

# Understanding the Link between Neighborhoods and Kidney Disease

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## Abstract

Neighborhoods are where we live, learn, work, pray, and play. Growing evidence indicates that neighborhoods are an important determinant of health. The built features of our neighborhoods, such as the ways in which the streets are designed and connected and the availability of green spaces and transit stops, as well as the social features, such as the trust among neighbors and the perceptions of safety, may influence health through multiple pathways, such as access to important resources, psychosocial stress, and health behaviors. In particular, the extant literature consistently documents an association between neighborhood features and renal-associated conditions, such as cardiovascular disease, hypertension, diabetes, and obesity. There is also some evidence suggesting an association between neighborhood poverty and ESKD. The link between neighborhood and earlier stages of CKD, however, has been less clear, with most studies documenting no association. It may be that the neighborhood measures used in previous studies do not capture features of the neighborhood important for earlier stages of disease development and progression. It may also be that our current biomarkers (e.g., eGFR) and urine protein are not able to pick up very early forms of renal damage because of the kidney's overall high reserve capacity. This paper critically reviews the state of the literature on neighborhood and renal disease, with recommendations for neighborhood measures in future research. Neighborhoods are designed, built, and informed by policy, and thus, they are amenable to intervention, making them a potentially powerful way to improve renal health and reduce health inequalities at the population level.

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## Introduction

The geographic variation in ESKD in the United States has been reported for decades (1,2) and can still be documented using the US Renal Data System (USRDS) (Figure 1). Since the early descriptive reports, a growing literature has indicated the importance of place in the development and progression of several major renal-associated conditions, such as cardiovascular diseases, hypertension, diabetes, and obesity (3–6). Reports also suggest an association between county- and neighborhood-level racial and economic characteristics and incident ESKD (7), hemodialysis survival (8), placement on transplant waiting list (9–11), and ESKD mortality (8). This link between context and disease has been shown to be important for population health overall and for racial and socioeconomic inequalities in health (12–14).

## The State of the Literature on Neighborhoods and Renal Diseases

At the core of the study of the association between place and health are neighborhoods—where we live, learn, work, pray, and play. Features of our neighborhoods can influence health through access to important resources, psychosocial stress, and health behaviors

(3). Although individual socioeconomic status (SES; e.g., education and income) is related to neighborhood quality, neighborhoods represent much more than is important for kidney health (i.e., the structural and functional well-being of the kidney in which the kidney has age-appropriate structure and function) than the composite of individual SES (3). Indeed, neighborhood features are related to incident diabetes and hypertension, independent of individual-level SES (15,16).

A recent review (17) outlined four general categories of neighborhood features that may be important for kidney health and health inequalities: sociodemographic context, the built and physical environment, the social environment, and health care resources (Figure 2). The sociodemographic context generally includes the social, economic, and racial/ethnic composition of the neighborhood. It is not the composition, *per se*, that drives disease development and progression. Rather, these measures are proxies for the variation in public and private investment and socially accepted behavioral norms (i.e., norms around nutritional diet and exercise) that are important for health. For example, neighborhood racial segregation (i.e., the sorting of different racial groups into neighborhoods of unequal quality through historical and contemporary policies and practices) is associated with incident

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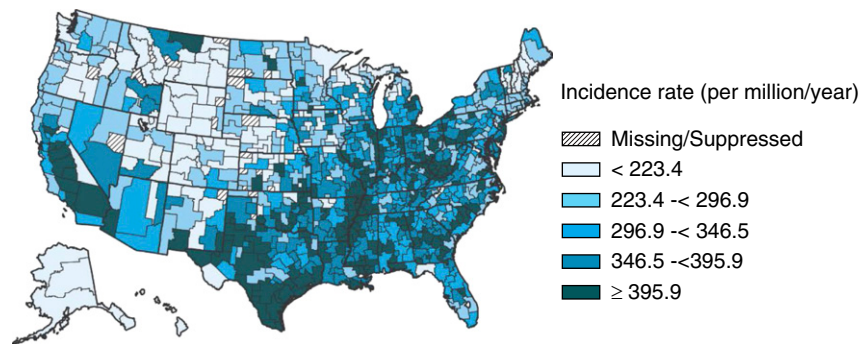
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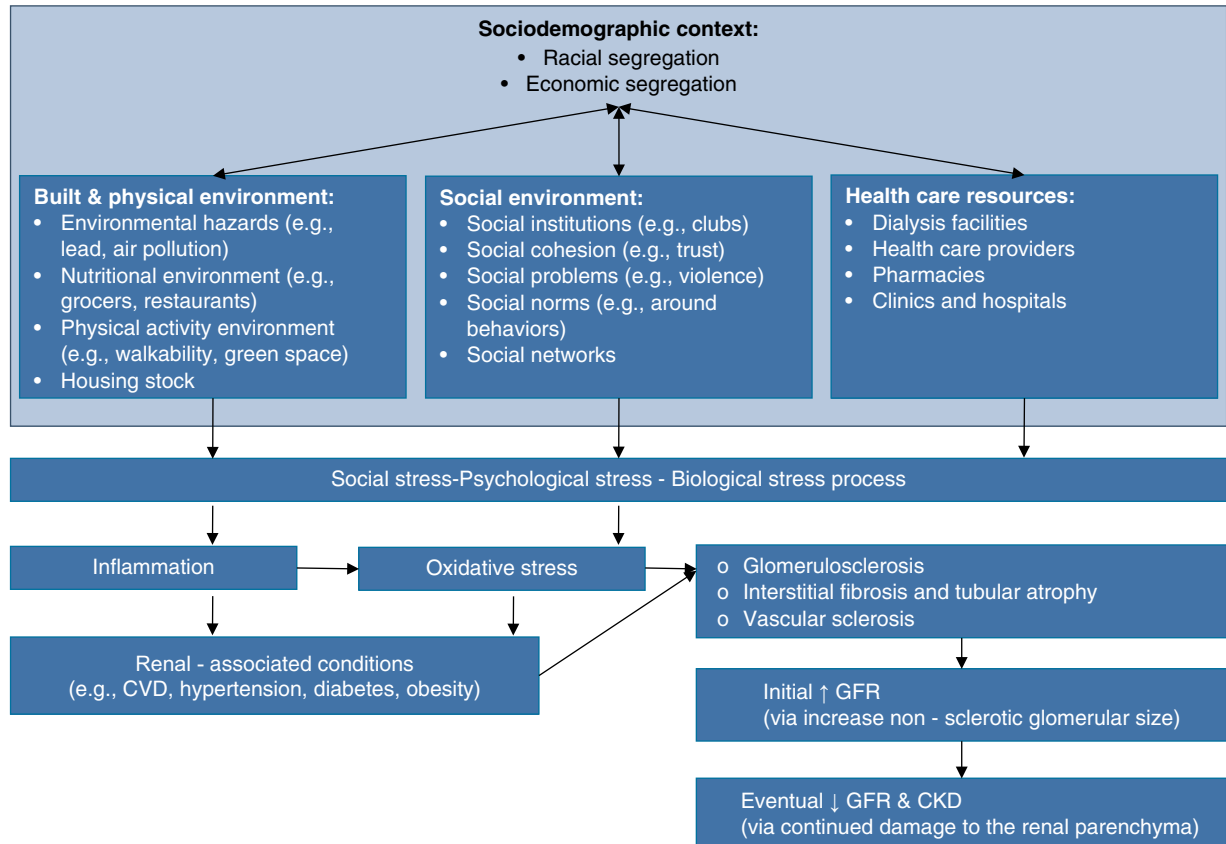


**Figure 1.** | Map of the standardized incidence rate of ESKD by health service area in the US population, 2012–2016. It is standardized to the age-sex-race distribution of the 2011 United States population. Special analyses exclude unknown age, sex, health service area, and unknown/other race. Values for cells with ten or fewer patients are suppressed. The data reported here have been supplied by the US Renal Data System (USRDS). The interpretation and reporting of these data are the responsibility of the author(s) and in no way should be seen as an official policy or interpretation of the US Government. Data source: Special analyses, USRDS ESKD Database (61).

cardiovascular disease (14). Further, moving to neighborhoods with less racial segregation is associated with improvements in cardiovascular health, such as decreases in BP (6).

Regarding sociodemographic context, some have examined the link between neighborhood SES and kidney function and damage. In general, this literature suggests little or

no association between neighborhoods and renal health, particularly at earlier stages of CKD. For example, some report an association between neighborhood poverty and incident ESKD using the USRDS (15), whereas others report no association between neighborhood (16) and county (17) poverty and low eGFR (16) or incident ESKD using the Reasons for Geographic Differences in Stroke (REGARDS)



**Figure 2.** | Conceptual model linking neighborhood context to renal pathology. Although not covered in the discussion, others have outlined the link between social, psychologic, and biologic stress and the kidney (62). CVD, cardiovascular disease.

cohort (17). When a more comprehensive SES index composed of multiple items, such as median household income, mean home value, and percentage in professional occupations, is used, neighborhood SES has been related to increases in serum creatinine (18) and decreases in eGFR to <45 ml/min per 1.73 m<sup>2</sup> over time (19)—but these results are not consistent across age, race, or sex (18–20). Some have also examined neighborhood SES over the life course, including childhood and adulthood; however, results suggest that neither childhood county SES (19) nor early adulthood neighborhood SES (19) nor the cumulative childhood and adulthood residential SES (21) is related to later adulthood declines in eGFR. Consistent with these reports, a recent study suggested that duration of residence in the southeast United States is associated with incident ESKD but not baseline albuminuria or an eGFR <60 ml/min per 1.73 m<sup>2</sup> (22). It may be that neighborhood racial and economic segregation better captures the resources and constraints important for the development and progression of CKD. Although no studies to our knowledge examine neighborhood segregation and measures of renal health, one study has shown an association between county-level segregation and mortality for patients on dialysis (8). In other words, black patients on dialysis who live in counties where black and white residents live apart from each other experience a greater risk of mortality compared with black patients who live in counties that are less segregated (regardless of whether the patient himself/herself lives in a neighborhood in the county that is composed of predominantly black residents). Future research on neighborhood segregation should ask: “Do black patients living in neighborhoods with predominantly black residents who are segregated from other neighborhoods experience faster CKD progression compared with other patients?” Although only a crude proxy for neighborhood segregation, there is evidence that neighborhood racial composition is associated with CKD-related measures. For example, neighborhoods with higher proportions of black residents did have high-quality dialysis facilities (23,24); however, black patients did not necessarily access these facilities (23,24).

The built and physical environment comprises neighborhood features ranging from housing to walkability (using map data on street connectivity) to local businesses (using data from public sources, such as the business census and private databases) to pollution (using data public data from the Environmental Protection Agency [EPA]) (25). These features have been associated with renal-associated conditions, including obesity, diabetes, and hypertension, as well as the social inequalities in these conditions (26–30). Although there is a dearth of empirical work linking these types of neighborhood features to renal health, evidence from other literatures suggests a link. For example, evidence from the environmental sciences links neighborhood SES and racial composition (using census data) to hazardous waste siting and industrial pollution (using data from the EPA) (31). Numerous pollutants are related to CKD (32–34). Further, environmental lead, for example, is associated with increases in BP and oxidative stress in endothelial cells and vascular smooth muscle cells (35,36), which intimately relate to kidney function and damage. Neighborhood food quality and availability, as another example, are linked to obesity

and diabetes (26,37,38), and they are thought to be linked to CKD and ESKD (39). Dietary protein and sodium can have a marked effect on intraglomerular pressure, glomerular hyperfiltration, and proinflammatory gene expression (40–42).

The social environment includes features that capture the social connections among its residents as well as the social effect of the context upon its residents. This literature, which generally uses surveys asking people how they feel about their neighborhoods, has yielded mixed results, even for renal-associated conditions. For example, neighborhood social cohesion (*e.g.*, trust among neighbors, *etc.*) was associated with lower hypertension (27,43) and diabetes (26) prevalence but was not associated lower body mass index (44). A different aspect of the social environment, neighborhood social problems (*e.g.*, physical disorder and violence), was not associated with either hypertension prevalence (45) or body mass index (44). There are not many studies linking social context to measures of renal diseases. However, researchers recently reported that social problems, but not social cohesion, were associated with annualized declines in eGFR only for black adults (46).

Neighborhood health care resources include dialysis centers but extend to the density and type of hospitals, community health centers, and health care providers and the density of health-related resources, such as pharmacies and dispensaries, and urgent care facilities. These features of the neighborhood mark access to health care resources (47) but also mark public and private investments in prevention and disease management care that may correlate with other investments in health. For example, reports have documented “pharmacy deserts” in neighborhoods with mostly poor or black residents (48). Similarly, neighborhood poverty is related to a decreased likelihood of being on a transplant waitlist (9).

A puzzle remains in that, although neighborhood characteristics are generally related to renal-associated diseases, RRT-associated outcomes (*i.e.*, access to transplant and dialysis facility quality), and ESKD, they have not been shown to be consistently related to earlier stages of CKD (2,19,16,20,49,50). This inconsistency may be due to measurement limitations: (1) a focus on neighborhood SES particularly at a single time point in the life course and (2) a reliance on eGFR alone in studies with healthy and/or younger adults. Much of what we know about neighborhoods and CKD is on the basis of information from a handful of datasets (Table 1). There are three broad categories of datasets with information (or the potential for information linkage) on both neighborhoods and kidney health, each with strengths and limitations.

- (1) Demographic studies are those with samples drawn from the noninstitutionalized population using complex stratified sampling approaches such that they, when weighted, represent a certain area, such as the nation. A strength of these data is that they are representative of populations. However, most of these datasets may have only basic blood-based renal biomarkers, ESKD information through linkage to USRDS, and kidney disease mortality through linkage to the National Death Index. Further, for those datasets, such as the National Health and Nutrition Examination Survey, that include urine albumin-creatinine ratio, the

Table 1. Demographic, epidemiologic, and clinical datasets used to study the association between residential context and kidney health

Datasets	Sample Size	Years	Locations	Age at Baseline, yr	Spatial Unit <sup>a</sup>	Kidney Measures					
						Urine Protein-Creatinine Ratio, Urine Albumin-Creatinine Ratio <sup>b</sup>	Serum Creatinine	Serum Cystatin C	Chronic Kidney Disease Mortality	End Stage Kidney Disease	Apolipoprotein L1
<b>Demographic studies and datasets</b>											
Americans' Changing Lives Health and Retirement Study	3617	1986–2019	US	25–84	Tract		IP	IP	X	X	IP
National Health and Nutrition Examination Survey, Wave III	25,444	1992–2019 <sup>c</sup>	US	51–61	Tract		X	X	X		X
National Health and Nutrition Examination Survey, Wave III	33,994	1988–1994	US	0–90	Address <sup>d</sup>	X	X	X	X		
National Health and Nutrition Examination Survey, Continuous	Approximately 5000/yr	1999–2020 <sup>c</sup>	US	0–90	Address <sup>d</sup>	X	X	X	X		
National Longitudinal Study of Adolescents	12,105	1994–2018	US	14–18	Block	X	IP	IP			IP
National Vital Statistics System, Mortality Data	All US	1968–2017 <sup>c</sup>	US	All US	County				X		
<b>Epidemiologic studies and databases</b>											
Atherosclerosis Risk in Communities	15,792	1987–2019	Multiple US	45–64	Tract	X		X	P	X	X
Coronary Risk Development in Young Adults	5115	1985–2016	Multiple US	18–30	Block	X	X	X	P	P	X
Dallas Heart Study	3500	2000–2009	Dallas, TX	30–65	Block	X	X	X	P	P	X
Jackson Heart Study	6500	2000–2012	Jackson, MS	35–94	Tract	X	X	X	X	X	X
Multi-Ethnic Study of Atherosclerosis	6814	2000–2018	Multiple US	45–84	Tract	X	X	X	X	X	X
Reasons for Geographic Differences in Stroke	28,878 (4)	2003–2016	Multiple US	45–98	Block	X	X	X	X	X	X
US Veterans Administration Database	All VA	1977– <sup>c</sup>	US	All VA	County	X	X	X	X	X	X
<b>Clinical studies and databases</b>											
Chronic Renal Insufficiency Cohort	5499	2003–2018	Multiple US	21–74	Tract	X	X	X	X	X	X
Clinical Phenotyping Resource and Biobank Core	1645	2009–2019	Multiple US	30–64 <sup>e</sup>	Tract	X	X	X		X	
Cure Glomerulonephropathy	2400	2014–2020	Multiple US	IP	Tract	X	X	X		X	X

**Table 1. (Continued)**

Datasets	Sample Size	Years	Locations	Age at Baseline, yr	Spatial Unit <sup>a</sup>	Kidney Measures					
						Urine Protein-Creatinine Ratio, Urine Albumin-Creatinine Ratio <sup>b</sup>	Serum Creatinine	Serum Cystatin C	Chronic Kidney Disease Mortality	End Stage Kidney Disease	Apolipoprotein L1
Nephrotic Syndrome Study Network	2561	2010–2019	Multiple US	0–80	Tract	X	X	X		X	X
US Renal Data System	All ESKD	1978– <sup>c</sup>	US	All ESKD	Zip code				X	X	

Clinical measures are not necessarily available for all waves of data. The years available include a range of temporal data collection efforts. For example, some studies collect information every 2 years, whereas others collect data every 6 years. US, United States; IP, data collection in progress; P, data possibly available; VA, US Department of Veterans Affairs.

<sup>a</sup>Represents the most spatially granular unit available.

<sup>b</sup>Information generally available on either urine albumin-creatinine ratio or urine protein-creatinine ratio.

<sup>c</sup>Represents ongoing data collection efforts into the indefinite future.

<sup>d</sup>Geospatial data are available to researchers through Census Research Data Centers.

<sup>e</sup>Interquartile range available only.

**Table 2. Clinical studies and databases with renal histopathology and residential context information**

Clinical Studies and Databases	Years	Locations	Sample Size	Demographic Characteristics			Biopsy Scored?
				Age, yr, Mean $\pm$ Standard Deviation	White, %	Women, %	
Aging Kidney Anatomy Study: Healthy Living Kidney Donors (63–65)	2011–2021	Multiple US	Adults: 2453 <sup>a</sup>	Adults: 44 $\pm$ 12	94	59	Complete
Aging Kidney Anatomy Study: Tumor Nephrectomy Patients (65)	2011–2021	Multiple US	Adults: 780 <sup>a</sup>	Adults: 64 $\pm$ 12	NR	36	Complete
Boston Kidney Biopsy Cohort (66)	2006–2016	Boston, MA	Adults: 676	Adults: 52 $\pm$ 17	64	53	Complete
Clinical Phenotyping and Resource Biobank Core (Patients with Renal Disease) (67)	2009–2018	Multiple US	Adults: 1374; peds: 271	Adults: 55 $\pm$ 20; peds: 11 $\pm$ 4	52	52	In progress
Cure Glomerulonephropathy Consortium (68)	2014–2020	Multiple US	Adults: 1680 <sup>a</sup> ; peds: 720	Adults: 46 $\pm$ 17; peds: 10 $\pm$ 4	67	43	In progress
Nephrotic Syndrome Study Network (69,70)	2010–2019	Multiple US, Canada	Adults: 355; peds: 313	Adults: 46 $\pm$ 16; peds: 6 $\pm$ 5	54	41	In progress

Each scored database contains pathology kidney data including glomerular size, percentage glomerulosclerosis, percentage of interstitial fibrosis and tubular atrophy, measures for vascular disease, and clinical indicators of renal function (*e.g.*, creatinine, creatine-based eGFR, and urinary protein/albumin). Some databases have more extensive kidney pathology data as well as additional clinical data, genomic data, and molecular data. US, United States; peds, pediatric patients.

<sup>a</sup>Recruitment is ongoing; sample size reflects current enrollment.



data are available only in cross-section, meaning that it is not possible to examine incidence.

- (2) Epidemiologic studies are those with samples drawn from the noninstitutionalized population in a specific number of places using various sampling methods. These data are not sampled nor weighted to be statistically representative of any particular population. However, there are important strengths of these data, including that they use an observational design to assess potential causal associations. Further, most are longitudinal with both blood- and urine-based biomarkers at multiple time points. They also often sample those without clinical presentation of certain diseases in order to capture disease development so that associations can be made with both prevalence and importantly, incidence.
- (3) Clinical studies are those with patients who were recruited specifically because they have some type of kidney disease. Generally, these studies have numerous urine- and blood-based biomarkers over specific time intervals. A major strength of these studies is that there is a deep interrogation of clinical, molecular, and pathology information. In addition to clinical studies, there are clinical data available for linkage to neighborhood information. The USRDS has been used in numerous studies to document the link between place and ESKD. Furthermore, there is tremendous potential in linking the clinical data available through electronic health records, both local and national, to neighborhood data (51,52). This method allows for monitoring of acute and chronic health conditions in real time in relation to neighborhood. At the national level, the Department of Veterans Affairs has a large integrated electronic health record including over 9 million veterans in the United States who receive care through the Department of Veterans Affairs. These data have been recently used to examine geographic clustering of rapid eGFR decline (53) and have the potential to be used to examine numerous neighborhood features in relation to disease progression.

### Improving Measurement of Neighborhoods in Studies of CKD and ESKD

Although efforts are underway, there are currently no known published studies using demographic data to examine the link between residential context and kidney health. There are several studies, however, using epidemiologic data, including the Atherosclerosis Risk in Communities (19–21), the Cardiovascular Health Study (18), the Multi-Ethnic Study of Atherosclerosis (46), and the REGARDs (16,17,22,54), as well as the US Department of Veterans Affairs patient database (53). We provide Table 1 as a companion to the detailed tables in a recent report (55), in which the authors outline numerous types of administrative data available for linkage to demographic, epidemiologic, and clinical datasets. In the published studies, the focus has been on neighborhood SES. We recommend drawing from the larger epidemiology literature on neighborhood context and renal-associated diseases in several ways.

First, we recommend examining racial and economic segregation, which may better capture the clustering within cities that guides public and private investment compared with measures that focus only on the racial composition or SES of one's immediate neighborhood. Racial segregation has been consistently associated with numerous renal-associated conditions (14), and recent reports suggest that moving to less segregated neighborhoods is associated with improvements in cardiovascular health (6). With the continued rise of socioeconomic inequality in the United States, we also recommend examining economic segregation in connection with racial segregation.

Second, we recommend examining neighborhood context across the life course rather than solely at a single point. Although some have reported inconsistent associations between county SES in childhood and neighborhood SES throughout adulthood and eGFR (18–21), we suggest building on these studies to include age-period-cohort analysis. In this type of analysis, researchers can examine the association between neighborhood context and kidney health markers among specific birth cohorts while disentangling potential effect of historical periods (*e.g.*, the Civil Rights Era) and chronological age (56,57).

Third, we recommend innovative approaches to modeling multiple features of the neighborhood context together. It may also be that different features of the neighborhood context interact with each other. Research suggests that social context, for example, amplifies the association between environmental pollutants and renal-associated diseases (58–60). These complex associations may clarify why neighborhood SES alone is not related to measures of kidney function and damage.

Fourth, we recommend considering the ways in which “neighborhood” is conceptualized for measurement. In reality, neighborhoods are cohesive areas of towns and cities; the cohesive element varies and may be, for example, built (*e.g.*, planned housing development) or sociohistorical (*e.g.*, Chicago's Bronzeville). However, in the reality of most CKD research, it is not possible to use these conceptualizations of neighborhood. Therefore, many use census tracts (*i.e.*, census-based administrative residential areas of roughly 4000 people), zip codes (*i.e.*, US Postal Service-based administrative areas used for efficient mail delivery; generally much larger than tracts), or even county. In some cases, researchers must use a single approach to neighborhood because it is all that is available in the dataset. This is the case with regard to zip code in the USRDS. Many epidemiologic datasets use census tract as the proxy for neighborhood. Which proxy for neighborhood is used depends on the exposure under study (*e.g.*, racial composition, SES, parks, dialysis centers, or grocery stores) and may affect the interpretation of the results.

Many neighborhood features have become recognized as important determinants of health and health inequalities. Although there is robust empirical literature linking neighborhood features and renal-associated conditions, the literature is inconsistent in relation to kidney function and damage. In this review, we recommend expanding the study of neighborhoods and renal diseases in the following ways: (1) examining racial and economic segregation, which may better capture the clustering within cities that guide public and private investment compared with measures that

focus only on the racial composition or SES of one's immediate neighborhood; (2) examining neighborhood context across the life course rather than solely at a single point; (3) using innovative approaches to model multiple features of the neighborhood context together (for example, including interaction effects between features, like social context, environmental pollutants and renal-associated diseases); and (4) considering the ways in which "neighborhood" is conceptualized for measurement, understanding, for example, that measures like zip code may not be an appropriate proxy for neighborhood.

Expanding our approach to the studying of neighborhood and renal health can clarify mechanisms and point to important primary as well as secondary and tertiary intervention points because residential context is shaped by policy, guided by public and private investment and disinvestment, and thus, amenable to change.

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#### Author Contributions

M.T. Hicken and C.J. Lapedis conceptualized the study; M.T. Hicken and C.J. Lapedis were responsible for data curation; M.T. Hicken provided supervision; M.T. Hicken and C.J. Lapedis wrote the original draft; M.T. Hicken was responsible for funding acquisition and visualization; and M.T. Hicken, J. Hodgins, B.J. Jang, C.J. Lapedis, and L.H. Mariani reviewed and edited the manuscript.

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