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Geographic information systems and chronic kidney disease: racial disparities, rural residence and forecasting

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Abstract

The dynamics of health and health care provision in the United States vary substantially across regions, and there is substantial regional heterogeneity in population density, age distribution, disease prevalence, race and ethnicity, poverty and the ability to access care. Geocoding and geographic information systems (GIS) are important tools to link patient or population location to information regarding these characteristics. In this review, we provide an overview of basic GIS concepts and provide examples to illustrate how GIS techniques have been applied to the study of kidney disease, and in particular to understanding the interplay between race, poverty, rural residence and the planning of renal services for this population. The interplay of socioeconomic status and renal disease outcomes remains an important area for investigation and recent publications have explored this relationship utilizing GIS techniques to incorporate measures of socioeconomic status and racial composition of neighborhoods. In addition, there are many potential challenges in providing care to rural patients with chronic kidney disease including long travel times and sparse renal services such as transplant and dialysis centers. Geospatially fluent analytic approaches can also inform system level analyses of health care systems and these approaches can be applied to identify an optimal distribution of dialysis facilities. GIS analysis could help untangle the complex interplay between geography, socioeconomic status, and racial disparities in chronic kidney disease, and could inform policy decisions and resource allocation as the population ages and the prevalence of renal disease increases.

Keywords

Chronic kidney disease; Geography; Geospatial analysis; Racial disparities; Rural health

Introduction

The dynamics of health and health care provision in the United States vary substantially across regions. There is regional heterogeneity in population density, age distribution, disease prevalence, future growth, environmental risk factors, race and ethnicity, poverty and the ability to access care. Against this backdrop, the distribution of health care resources such as providers, clinics and specialized centers also varies substantially across regions. The importance of such geographic variation in health care needs and resources has been appreciated for some time, leading the US Department of Health and Human Services to establish a goal of increasing the proportion of major national health data systems employing geocoding and geographic information systems (GIS). Geocoding is the process of enhancing records without explicit location identifiers by the addition of coordinates or geographic identifiers (1). GIS allow data which is linked to location to be captured, managed, analyzed and displayed.

Chronic kidney disease (CKD) and end-stage renal disease (ESRD) are uniquely suited to analysis by GIS methods. Optimal management of CKD requires time- and resource-intensive care, and failing to provide such care can lead to increased costs, more rapid disease progression and higher mortality rates. ESRD is an extremely costly condition, often requiring specialized, technologically intensive care in dedicated facilities. Transplantation, the most cost effective treatment for ESRD, requires sophisticated planning and multifaceted evaluation and management, often spanning wide geographic areas. The care and outcomes of patients with kidney disease is also highly sensitive to social factors not captured by clinical and biologic measures. For example, patients in impoverished areas may be unable to access needed preventive care, a paucity of specialists can impede access to disease-specific interventions and a sparse distribution of dialysis facilities can increase the burden of this intensive treatment by increasing travel time, compromising quality of life and ultimately, clinical outcomes. Epidemiologic analyses identifying remediable social or environmental factors promoting progression of renal disease can also be informed by geographic information. Knowledge of the distribution of advanced CKD could prove useful in predicting where resources will be needed in the future (Fig. 1A, B). Because optimal management of patients with CKD and ESRD requires the presence of specialist providers as well as an extensive and expensive built infrastructure (e.g., clinics or dialysis units), such information may be useful for guiding resource allocation.

Employing GIS techniques can complement and strengthen traditional research methods. For example, the work of John Snow provides a classic example of how geographic data can provide novel insights about disease processes. In his investigation of the cholera outbreak in London, England, in 1854, he used a map to identify a cluster of cholera cases occurring around a water pump (2, 3). Some investigators are using a similar approach to understand contemporary disease processes. For example, renal “hotspots” have been identified in neighborhoods with a high proportion of vulnerable patients, using data from the University of Southern California County Hospital emergency room (4). In El Salvador, agricultural workers living in lowland areas appear to have a higher risk of CKD than those living in highland areas (5). The potential utility of GIS in research and planning was recently recognized in objective 23-3 of Healthy People 2010 – to increase the proportion of major

national health data systems that use geocoding to promote nationwide use of GIS. A goal of this initiative is to increase the number of national health data systems with geocoded records from 45% to 90% (6).

Efforts to link patient or population location to information on the characteristics of that location have immediate utility as follows:

1. Factors modulating interactions between patients and the health care system, such as race, poverty, rural residence, unemployment and the cost of health care insurance vs. income can be evaluated;
2. The identification of high prevalence or high risk regions can be used to inform numerous strategies such as community-level screening and epidemiologic and randomized prospective investigations to identify and address remediable risk factors;
3. Current or anticipated “mismatching” between health care resources (providers, facilities) and population needs can be identified and mitigation measures— such as increases in allocated resources – can be appropriately targeted. Such endeavors are fundamental to any public health service program, and could be mirrored by economic incentives for health care facility construction and operation in areas of current or anticipated need (e.g., rural areas).

In this review, we will provide a brief overview of basic GIS concepts with examples to illustrate how GIS techniques have been applied to the study of kidney disease, and in particular to understanding the interplay between race, poverty and rural residence, and in the planning of medical services for this population.

Review of basic geocoding methods

Geocoding involves assigning geographic coordinates (e.g., latitude and longitude) to other geographic data such as street addresses or ZIP Codes (postal codes). The exact and approximation methods are the 2 broad approaches to geocoding.

The exact method (also known as the parcel-matching method) assigns a unique coordinate value to a residential address. In the exact method, a residential address would be linked to a geographic base file which contains the coordinates of individual street addresses. This approach is most useful in situations in which precise information on residential location is needed (e.g., information on travel distance or travel time). However, in many instances, such precise information on location is not needed.

The approximation method involves matching street addresses to a particular location. The location may be a relatively standardized area such as a census block or ZIP Code (areal geocoding) or may be to an area that includes a range of addresses (range geocoding) (1, 7). Most GIS software utilizes range geocoding and employs the Topologically Integrated Geographic Encoding and Referencing (TIGER) system, TIGER derivatives or other commercial products (8). TIGER is a digital database developed by the US Census Bureau that defines the location and relationship of streets, highways and other geographic features to each other. The TIGER files contain information such as latitude and longitude, address

ranges for most streets and information on the relationship to other geographic features. The TIGER files are available for download on the US Census Bureau website, and are updated on an annual basis. Range geocoding first reads the residential address and then matches the street address with the appropriate geographic base file in TIGER. The geographic base file contains a range of addresses on a particular street from which the program then calculates the position of a residence on that street (7, 8).

The exact and approximation methods have unique strengths and weaknesses. The exact approach may be preferable for some forms of renal research such as measuring travel distance from patient homes to medical centers, dialysis clinics or neighborhood resources. However, the approximation method may suffice for linking information on area characteristics (e.g., median ZIP Code income) to a patient database. A large number of GIS software products are available, allowing for the creation of maps and layers, geocoding of data, geographic analyses and dataset construction. Software costs will vary depending on the sophistication of the program.

Geocoding errors

The 2728-ESRD Medical Evidence Report Medicare Entitlement Patient Registration form is completed for all new dialysis patients in the United States and is available in US Renal Data System (USRDS) standard analysis files. The form includes an address field (“Full Address (Include City, State, and ZIP)”) at the time of onset of ESRD. The State and ZIP Code data for each patient are then incorporated into USRDS standard analysis files. The accuracy of some information on the ESRD Medical Evidence Report Form (e.g., comorbidities, nephrology referral) is limited (9–11). Nevertheless, USRDS source data provide an example of a data source that contains geographic information that could be geocoded using the approaches described. Geocoding errors often relate to inherent limitations in the source data. For example, in entering address information on the 2728 form, the patient address is first transcribed by a member of the dialysis unit staff, the form is then returned to the renal network office where the address is entered manually into a database, and then reported to the Centers for Medicare and Medicaid Services (CMS). Even simple errors, such as misspelling, failure to include modifiers such as “West” in street designations or using nonstandard abbreviations, can prove problematic. Rigorous monitoring of data quality, as well as the use of parallel information sources (such as using telephone numbers when a post office box is the listed address) can improve data accuracy. Notably, use of US Postal Service addressing standards could reduce address-matching errors (12). The geographic base files derived from TIGER represent another possible source of error. These files are updated and released annually and therefore may not contain streets in new building developments or may inaccurately depict street connections.

Privacy and confidentiality issues

When mapping confidential health data for small geographic areas, the obvious concern is the possibility of identifying households with the mapped disease entity. This a particular concern for relatively rare conditions such as ESRD. Reverse geocoding is the process of identifying an exact address from coordinates and is feasible with contemporary technology. Therefore, geocoded patient addresses are considered confidential and protected in the

United States by the US Health Insurance Portability and Accountability Act (HIPAA). Even on low-resolution maps displaying health-related patient information, it may be possible to identify individual patient addresses (13, 14). Geographic masking refers to the practice of modifying the geographic coordinates of the original data to protect confidentiality (15). Examples include aggregating incident locations at the midpoint of street segments or to their closest street intersection, while another methods place locations on a grid and then flip incident locations on a regular grid (16). Further research is needed to develop methods to protect subject confidentiality while optimizing the quality and completeness of geographic information. Ultimately, the need to protect subject confidentiality may also favor the use of approximation over exact methods of geocoding.

Examples of gis techniques in the renal literature

In the following 3 sections, we will provide examples of how GIS have been used in the study of CKD. Linking US Census data geographically to renal data sources has been very useful in understanding racial disparities in CKD. Using GIS software to measure distances from providers to patients has been helpful in investigating the barriers to renal care in rural populations. Geospatial approaches are utilized in the planning of renal services such as efforts to identify sites for future dialysis facilities.

Race, poverty and chronic kidney disease

Pronounced racial differences in the incidence of ESRD in the United States were first described over 30 years ago (17, 18). The underlying reasons for racial differences in ESRD incidence and in the care of patients with CKD and ESRD (e.g., access to kidney transplant) remain elusive despite intensive research (19–22). Given the known socioeconomic inequalities among US racial and ethnic groups, the interplay of socioeconomic status and renal disease outcomes remains an important area for investigation. However, many of the administrative and clinical data sources that have supported research on racial and ethnic disparities in kidney disease have lacked detailed information on individual-level socioeconomic status (e.g., income, educational attainment and employment status). Because there is geographic variation in some of these measures, area-level information can serve as a useful surrogate for individual-level socioeconomic status in some instances. Most commonly, individual-level information from clinical data sources is combined with area-level socioeconomic data derived from sources such as the US Census (23–25).

For example, the 2728 form includes information on race and ethnicity, but only limited information on socioeconomic status (i.e., “employment status at the start of dialysis and 6 months prior”). Geocoding technology may be used to supplement information on socioeconomic status and provide a greater understanding of the interplay between race, socioeconomic status and renal outcome measures. Because there is often homogeneity in socioeconomic status over small geographic areas, use of area-based measures of socioeconomic status can provide a useful approximation of individual-level socioeconomic status (23, 25, 26). However, there is no consensus regarding the optimal level of geographic resolution, and this may depend at least in part on the question being addressed and the degree to which there is homogeneity in the relevant measure(s) over different areas. The US Census reports socioeconomic measures by census block group (average population of

1,000) and tract (average population of 4,000) and by US Postal Service ZIP Code (average population of 30,000). The Public Health Disparities Geocoding Project was designed to determine the optimal level of geographic resolution for research studies (24, 27). The work of this project has generally supported the use of census block group and census tract. ZIP Codes can cover much larger areas with potentially more diversity in socioeconomic status among the population. The project has also attempted to identify which measures of socioeconomic status provide the best estimates of poverty. The work of the project has suggested that of the measures of socioeconomic status available in the Census, the “percentage of persons living below the US poverty line,” may best capture economic deprivation (24). The US Census Bureau determines who is in poverty by using a set of money income thresholds that vary by family size and composition, and the number of households living in poverty is reported by census tract. Interestingly, the topography of poverty in the United States reveals a striking demarcation between North and South (28).

Despite their limitations, ZIP Codes are often used in geographic analyses of data from the USRDS, driven mostly by the availability of this information in USRDS standard analysis files. There are a number of potential shortcomings of using ZIP Code-level socioeconomic data. The US Postal Service ZIP Codes are networks of streets or individual post offices which were designed to facilitate mail delivery. It is important to note that there is no correlation between US Postal Service ZIP Codes and US Census blocks and tracts. ZIP Codes pose many challenges when used for longitudinal health studies, as they are frequently discontinued or added by the US Postal Service depending on service needs and do not necessarily correspond with homogenous residential areas (e.g., neighborhoods). Some ZIP Codes correspond to a single building, and others to much larger areas (29, 30). The US Census Bureau developed a new statistical entity called the ZIP Code Tabulation Area (ZCTA) intended to align ZIP Codes with census geography. It is important to note that there is not a perfect correlation between ZCTAs and postal ZIP Codes (29).

Because standard analysis files from the USRDS include only the patient’s state and ZIP Code of residence, most studies of racial disparities among patients with ESRD have leveraged ZIP Code data from the USRDS linked to ZCTAs in the US Census (24, 31–33). Prior work using GIS techniques to evaluate the relationship between race, poverty and kidney disease have found that the incidence of ESRD and rates of kidney transplants among racial and ethnic groups do vary according to residential area poverty. However, most studies have not found strong relationships between residential location and mortality among ESRD patients (31, 34–37).

Examples: geocoding, racial disparities and CKD—Gore et al demonstrated that patients living in areas of lower socioeconomic status were less likely to receive live donor renal transplants. These authors linked recipient ZIP Codes to 2000 US Census Bureau data to obtain median ZIP Code income (34). The same method was used by Hall et al to categorize their study population by percentage of ZIP Code residents living in poverty. In this study, Asians and Pacific Islanders experienced lower transplant rates compared with whites, and this disparity widened with increasing neighborhood poverty (33).

Volkova et al geocoded street addresses recorded in a regional ESRD registry to the census tract level for patients initiating dialysis in Georgia, North Carolina and South Carolina (37). These authors found that neighborhood poverty was strongly associated with a higher incidence of ESRD among both African Americans and whites and that the racial disparity in ESRD incidence was more pronounced in neighborhoods with higher levels of poverty. As the authors discussed in their paper, previous publications showed that adjustment for community socioeconomic status resulted in only a modest attenuation in the relative risk for ESRD among African American compared with white patients (37).

The ideal approach to understanding the effects of individual patient socioeconomic status on racial disparities in renal outcomes would be to ascertain individual-level socioeconomic information in conjunction with community-level data on income to reflect community resources. The Reasons for Geographic and Racial Differences in Stroke (REGARDS) cohort study is a population-based longitudinal study of 30,000 African American and white adults. The goal of this study was to identify causes for excess stroke mortality in the southeastern United States and particularly among African Americans (38). A renal ancillary study of REGARDS has focused on poverty and racial disparities in CKD using individual-level socioeconomic information collected during subject recruitment (38–42). Self-reported socioeconomic information collected as part of REGARDS included access to care, insurance status, marital status, education and income. Preliminary studies from REGARDS have found that household poverty is independently associated with CKD but does not fully account for differences in the prevalence of CKD between African Americans and whites (40). The authors had access to fairly comprehensive information on individual-level socioeconomic status, and also geocoded home addresses to census tracts. By combining these different sources of socioeconomic information, these authors found that individual- but not area-level poverty was independently associated with CKD.

Segregation—A variety of factors in the social environment may impact health, including neighborhood poverty, pollution, unemployment, racial segregation, crime and availability of resources to support a healthy lifestyle such as access to leisure time activities and healthy food (43, 44). Recently, there has been increased interest in the public health literature in the impact of racial residential segregation on health outcomes. Segregation among African Americans has a unique history spanning 3 distinct periods: The first period (1890 to 1940) saw the birth of the ghetto attributed to the migration of African Americans from the rural South to urban areas in the North (45, 46). During the second period (1940 to 1970), these segregated areas were consolidated and expanded in size, which is a different pattern than that observed for most immigrant communities in the United States (47). During the third period (1970 onward) there has been a modest decrease in the degree of segregation among African Americans. The dissimilarity index is often used to provide an objective measure of segregation. This index describes the proportion of members of a minority group that would need to move to an adjacent area in order to achieve complete integration (“0” indicating complete integration and “100” complete segregation) (48, 49). Among the 10 largest US metropolitan areas, Chicago is the most segregated city, with a dissimilarity index of 71.9% (Fig. 2) (50). However, the dissimilarity index can be difficult to interpret as it does not provide direct information on the percentage of residents in a particular area belonging to a

particular racial group. For this reason, some studies have used the proportion of the population in a particular area who belong to a particular racial group as a crude measure of segregation. However, unlike the dissimilarity index, this measure does not provide a comparison with the racial composition of the surrounding community (36, 51). Thus, measures of residential segregation and residential composition are not equivalent. The utility of using the dissimilarity index can be demonstrated by comparing Chicago and Atlanta where African Americans comprise 32.9% and 54% of the population, respectively. Atlanta has a high proportion of residential neighborhoods where most residents are African Americans but a dissimilarity index of 54.1% as compared with Chicago where African Americans are much more concentrated in just a few neighborhoods resulting in a dissimilarity index of 71.9% (Figs. 2 and 3).

Maps of neighborhoods by racial composition are instructive and help to illustrate some of the previous points in this review. For example, Figure 4A, B shows maps of Los Angeles describing the racial composition of ZIP Codes and census tracts, respectively. The subtle differences between ZIP Code and census tract maps demonstrate the importance of choosing the appropriate level of geographic resolution. The finer resolution of census tracts in Figure 4B shows areas of predominantly African American populations which would be missed if using ZIP Code data. Figure 4C provides an example of the shifting demographics and changes in segregation (in this case the conversion of historically African American neighborhoods in South Central Los Angeles which was 80% African American in the 1980s to predominantly Hispanic neighborhoods at the present time) (47, 52). While managing an inner city dialysis unit in San Francisco, we were struck by how many of our African American patients lived in a handful of predominantly black neighborhoods. Similar to many large metropolitan areas, the San Francisco Bay Area is composed of a number of neighborhoods with unique racial, income and environmental characteristics, including some that are predominantly African American (Fig. 5). Due to the high incidence and prevalence of ESRD among African Americans, predominantly African American neighborhoods would be expected to have a high density of ESRD patients and therefore unique renal care delivery needs. These neighborhoods traditionally have high infant mortality rates, high levels of air pollution and a lack community resources (53–55). We wondered whether dialysis patients living in these areas received different care and experienced different outcomes compared with those living in other areas, and we were inspired to conduct a national study examining the relationship between residential area racial composition and patient outcomes and dialysis facility characteristics. We found that among both African American and white dialysis patients living in predominantly African American ZIP Codes, time to transplantation is longer and dialysis facility performance on standard quality measures is generally less favorable (36).

Rural residence and chronic kidney disease

A variety of different definitions of “rural” have been proposed. The US Census Bureau defines rural as “open country and settlements of less than 2,500 residents, exclusive of embedded suburbs of urbanized areas of 50,000 or more populations” (56). The US Department of Agriculture’s Economic Research Service has developed Rural-Urban Commuting Area (RUCAs) codes to describe a spectrum of rurality. These codes combine

the standard Census Bureau urban area and place definitions with commuting information to characterize all US Census tracts according to level of rurality (57). A ZIP Code approximation for RUCAs is available from the University of Washington (58).

There are many well-studied barriers to optimal health care in rural areas, including access to quality health services, scarcity of physicians and other health professionals and less than optimal emergency medical services (59). The rural population in the United States also has a high prevalence of obesity, hypertension, suicide, diabetes and alcohol and tobacco use (60). Potential challenges for patients with kidney disease living in rural areas include obtaining access to a nephrologist, dialysis services and kidney transplantation. We compared the characteristics of ESRD patients and facilities with differing levels of rurality defined using RUCA codes based on ZIP Code data from USRDS and facility-level data from the CMS's Dialysis Facility Compare (61). Despite large differences in the structure of dialysis care in rural areas, rural dialysis facilities performed at least as well as urban facilities, and mortality rates did not differ greatly in rural compared with urban areas. However, the impact of rural residence on time to transplant was somewhat complex. Whites living in rural areas were more likely to receive a transplant compared with whites living in urban areas, whereas the opposite was true for blacks. Of note, this study did not estimate the effect of distance from patient residence to the closest transplant center, and thus did not account for heterogeneity in these distances among patients living in different rural areas across the United States. Rural areas are extremely heterogeneous. Frontier rural areas have been defined by several factors including population density (persons per square mile), distance in miles to services/market and time in minutes to services/market (62). Alaska is by far the top-ranking frontier state in the United States, with 31% of the land considered frontier, followed by Texas (7.4%), Montana (6.2) and New Mexico (5.1%) (62, 63). In contrast, North Carolina has 3.2 million rural residents accounting for 39.8% of the state population, but less than 1% of the land area meets frontier criteria. The challenges and implications of delivering renal services in remote rural states are illustrated in Figure 6A–C. Alaska has 7 dialysis units in 5 cities servicing 586,412 square miles, Montana has 12 units and covers 147,046 square miles and North Carolina has 186 units and covers 48,843 square miles. Some states have incentivized the construction of dialysis facilities in rural areas. For example, the high density of dialysis facilities in North Carolina likely reflects that state's Certificate of Need. This is a legal document needed in most states for the construction of medical facilities and confirms that the plans fulfill the needs of the community. North Carolina's Certificate of Need specifies that "end-stage renal disease treatment should be provided such that patients who require renal dialysis are able to be served in a facility no farther than 30 miles from the patients' homes" (64). It is not surprising that frontier rural states have higher-than-average utilization of home dialysis therapies compared with non-frontier rural states such as North Carolina.

The distance from a patient's residence to the nearest physician or health center is often used as a proxy for access to care. A 1983 article in the *New England Journal of Medicine* entitled "How Many Miles to the Doctor?" estimated "as the crow flies" and travel distances between patients and physicians in a rural area (65). The study highlighted some of the challenges involved in providing access to physicians in geographically isolated areas. The

study also illustrated several different approaches to estimating distance. Direct or “as the crow flies” distances can sometimes be a poor proxy for access to care because they do not account for road distances, availability of public transportation and whether patients are actually eligible to access the services of the nearest physician or health center (e.g., because of health insurance, availability of clinic appointments etc.). Because Medicare coverage for patients requiring renal replacement therapy in the United States is nearly universal, there may be less concern about whether patients are eligible to access the closest nephrologist or dialysis facility. However, because address fields may not be readily available in many public use data sources, new methods for estimating geographic distance to health services when only the region of residence is known may be helpful (66).

Tonelli et al examined access to kidney transplantation among rural patients in the United States (67). These authors hypothesized that people residing farther from the a transplant center would be less likely to undergo transplantation, and examined the association between distance from the closest transplant center and time to placement on the kidney transplantation waiting list and time to kidney transplantation. These authors used GIS software (ArcView) to estimate the driving time between the centroids of patient and transplant center ZIP Codes (68–70). After accounting for travel distance, rural residence was not associated with time to transplantation in this study, perhaps highlighting the substantial heterogeneity in travel time to transplant centers among patients living in different rural areas across the United States.

GIS and planning of renal services

Geospatially fluent analytic approaches can crucially inform analyses of health care systems (71, 72). Detailing local densities and “types” (epidemiologic, physiologic or demographic) of data using GIS methodologies is fundamental to understanding current and future health resource needs. The utility of this information falls along 3 basic axes: quantifying current needs, characterizing mismatches between needs and available resources, and identifying regions that may face an increasing need in the future (73–76). Notably, when applied from a “national perspective,” ZIP Code– or county-based analyses are straightforward and provide reasonable first approximation analyses.

In-center hemodialysis offers a convenient illustration: patients must undergo thrice weekly treatments (imposing a geographic constraint), and the ZIP Code–level densities of patients requiring this treatment are known. The system is constrained in that commute distances faced by patients must be reasonable, and facilities must serve an adequate patient volume to be economically sustainable. However, there is significant variability in the regional density of ESRD patients. Accordingly, uniform spacing of facilities is impractical from the standpoint of the daily commute distances faced by patients and financially infeasible from the vendor’s perspective. Geospatial approaches can help to identify ensembles of dialysis facility locations satisfying the joint constraints of acceptable commute distances and sufficient numbers of patients to ensure economic viability:

1. The latitude and longitude of each ZIP Code centroid can be combined with the number of ESRD patients in that ZIP Code to create density maps;

2. An “average” capacity and standard deviation for a dialysis unit are specified (in the continental United States the average size is 78 patients, with a standard deviation of 43);
3. “Catchment areas” combined ZIP Code ensembles capable of supporting 1 or more dialysis unit(s) by virtue of “containing” at least a threshold number of patients are identified;
4. The approximate location of the facility within each catchment area that minimizes mean travel distance is identified;
5. Suggested broad-scale locations having sufficient patients within an acceptable commute distance can then be conditioned on considerations such as highway and mass transit access, building costs and other infrastructure details.

Figure 1B presents such a density map for optimal unit locations with an enforced average unit size of 80 patients; the precise locations in the figure have been deliberately “masked” to ± 6 miles. For comparison, the locations of 5,436 units registered in Dialysis Facility Compare are also presented (Fig. 1A). Visual inspection suggests that the observed distribution of extant facilities and that predicted based on regional patient density are quite similar. Quantitative analyses demonstrate that the mean distance between a suggested facility location and the corresponding (nearest) actual unit averages 15 miles, with approximately 15% of existing units more than 30 miles from the location suggested on density considerations alone – a scale of variance consistent with conditioning based on non-patient-related local infrastructure considerations or the presence of facilities held by a competing vendor. When indexed to future regional growth in the ESRD population, such analyses may help to guide the rational expansion of the US dialysis network.

In contrast, the regional distribution of nephrologists and, more importantly, the number of dialysis patients per board-certified nephrologist is much less uniform, varying from approximately 20 dialysis patients to 74 dialysis patients per nephrologist. To the extent that there is an optimal number of patients that can be safely and efficiently managed by a single nephrologist, this raises potential for a nonoptimal workforce distribution. More detailed evaluation of this issue will require regional enumeration of physician extenders, quantification of competing clinical or service obligations of the providers and estimation of the approximate number of ESRD patients that can be managed safely and efficiently by a single nephrologist, with or without a physician extender.

Finally, future needs of both built infrastructure (dialysis facilities) and providers in a particular region will be conditioned by regional variability in the anticipated growth of the ESRD population. In addition to variance in gross population density and migration, considerations such as the regional prevalence of CKD, rate of progression and stage-specific mortality will likely lead to shifts in resource demand as the population ages. Detailed geospatial analyses of such considerations may prove crucial to future planning.

Summary

This review provides a brief introduction to GIS methods used in renal research, along with some of the current limitations and challenges of these methods. Such GIS approaches can also be useful in many other areas important to patients with CKD (77). If privacy concerns can be adequately addressed, geocoding of large renal data sources to finer levels of spatial resolution will be helpful in supporting such efforts. The enhanced capacity for nuanced analysis would help “unpack” the complex interplay between geography, socioeconomic status and racial disparities in CKD. Moreover, geospatially fluent analytic approaches similar to those outlined in this review could critically inform policy decisions and resource allocation as the population ages and the prevalence of renal disease increases.

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Fig. 1.

A) US dialysis units (blue stars). Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare data. B) Geometrically optimal locations for dialysis facilities, based on ZIP Code level end-stage renal disease (ESRD) density data (provided for administrative use by Mr. Michael Cagan and Mr. Monir Hossain of the Medicare Administrative Center). Purpose-written software was utilized to identify sites for facilities that minimize commute distances, assuming a mean unit size of 80 ESRD patients.

Fig. 2.

In Chicago, 32.9% of the population is African American, but the dissimilarity index of 71.9% reflects the fact that African Americans tend to live in a relatively small number of predominantly African American neighborhoods (orange census tracts). Percentages of African American population are shown by census tract: purple <25%, green 25%–50%, orange >50%. Dialysis units are indicated by the blue stars. Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare and 2010 US Census data.

Fig. 3.

In Atlanta, 54% of the population is African American, but the dissimilarity index is 54%, which is lower than in Chicago. This reflects the fact that African Americans tend to live in a large number of predominantly African American neighborhoods in Atlanta (orange census tracts). Percentages of African American population are shown by census tract: purple <25%, green 25%–50%, orange >50%. Dialysis units are indicated by the blue stars. Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare and 2010 US Census data.

Fig. 4.

A) Map showing predominately African American neighborhoods by ZIP Code in Los Angeles (see orange areas). Comparing panels A and B reveals the subtle differences and possible disadvantages of using ZIP Code area data vs. the finer areas of resolution of census tracts. Percentages of African American population are shown by ZIP Code: purple <25%, green 25%–50%, orange >50%. Dialysis unit are indicated by the blue stars. Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare and 2010 US Census data. B) Map showing predominately African American neighborhoods by census tract in Los Angeles (see orange areas). Comparing panels A and B reveals the subtle differences and possible disadvantages of using ZIP Code area data vs. the finer areas of resolution of census tracts. Percentages of African American population by census tract: purple <25%, green 25%–50%, orange >50%. Dialysis units are indicated by the blue stars. Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare and 2010 US Census data. C) Map of Los Angeles showing predominately Hispanic neighborhoods (orange areas). Note that even historically African American neighborhoods such as Watts/Willowbrook and Compton which were 80% African American in the 1980s are now predominately Hispanic neighborhoods. Percentages of Hispanic population by ZIP Code: purple <25%, green 25%–50%, orange >50%. Dialysis units are indicated by blue stars. Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare and 2010 US Census data.

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Fig. 6.

A) Map of Alaska showing dialysis facility locations in the state and highlighting the geographic challenges some patients may face if they do not live near a major city. Dialysis facility locations (blue stars). Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare. B) Map of the Pacific Northwest showing dialysis facility locations in the area. Like Alaska, the Pacific Northwest has a large land mass which is sparsely populated. The challenges and implications of delivering renal services in remote rural states are illustrated in this map. These geographic challenges likely lead to the relatively high utilization of home dialysis in this region. Dialysis units are indicated by blue stars. Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare. C) North Carolina has 3.2 million rural residents accounting for 39.8% of the state population. However, the state is not sparsely populated like the Pacific Northwest. The map illustrates the relatively large number of dialysis facilities in the state. Dialysis units are indicated by blue stars. Created with Maptitude 2012 by Caliper, utilizing Dialysis Facility Compare.