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Body Mass Index and Neighborhood Socioeconomic Status in Washington State

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Abstract

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[Introduction: Obesity and overweight are a critical public health problem in the United States^{1,2} and worldwide³. Obesity is affected by multiple factors including socioeconomic status (SES), built environments including opportunities for active transportation and access to supermarkets or fast food outlets, as well as disordered nutrition^{3–6}. This study contributes to our knowledge by examining the relationship between Messer's neighborhood deprivation index⁷ and census-tract level body mass index (BMI) measures created using driver's license data⁸. Messer's

neighborhood deprivation index and census-tract BMI scores are new measures for Washington State.

Methods: Messer's neighborhood deprivation index, based on census data, was combined with BMI outcomes calculated using Washington state driver's license height and weight to explore neighborhood SES relationships to BMI. A second analysis explores which of Messer's neighborhood deprivation index variables are most closely related to BMI outcomes.

Results: BMI is strongly associated ($R^2 = 40.6\%$) with neighborhood deprivation in 1449 census tracts in Washington state. Among components of neighborhood deprivation index analyzed without Messer's scale, unemployment rate among all adults over 16 years old and percent of female headed households were most associated with BMI outcomes. Together, unweighted components of Messer's neighborhood deprivation index explained 54% of the variation in age-adjusted BMI outcomes.

Conclusion: Study results support association of BMI with SES variables. Neighborhood deprivation indexes have been used as proxies for health status⁹ and allow targeting of interventions where they can have the most beneficial effect. Given the magnitude of the variance in BMI explained by the neighborhood deprivation, inclusion of SES measures in targeted multi-level built environment interventions for obesity could result in significant health savings¹⁰⁻¹⁴.

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DEDICATION

To my dad, with love and thanks.

Chapter 1. INTRODUCTION

1.1 BACKGROUND

The obesity epidemic is a problem with many roots including genetics, culture, behavior, socioeconomic status, and the environment³. According to 2014 National Health Interview Survey data, 65% of Americans are overweight or obese¹⁵ and only 20% of adult Americans met the baseline recommendations for aerobic and muscle strengthening activity¹⁶. 19.5% of Washington adults reported no physical activity in the last month¹⁷. These trends are expected to continue^{18, 19}.

Obesity increases risks for preventable diseases including heart disease, diabetes, stroke, arthritis, sleep apnea and increased risk for some types of cancer^{20, 21}. The resulting costs of health care (mostly due to excess costs of diabetes and heart disease) and years of quality life lost are large and growing^{14, 22}. Obesity morbidity and high prevalence combine to produce higher quality-adjusted life years lost (QALY) lost than smoking²³. Wang, in a 2011 issue of *The Lancet* says that obesity trends will cost “26–55 million quality-adjusted life years forgone for USA and UK combined” (emphasis mine) and estimates the medical costs of treating obesity-associated preventable diseases will increase by \$48–66 billion/year in the USA.¹⁴ Over 20% of youth are obese, using 2012 data²⁴ and 2013 research shows low physical activity rates in youth, especially females, and poor consumption of fruits and vegetables²⁵. The obesity epidemic, with associated costs to health, will continue without intervention^{18, 26}. As research has shown at least since 1999²⁷, socioeconomic status mitigates and often brings worse outcomes for more vulnerable populations^{27, 28}.

A socioecological model was adopted from Franzini to frame the relationship between neighborhood socioeconomic status and BMI outcomes of overweight or obesity (see Figure 1) with the addition of individual-level caloric inputs and physical activity outputs²⁹. Consideration of health effects other than obesity are outside the scope of this study, but are well documented²⁰.

While measures of neighborhood physical activity were not available, creation of a novel measurement of BMI was possible at the neighborhood or census tract level. Data for obesity

monitoring is needed and a novel method using driver's license height and weight to calculate BMI was developed.^{8,30} Research in Oregon suggests that driver's license weight is predictably underestimated, especially among women, and that men frequently overestimate height⁸. Similar weight underreporting was found in an earlier study in Washington³¹. For this reason, this study combined classifications for overweight and obese, because it is likely that those categorized as overweight are really obese (see Table 4 for variable classifications used in mapping). Future research should explore systemic correction of reported BMIs⁸.

Individual socioeconomic status is related to BMI, however, SES at the neighborhood level also affects the neighborhood built environment due to differential jurisdictional and commercial investments over time. Due to the correlation of socioeconomic conditions with obesity^{27, 32-37}, and built environment^{26, 32-39}, this study also contributes to the literature by providing a neighborhood deprivation index at the census tract level for Washington state. Similar indexes are used to estimate health disparities based on geography²⁷, a useful tool for intervention design and targeting. According to Wang, effective obesity interventions could result in obesity-associated preventable disease health care savings of up to 66 billion dollars per year in the US¹⁴.

Policy and environmental interventions are expected to yield the greatest effects and resultant health savings from obesity improvements⁴⁰⁻⁴², particularly though the use of multi-level designs²⁸. Evidence-based neighborhood and built environmental interventions are associated with decreasing BMI^{12,21}. A study conducted in Baltimore and Seattle found that highly walkable neighborhoods relate to healthier BMIs, with the magnitude of the benefit mediated by income⁴. A cost-benefit analysis in Dane County Wisconsin found a 1.87 cost benefit ratio over 10 years, offsetting the cost of county-wide sidewalk installation mitigated by savings in health spending from decreased obesity and improved air quality⁴³. Light-rail installations in Salt Lake City and Charlotte, NC have both been associated with decreased obesity and increased walking trips by transit-riders^{12, 13, 44, 45}. The SLC project estimated a \$12.6 million dollar savings in health costs over 9 years of light rail usage¹³.

1.2 CONCEPTUAL DIAGRAM

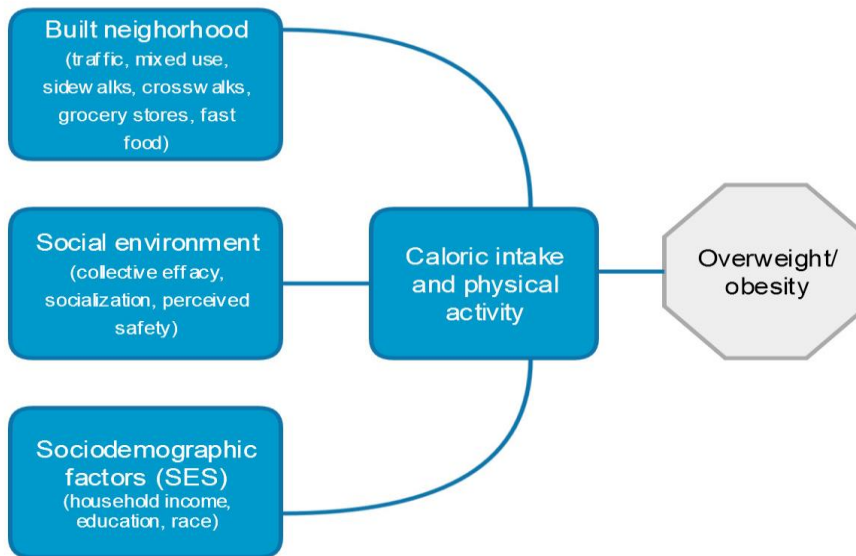


Figure 1: Conceptual diagram adapted from Franzini, et al. Influences of Physical and Social Neighborhood Environments on Children's Physical Activity and Obesity⁴⁶ using Gliffy⁴⁷

This conceptual diagram was adapted from Franzini's work on neighborhood and social environmental influences on children's physical activity and obesity⁴⁶ along with contribution from Faith and Kraul's work on obesity and obesity-promoting behaviors²⁹. While Franzini's work focuses on children's obesity, adult obesity is mediated by similar factors, particularly neighborhood and social environments, but with the addition of workplace activity and behaviors, which are outside the scope of this study. Input/outputs for individual-level behavior related to BMI from Faith and Kraul add choice to Franzini's model²⁹.

Chapter 2. METHODS

2.1 NEIGHBORHOOD DEPRIVATION INDEX DATA

American Community Survey 2013 tables (data from 2009-2013) were downloaded from US Census FactFinder⁴⁸ and provided data for the neighborhood deprivation index construction using methods of Messer⁷ which incorporate variables related to income, housing, employment, and

education - see **Error! Reference source not found.** for variables included in index. Higher scores are associated with more area-level deprivation.⁷

The following changes were made to the index due to census variable changes: percent households with under 30k income was changed to 35k, percent males in management and professional was changed to only percent of males in management, because professional class variables were extensive. Percent males and females unemployed plus males no longer in the workforce was changed to simply percent unemployed due to a change in the census variable.

Census tracts were the most granular boundary for which needed census data was available and thus all calculations were performed with census tracts as the unit of analysis.

2.2 BODY MASS INDEX

Washington Department of Health's Washington Tracking Network³⁰ obtained heights and weights of Washington drivers without personal identifiers from Washington State Department of Licensing⁴⁹ and using published methods⁸, age-adjusted for 4 categories (20-34, 35-49, 50-69, 70-85), producing average BMIs for all census tracts in Washington state. Excluded from this dataset were military service members and any individuals listed with weight under 50 pounds or over 600 pounds. Also excluded were individuals with heights under 48 inches or over 84 inches. BMIs were calculated and any individual with a BMI over 65 or less than 14.5 were also excluded. This was done to correct for errors, and in the case of military service members, who are often deployed, and are under service-related weight restriction, to best measure the bodily effect of living in the Washington built environment.^{8, 30} Four census tracts had missing values in one age category, so weights were recalculated for the existing categories for those tracts.³⁰ All exclusions described only removed 2.61% of the records, resulting in inclusion of 6,015,456 records³⁰.

2.3 VARIABLE DEFINITION

Variables were defined for mapping differently than for regression analysis. For map creation, categorical variables were required, and were defined according to below procedures. For regression analysis, variables were continuous. Messer's deprivation index is based on American

Community Survey data from 2013⁴⁸ 5 year rollup, the most recent available at the time of analysis. Source tables and variable names are described in Table 3: Neighborhood deprivation index variables, factors, and data sources.

Categorical variables were defined for mapping purposes for neighborhood deprivation index while BMI was categorized²⁰ as normal or high (including both obese and overweight values). **Error! Reference source not found.** describes cutoffs, which were determined using ArcGIS©⁵⁰ Jenks natural breaks⁵¹. Variables were mapped using colors picked using ColorBrewer.⁵²

Chapter 3. ANALYSIS

3.1 ANALYTICAL OVERVIEW

To explore associations between BMI outcomes and neighborhood SES as well as individual deprivation index measures relation to BMI outcomes, regression analysis was performed. In addition, to provide geo-visual exploration of the results, bivariate choropleth maps were created using ArcGIS©⁵⁰ software and basemap⁵³ provided by Environmental Systems Research Institute (ESRI).

3.2 STATISTICAL ANALYSIS

Using StataIC Release 14⁵⁴, data were prepared and analyzed in 2015 using significance level of less than or equal to 0.05. Robust standard errors were used.

Regression was performed with predictor variable of neighborhood deprivation index and outcome of BMI at the census tract level. A second regression was performed with Messer's neighborhood deprivation index components to explore which components were most predictive of BMI outcome.

Chapter 4. RESULTS

4.1 DESCRIPTIVE RESULTS

Data included 1445 census tracts with associated census data. Washington state residents residing in the 66 thousand square miles of the state number just over 7 million individuals⁵⁵. Washington state population per square mile in 2010 was just over 101 individuals⁵⁵. Census tract size varied from .05 square miles in urban census tracts in western Washington to 1112 square miles in rural areas of eastern Washington. Census tract median area was 29.3 square miles. Census tracts were the unit of analysis as described below.

Maps (Figure 2, Puget sound, Figure 2, Spokane, Figure 3, State) created using neighborhood deprivation index and BMI categorized using cutoffs described in Table 4 were created for visual exploration of relationships between neighborhood deprivation and high and normal BMIs. In maps, dark blue and dark brown areas point to areas with both high BMI and high or moderate neighborhood deprivation. Notice particularly areas south of Seattle in Figure 2 – those darker areas would be ideal sites for a mixed-design intervention targeting both obesity, perhaps though investigation of built environment variables (sidewalks, safe crosswalks, lighting), food (grocery stores vs fast food), or recreation (parks, gyms, or community centers) as well as SES variables aimed at improving high school graduation rates or improving employment opportunities. In Puget sound region, seen in Figure 2, high-deprivation tracts are often overweight (78/84, 93%) compared to low-deprivation tracts (386/509, 76%), in comparison to the Spokane region in Figure 3, where BMI is uniformly high in all levels of deprivation (109/111, 98%). A state level map (Figure 4) is provided for overview – BMI is high across the state (1290/1435, 90%), especially in rural areas. Even tiny changes in the upstream determinates of socioeconomic status can have major impacts on a wide variety of outcomes such as obesity, other health effects, later employment as well as education later in life or in subsequent generations²⁸.

4.2 STATISTICAL RESULTS

To answer the research question of “Is BMI in Washington associated with neighborhood deprivation index?” a linear regression analysis was performed in Stata⁵⁴.

	β	95% Confidence Interval	ρ -value
Messer’s Neighborhood Deprivation Index	2.98	2.75 to 3.21	<.05
Overall $R^2 = 40.6\%$, F statistic = 657.41, n=1445			

Table 1: Linear regression results of Messer’s Neighborhood deprivation index including weighting and BMI in Washington state

Linear regression of Neighborhood deprivation index explained a little over 40% of the variation in census tract BMI at the .05 significance level. This supports the association between obesity and neighborhood SES drawn from the conceptual diagram in Figure 1.

A second linear regression analysis was performed using Neighborhood deprivation components (listed in Table 3) without application of Messer’s index⁷ to predict effects on BMI. This explored which components are most strongly related to BMI outcome. Due to small numbers of respondents per census tract and resulting missing values from many divisions by zero, % household with crowding was removed from the analysis.

	β	95% CI	ρ -value
Unemployment in +16yo adults, %	.0412	.032 to .051	<.0001
Female-headed household, %	.0404	.031 to .050	<.0001
Households under poverty line, %	-.0312	-.038 to -.024	<.0001
High school graduates, %	.0292	.024 to .035	<.0001
% Males in management	-.0274	-.033 to -.021	<.0001
Households under 35k, %	.0116	.007 to .017	<.0001
Households receiving public assistance, %	.0098	.005 to .014	<.0001

Overall $R^2 = 54.1\%$, F statistic = 241.1, n=1443* (due to missing data)

Table 2: Linear regression results of unweighted Messer's Neighborhood deprivation components and BMI in Washington state

Linear regression of unweighted Neighborhood deprivation index components, with the exclusion of crowding, together explained 54% of the variation in census-tract level BMI at the .05 significance level. Variables associated with the most change in BMI outcomes were % unemployment in the population of over-16 year old adults and the percentage of female-headed households in a census tract. As expected, percentage of males in management occupational class was protective against increases in BMI, however, percentage of households under the poverty line also showed a small protective relationship with BMI. Increased variance explained by unweighted model might be related to exclusion of crowding variable or Messer's index weighting.

Chapter 5. DISCUSSION

Research on obesity is important due to the magnitude of the population affected and due to the resulting costs associated with health outcomes and quality-life years lost^{14, 23}. Obesity is affected by multiple factors as illustrated in the conceptual diagram in Figure 1, and this research finds an association between neighborhood SES and age-adjusted neighborhood BMI. This relationship not simple, though growing evidence points toward complex causal mechanisms^{6, 27, 28, 56, 57}. These findings also support the need for multi-level intervention designs; designing interventions with aims both proximal and distal to the outcome. For example, designing an obesity intervention to include built environmental improvements (crosswalks, lighting) as well as interventions designed increase graduation rates. This requires partnership and coordination between school stakeholders, neighborhood residents and community activists, city planners and health professionals.

5.1 STRENGTHS

Strengths of this research include use of a standardized calculation of neighborhood deprivation for Washington and mean BMI measures calculated at the census tract level using a novel data source^{7, 8, 30, 31}. Both methods have been published but not used in this way in Washington.

5.1.1

Neighborhood deprivation index

Population health is difficult to measure at a granular level without specialized databases or expensive surveys. One solution to this problem is to find proxy measures for health such as deprivation indexes, based on widely-available census data, and then use deprivation indexes when health measures are too expensive to collect⁹. The addition of a state-level measure of neighborhood deprivation to the literature provides researchers and planners with a tool to easily identify locations with a high need and potentially outsize savings that could result from multi-level health and built environment interventions.

Single-unit measures of SES such as income are also used to measure area SES, but the complex and interconnected relationship of socioeconomic status effects on health seems best measured in multi-unit measures validated for that purpose. The Public Health Disparities Geocoding Project (PHDGP) was intended for use in predicting lead exposures and was validated using predictions about low birth weight⁵⁸. It includes measures of occupational class, income, poverty, wealth, education, crowding, as well as a more novel measure, percentage of housing units built before 1950⁵⁸.

Messer's Neighborhood deprivation index was chosen because it included all domains commonly cited in the literature and but excluded housing age⁷. It was validated in several disparate geographies, in contrast to the PHDGP⁷. Additionally, Messer's index lacked a western state application, and it was hoped that this study could contribute to that literature.

5.1.2

Census tract geographic unit of analysis

Neighborhoods are variously defined in the literature. Measurement at the most granular level is preferred, particularly because neighborhood physical activity is quite geographically localized, and therefore small spatial scale is required for measurement^{59,60}. Due to data availability, this is not always possible, and has led to problems with interpretation. For example, a key drawback in the Harvard Alumni Health study of built environment and physical activity levels was the use of counties as the geographic measure – researchers concluded that “assessment of sprawl may have been too imprecise... to observe an association.”⁶¹ Census tract calculations were found to be

comparable to census block group calculations by the Public Health Disparities Geocoding Project⁶².

This study contributes BMI and deprivation measures at the census tract level to the literature and avoids inappropriate spatial scale problems for the majority of census tracts in Washington. According to Boone-Heinonen, et. al's research, a 1km buffer around a person's home is most representative of their personal built environment⁶³. That research found intersection density within a 1km buffer was most associated with moderate-to-vigorous physical activity⁶³. Given the size variation in census tracts found in Washington from .14sq km to 2880sq km in rural areas of eastern Washington with a mode of approximately .16sq km and median of 76sq km, census tracts are a good but less than perfect measure of neighborhood environment at the state level. In urban areas, census tracts may be closer to the ideal 1km buffer.

5.1.3 *Granular BMI data*

Granular obesity measurement as a proxy for health outcomes was needed and inspired creation of a novel method of calculating BMI using driver's license height, weight, and age⁸. Extensive coverage is an advantage of this data set, however optional updating of driver's license height at and weight at renewal is a drawback of this data⁸. Self-reporting bias is a major concern but self-reported heights and weights for calculating BMI are widely used, including by CDC Behavioral Risk Factor Surveillance System (BRFSS)⁶⁴. Due to a documented trend of weight underestimation in driver's license data^{8,31}, BMI variable cutoffs in this study were selected to include both overweight and obese as "high" for mapping purposes.

Intervention measures, particularly extensive and free measures, are needed for intervention design and measurement. This method can be replicated to calculate BMI at census block level, zip code, or other geographic categories at levels where BMI measures are not available⁸. It could be further refined through development of a standardized adjustment calculation⁸.

5.2 LIMITATIONS

Due to the cross-sectional nature of much of the built environment research, including this study, causality determination is limited. This is why research is needed that uses prospective cohorts,

such as the Black Woman's Health Study,⁵⁹ natural experiments such as pre and post transit installation (NC and UT ^{12, 13, 44}), and longitudinal designs (such as Wells' innovative study of African-American women pre and post-move to different neighborhood types⁶⁵). Most ideal would be longitudinal design where a built environmental change can be introduced and then effects on health measured over an appropriately lengthy period of time. This would allow determination of causality and the ability to explore directional changes in health, especially those secondary to built environmental changes. Funding and integration of health measurement and study into existing built environmental changes have been lacking.

Spatial data are known to be dependent on geographic distribution and cannot be considered fully independent. A variety of methods have been developed to analyze geographic independence and perform spatial statistics. However, those methods were outside of the scope of this research. Performance of spatial statistical tests is recommended for future research^{66, 67}.

5.3 HOW KEY FINDINGS COMPARE OR CONTRAST WITH PREVIOUS WORK

The NQLS study found 35% higher odds of being overweight or obese when comparing high vs low-walkability neighborhoods and low-income residents had a 53% higher odds of being obese than those in higher-income neighborhoods⁴. The NQLS found higher objectively measured total physical activity in high vs low-walkable neighborhoods – the objective difference was 47-34 minutes for higher income vs lower-income residents⁴. In a Portland study of older adults, neighborhood socioeconomic status was independently associated with healthier BMIs at the start of the study and provided an additional protective effect from age-related decline⁶⁸. A study of King County Washington adults (with healthcare-reported BMI) found BMI closely related to census tract housing values and college education over even census tract median income and was able to control for spatial dependence and other variables including healthful food environments – explaining 70% of the variation in census tract BMI with three SES variables³⁶. Like this study, they particularly noted south Seattle's differential SES depravity and high BMIs³⁶.

5.4 IMPLICATIONS OF FINDINGS

This research supports the association between neighborhood SES and population health as measured by obesity outcomes. The importance of this work is that it suggests methods for identifying locations for targeted interventions – low-SES neighborhoods should be targeted for obesity interventions, and those interventions should aim outside of the confines of individual-level obesity determinates to include community-level education, employment, and other SES-related outcomes. Task force reviewed recommended strategies to decrease obesity at the community level involve improving healthy food availability⁶⁹, influencing decisions made by planners and city government about transportation, parks, and funding for outdoor recreation⁷⁰, increasing and making physical activity at schools mandatory, as well as outreach and educational campaigns⁵. In this, the literature exploring causal pathways between obesity and health outcomes is informative^{21, 27, 56} and provides possible secondary target outcomes for obesity interventions.

Considering the economic costs of health care and loss of quality-adjusted life years in the increasingly obese population, large targeted interventions are needed^{14, 23}. Policy and environmental interventions are considered to be the most effective way to affect population physical activity and obesity^{21, 28}. Among the most effective policy interventions for increasing physical activity are community and street urban design and land use policy, increasing access to recreational physical activity locations with educational outreach, and point-of-decision prompts to use stairs^{5, 71}. This research supports inclusion of SES in targeting interventions and provides a low-cost granular BMI measure for community impact measurement.

5.4.1 *Future Research*

Complex study designs that allow causal determination are needed, particularly pre-post designs with intervention and health outcome costs, such as the studies done of light rail stop installation in UT and NC^{12, 13, 44} and studies pre and post moving to different built environments⁶⁵. These studies should take into account health effects from obesity secondary to changes in physical activity, but should also account for cardiovascular and asthma effects due to changes in air quality^{43, 72-74}.

Due to rapid changes in health care costs, economic burden of obesity studies such as Wang's and An's should be updated regularly^{14, 22}. Driver's license BMI standardization methods should be developed⁸. Spatial statistical methods should be used, whenever possible, as they are most capable of separating out geographic effect from measurement variables³⁶ and can better pinpoint areas most in need of intervention.

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TABLE 3: NEIGHBORHOOD DEPRIVATION VARIABLES

	<i>Variable</i>	<i>Index</i>	<i>Variable description</i>	<i>Source Table and</i>	
Poverty Domain	%Poverty	0.397	% households below poverty line	S1701 Poverty status in last 12mo by sex by age	ACS 2013 5y roundup ⁴⁸
	% FHHH	0.357	% female-headed households with dependents	P30 Household type for population in households	
	% < \$35k	0.386	% households income under 35k	DP03 Selected Economic Characteristics	
	% pub assist	0.382	% households receiving assistance	DP03 Selected Economic Characteristics	
Occupation domain	% Mgmt (m)	-0.285	% of males in management compared to other occupations	C24010 Sex by occupation for civilian employed pop 16+yo	
Housing domain	% crowd	0.261	% persons living with more than 1 person/room (both rent and own)	B25014	
Employment domain	% unemp	0.366	% unemployed	S2301 Employment status	
Education domain	% no HS	0.369	% with less than high school education	S1501 Educational Attainment	

Table 3: Neighborhood deprivation index variables, factors, and data sources

TABLE 4 CATEGORICAL VARIABLE CUTOFFS

	High or Worse	Med or Moderate	Low or Better
Neighborhood deprivation index	3= .5795 to 1.340	2= .3043 to .5795	1= -.0590 to .3043
BMI ²⁰	High: over 25		Normo= under 25

Table 4: Categorical variable cutoffs and classifications for mapping

NEIGHBORHOOD DEPRIVATION & BMI IN PUGET SOUND

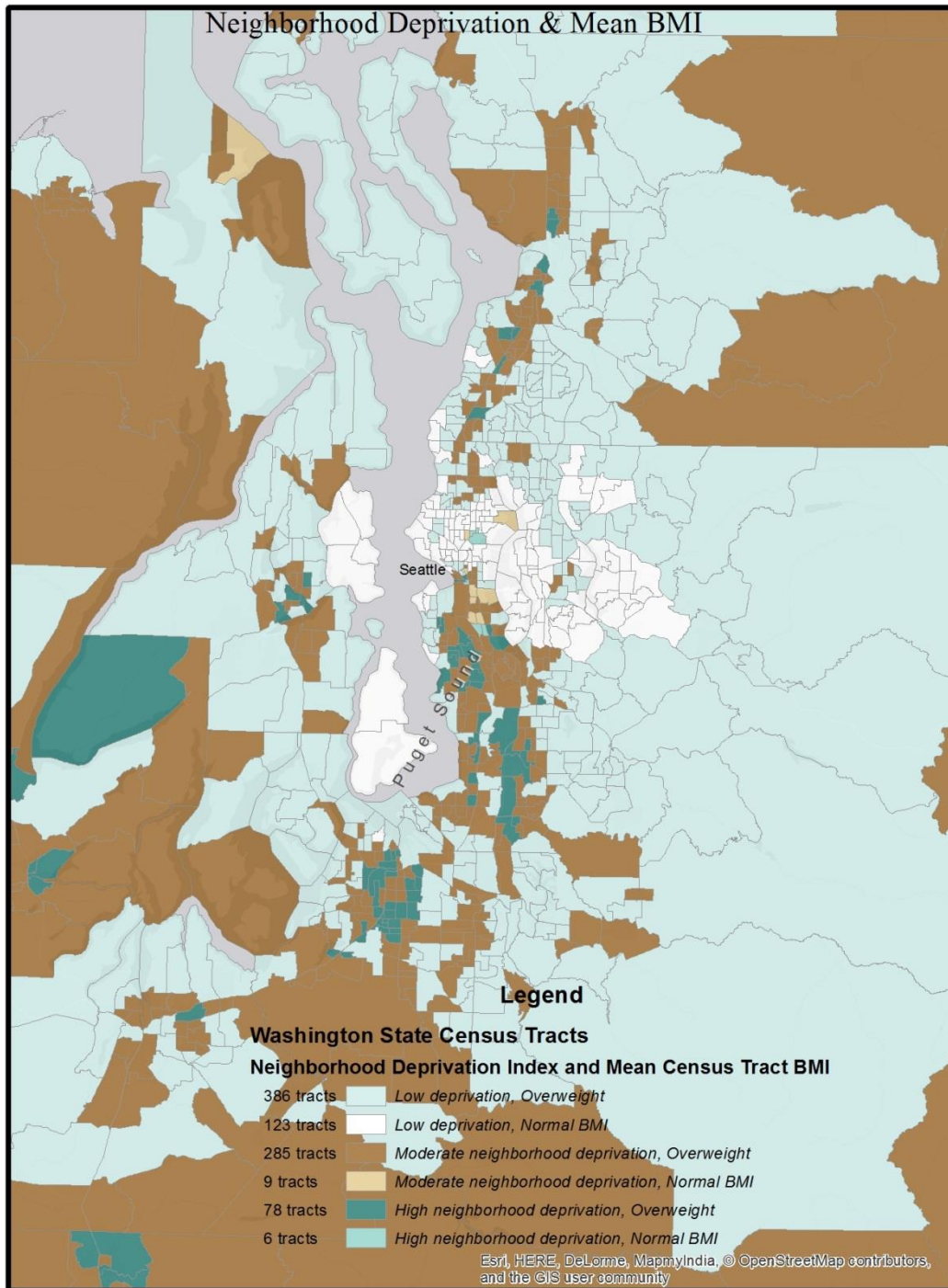


Figure 2: Map of Neighborhood deprivation and BMI in the Puget Sound region

NEIGHBORHOOD DEPRIVATION & BMI IN SPOKANE

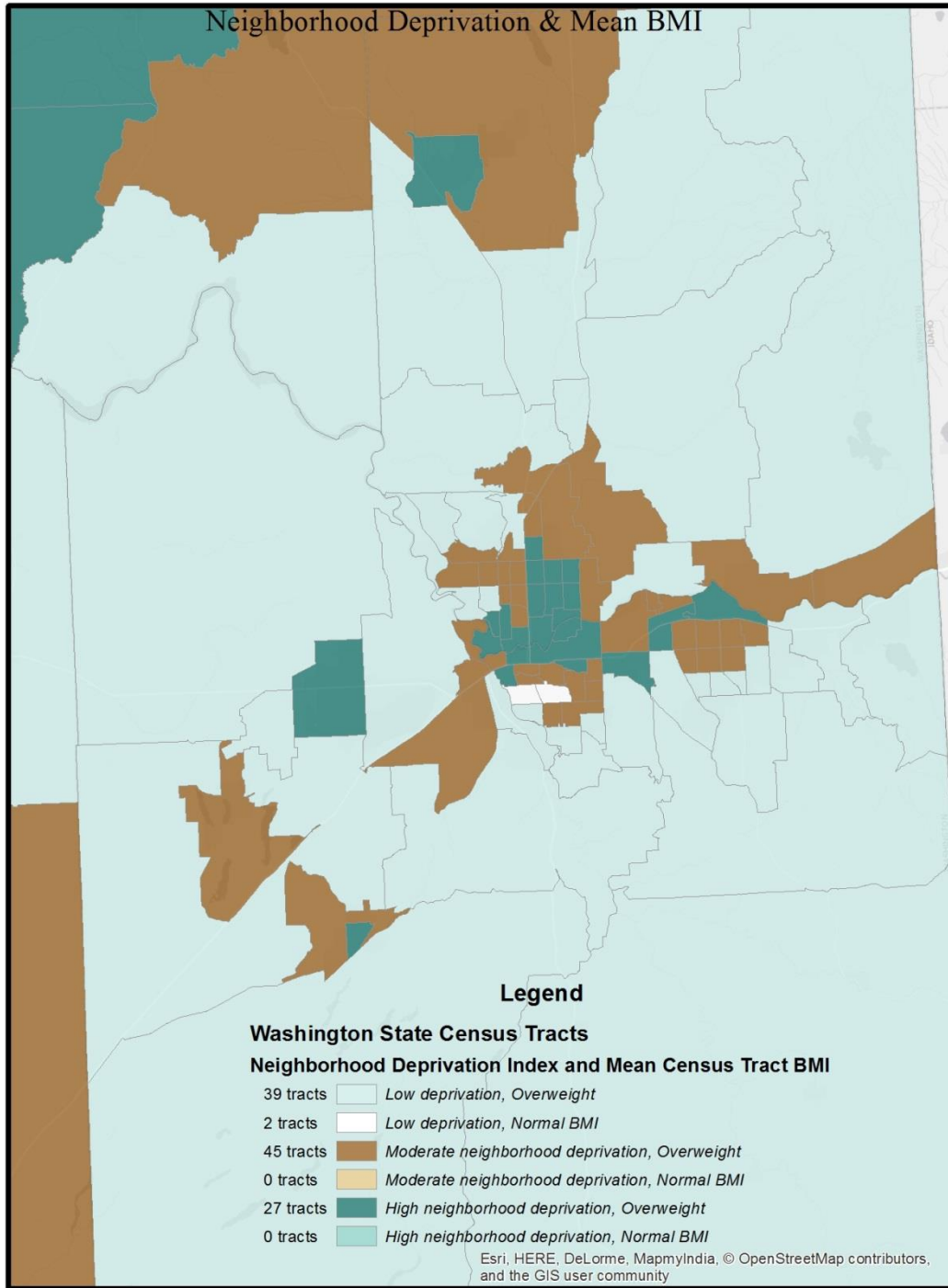


Figure 3: Map of Neighborhood deprivation and BMI in the Spokane region

