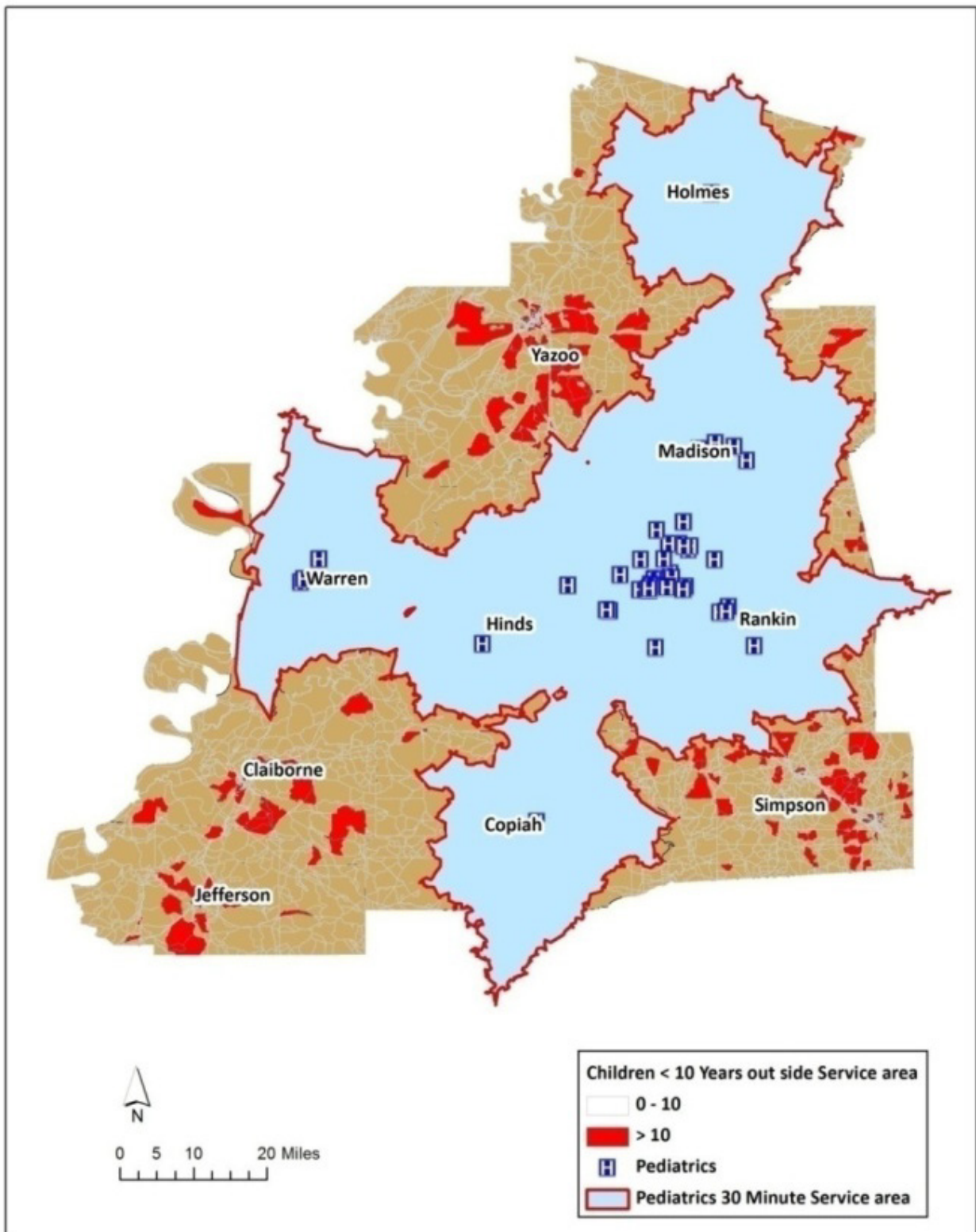**Figure 5.** Optimal 30-minute service areas and spatial distribution of children

Figure 6. Hotspots of concentrations of childresn outside the optimal service regions
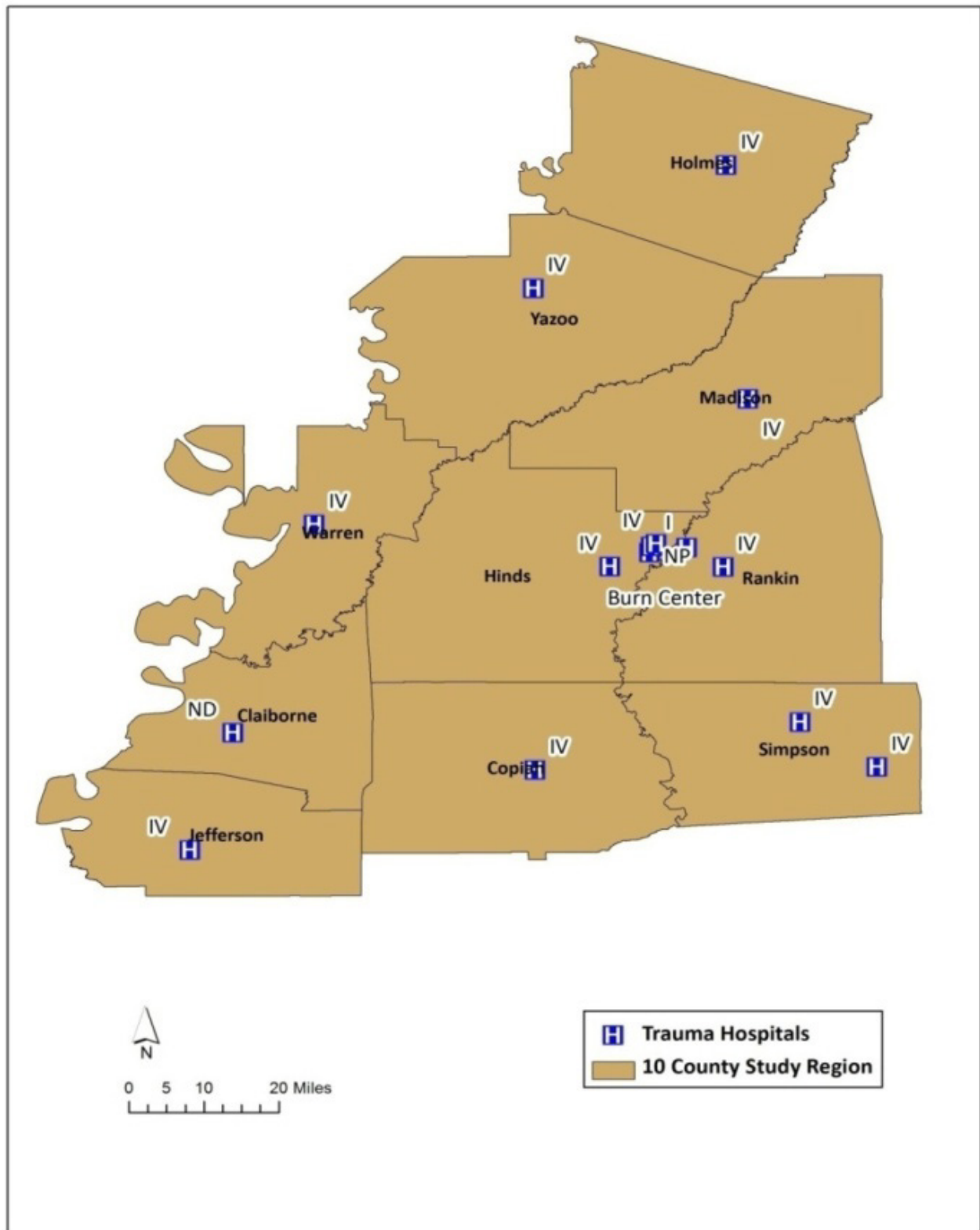
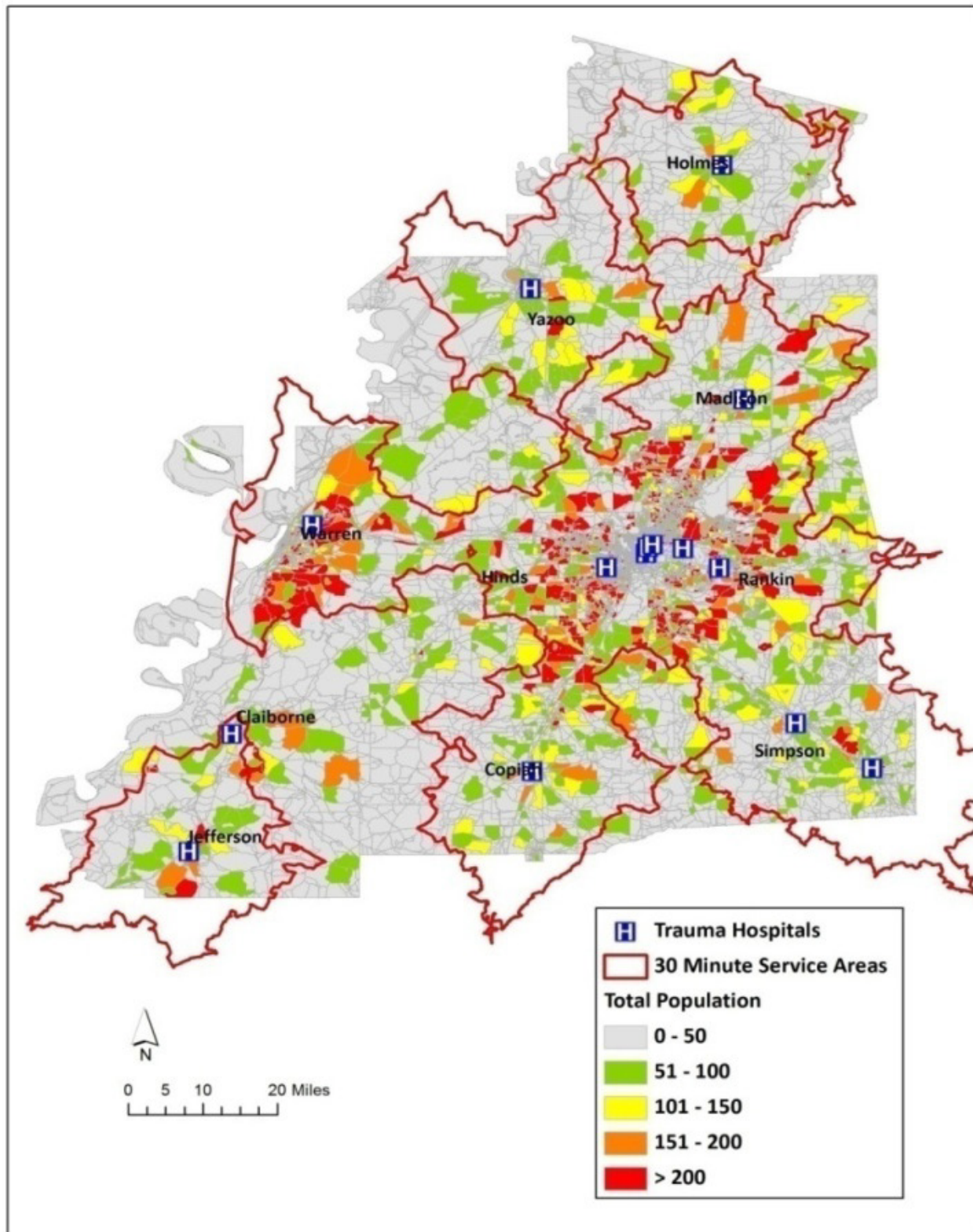**Figure 7.** Spatial Distribution of Truama and burn centers

Figure 8. Optimal 30-minute service areas and spatial distribution of general population
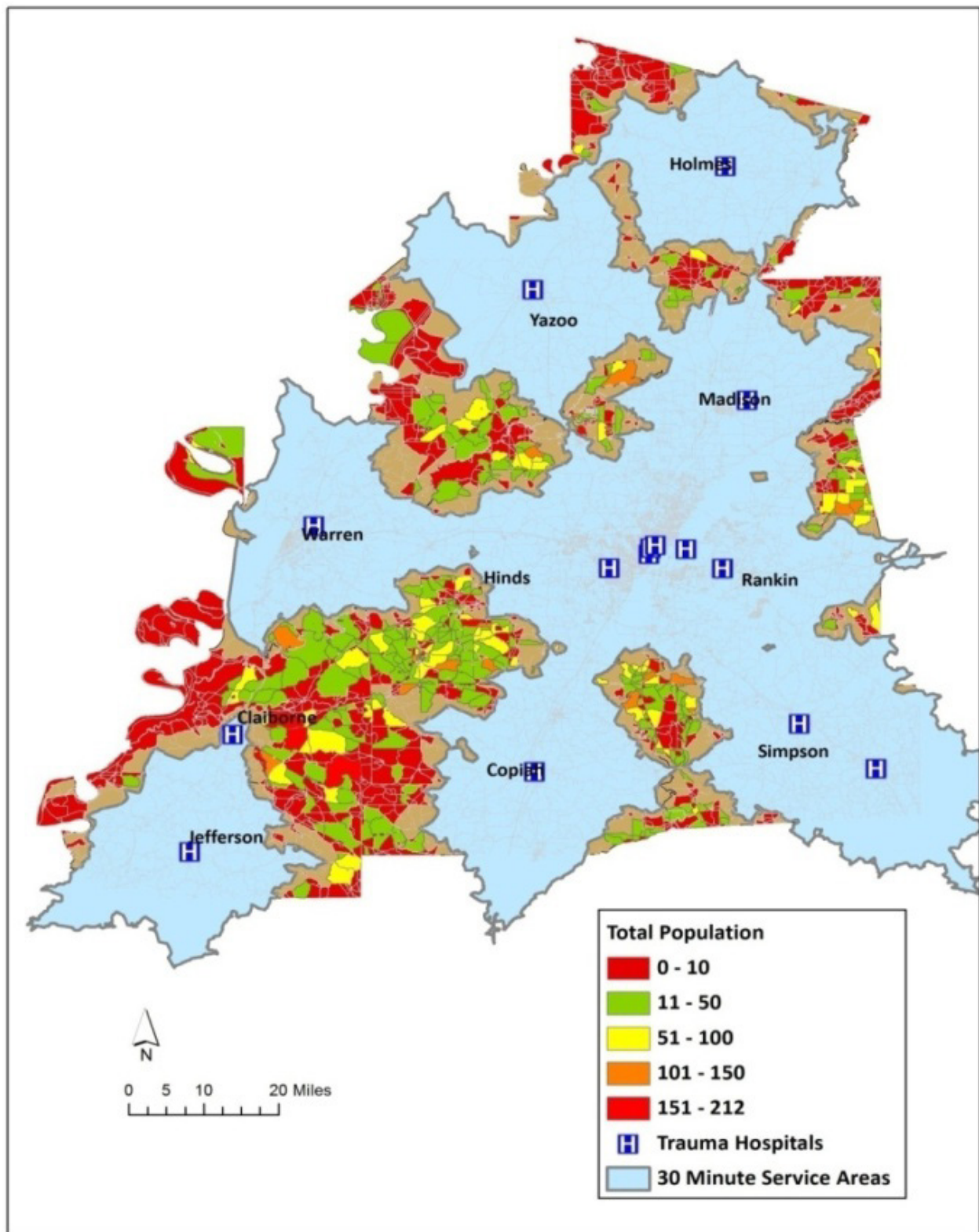
Figure 9. Hotspots of concentrations of general population outside the optimal service regions

3.3. Geographic Access to Trauma and Burn Centers

Four levels of trauma centers (I, II, III, and IV) and burn centers are geocoded and mapped in the study region (Figure 7). A 30-minute service area generated using transportation network routes is presented in Figure 8.

There are 16 trauma centers and 1 burn center located in the study region. Even though the spatial distribution of these facilities appears to be evenly distributed (Figure 9), the GIS network analyst generated 30-minute service areas revealed

the real scenario of inaccessible areas to these emergency facilities. Rural counties host almost all of the hotspots; falling outside the optimal travel times, taking the total burden of geographic inaccessibility issues (Table 4).

With only one burn center, the removal of this facility leaves the state of MS vulnerable putting the entire population under no service zone and looking to neighbouring states for service.

Table 4. Urban and Rural concentrations of population outside optimal service areas

Total number of Trauma centers (Level I-IV)	Total Population outside optimal 30min service area	
	Urban	Rural
16	0	25448

This methodology provides an advantageous approach in assessing community's health care needs from a geographical perspective. Geographical inaccessibility is clearly seen among rural populations. Pertinent to the relative health care facility type the model extracts the spatial locations of: women in the childbearing age; children under the age of 10 years; and population above 65 years. The results identify hot spots of vulnerable populations residing outside the service areas and equip health administrators and policy makers in providing comprehensive view of the health systems from a territorial perspective while assisting them in making conscious policy decisions. Assessing the geographic inaccessibility from various health specialty perspectives provides the requirement of right kind of services to the right kind of people in need.

4. Conclusions

The most significant features affecting the health status and health outcomes involve distance between the population's geographic regions and health care facilities and the travel time taken to reach the health care delivery system. This research investigates these features by using network-based GIS methods. Spatial distribution of health care facilities in terms of size/number, type and location are geographically analyzed to observe the feasibility of individual's access to desired services, which in turn impacts overall wellbeing of the communities. This study presents the use of GIS in analyzing health care needs and optimal geographical access in evaluating and planning future health care locations; and provides spatial decision support information for an efficient health care system.

This study has demonstrated the power of GIS in modeling the travel times for health care facilities and spatially evaluating the hotspots where people take the burden of mortality rated due to geographic inaccessibility. The geospatial simulation of variations in optimal time when specific health services are required provides crucial information, especially planning for non-urban areas.

REFERENCES

[1]   Mayberry, R. M., David, N. A., Qin, H., & Ballard, D. J. (2006). Improving quality and reducing inequities: a challenge in achieving best care. Proceedings of Baylor Health Care System. 19(2), p. 103. Dallas, TX: Baylor University. Medical Center.

[2]   Steinwachs, D. M., & Hughes, R. G. (2008). Health Services Research: Scope and Significance. In H. RG, Patient Safety and Quality: An Evidence-Based Handbook for Nurses (p. 8). Rockville, MD, USA: Agency for Healthcare Research and Quality.

[3]   Delamater, P., Messina, J., Shortridge, A., & Grady, S. (2012). Measuring geographic access to health care: raster and network-based methods. International Journal ofHealth Geographics, 11 (1), 15.

[4]   Ricketts, T. C. (2002). Geography and Disparity in Health. University of North Carolina at Chapel Hill, Cecil G. Sheps Center for Health Services Research. Chapel Hill: Institute of Medicine of the National Academies.

[5]   Haggertya, J. L., Robergeb, D., Lévesque, J.-F., Gauthier, J., & Loignon, C. (2014). An exploration of rural–urban differences in healthcare-seeking trajectories: Implications for measures of accessibility. Health & Place, 28, 92-98.

[6]   Carol Jones, T. P. (2009, August 10). Health Status and Health Care Access of Farm and Rural Populations. Economic Information Bulletin No. (EIB-57), p. 72.

[7]   J.F. Levesque, M. H. (2013). Patient-centred access to health care: conceptualising access at the interface of health systems and populations. International Journal of Equity Health, 12, 16-28.

[8]   Duke Center for Health Policy and Inequalities Research. (2011, September 2). Geographich Access Barriers. Retrieved May 19, 2014, from U.S. Health Policy Gateways: http://ushealthpolicygateway.com/vi-key-health-policy-issues-financing-and-delivery/k-barriers-to-access/geographic-access-barriers/.

[9]   Thomas C. Ricketts. (2002). Arguing for Rural Health in Medicare: A Progressive Rhetoric for Rural America. North Carolina Rural Health Research and Policy Analysis Center, The University of North Carolina at Chapel Hill. Chapel Hill: Cecil G. Sheps Center for Health Services Research.

[10] Center for Health Policy Research. (2009). PUTTING WOMEN'S HEALTH CARE DISPARITIES ON THE MAP: Examining Racial and Ethnic Disparities at the State Level. University of California. Los Angeles: The Henry J. Kaiser Family Foundation.

[11] U.S. Department of Health and Human Services. (2014, 5 23). Shortage Areas: HPSA by State & County. Retrieved 5 23, 2014, from HRSA: http://hpsafind.hrsa.gov/HPSASearch.aspx.

[12] Kaiser Family Foundation State Health Facts. (2010, April). Mississippi: Health Professional Shortage Areas. Retrieved May 23, 2014, from State Health Facts: http://www.statehealthfacts.org/profileind.jsp?cat=8&sub=156&rgn=26.

[13] Mississippi State Department of Health. (2011). 2011 Mississippi Infant Mortality Report. Jackson: Mississippi State Department of Health.

[14] Pickle, L. W. (1996). Atlas of United States Mortality. U.S. Department of Health and Human Services. Hyattsville: U.S. Department of Health and Human Services.

[15] Kindig, D. A. (2002, Apr 10). Death rate variation in US subpopulations. Bulletin of the World Health Organization, pp. 9-15.

[16] Cossman, R. E. (2003). Mapping high or low mortality places across time in the United States: a research note on a health visualization and analysis project. Health Place, 9 (4), 361-369.

[17] Yerramilli, A., Dodla, V., & Yerramilli, S. (2012). GIS based Decision Support Systems for Air Quality Risk Assessment. In F. Nejadkoorki, Advanced Air Pollution (p. 307). Craotia: Intech Open Science.

[18] Yerramilli, S. (2013). Potential Impact of Climate Changes on the Inundation Risk Levels in a Dam Break Scenario. ISPRS International Journal of Geo-Information, 110-134.

[19] Lin G, A. D. (2002). Examining distance effects on hospitalizations using GIS: a study of three health regions in British Columbia, Canada. Environment and Planning A, 34, 2037-2053.

[20] Birkin M, C. G. (2005). GIS for business and service planning. In G. M. Longley PA, Geographical Information Systems: Principles Techniques Management and Applications. New York: John Wiley & Sons.

[21] Witlox, F. (2007). Valuating the reliability of reported distance data in urban travel behaviour analysis. Journal of Transport Geography, 172-183.

[22] Ravelli, A. C. (2011). Travel time from home to hospital and adverse perinatal outcomes in women at term in the Netherlands. BJOG: An International Journal of Obstetrics & Gynaecology, 457-465.

[23] Eda Unal, S. C. (2008, 11 01). Health care access in Indiana. Retrieved 05 28, 2014, from Purdue University: http://www.pcrd.purdue.edu/documents/publications/PCRD-R-5.pdf.

[24] Jon Nicholl, J. W. (2007). The relationship between distance to hospital and patient mortality in emergencies: an observational study. Emergency Medicine Journal, 665-668.