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Master of Public Health

Epidemiology

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Bachelor of Science
University of California, Irvine
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An abstract of
a thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
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Abstract

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Previous research done in Lausanne, Switzerland found persistent spatial clusters of high body mass index (BMI) over a 5 year period. Reasons for this spatial dependency of BMI have not been investigated. The spatial distribution of neighborhood destinations (shops, food outlets, open spaces) may be related to BMI. Kernel density estimation (KDE) is a spatial analysis technique that accounts for spatial variation in the density of environmental features. Using KDE, this study investigated the association between living in an area of low density of neighborhood destinations and elevated individual-level BMI. Data comes from the 6,481 individuals from CoLaus study cohort at baseline and 4,460 individuals at follow-up. Destinations were geocoded, and kernel density estimates of destination intensity were created using kernels of 200, 400, 800 and 1200 m. Using multilevel linear regression, the association between destination intensity (classified in quintiles 1(least)–5(most)) and individual BMI was estimated at baseline visit and 5 year follow-up. At baseline, higher density of neighborhood destinations was associated with higher raw and adjusted BMI at the 200m and 800m kernel sizes. However, the opposite effect was observed at the 400m kernel size. In the second wave of data collection five years later, the observed associations at baseline do not hold. These inconclusive results suggest that proximity to parks, open spaces, shops, food outlets and other services may not be a strong predictor BMI in Lausanne. Future research should investigate other neighborhood level factors that can explain spatial dependence of BMI.

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Contents

Introduction

Body mass index (BMI) is an indicator that is used to classify adults as overweight or obese. An elevated BMI is associated with both cause-specific and all-cause mortality (1, 2), as well an increased risk in morbidity of non-communicable disease such as hypertension, diabetes, coronary heart disease, stroke, respiratory problems, and certain types of cancers (3). Over the past three decades, the prevalence of overweight and obesity in Europe has dramatically increased. According to the World Health Organization, over 50% of both men and women are overweight, and approximately 23% of women and 20% of men are obese (4).

There is growing research on the influence of the built and physical environment on elevated BMI (5). The literature on built environments vary in both design and the definition of place. This heterogeneity makes it difficult to evaluate the associations between built neighborhood features and BMI (6). Also of note in the literature is that most research is done in North America, and results are not generalizable to other parts of world. (7)

Most studies look at neighborhood-level contextual effects (e.g. street walkability, number of food establishments in an area, distance to establishments) to observe associations between the built environment and BMI. These types of analyses might use statistical models that assume that individual results are independent from their location; or, if location is used, results may be aggregated into an arbitrary defined space, which can introduce statistical bias. The latter results in the modifiable areal unit problem, or MAUP, where altering the shape of an aggregate unit may alter the value within the unit. (8)

Spatial analysis, or analysis using the geographic location of features of interest, is becoming a popular way to further investigate this relationship. Results from a spatial analysis depend on the physical location of an observation in a user defined spatial frame. Because we are dealing with the concept of neighborhoods, or place, it is appropriate to use spatial analysis to explain patterns of human health and behavior.

This study aims to build on previously published work that gives evidence of spatial dependence of BMI among adults living in the Swiss city Lausanne (9). Though clusters of elevated BMI have been identified, there has not been an investigation of the influence of built neighborhood features on the spatial dependence of elevated BMI. An aspect of the built environment that can be measured is the amount of local destinations that are accessible to individuals. There is evidence that access to these neighborhood destinations is correlated with physical activity, and that physical activity is correlated with BMI (10). A study conducted in a large urban area in Melbourne, Australia found that individuals living in areas of greater neighborhood destination density walk more frequently, and had higher odds of being sufficiently physically active. (11) The presence and the amount of neighborhood destination may be a factor that could partly explain the observed spatial pattern of BMI in Lausanne. The objective of this study is to see if there is an association between living in an area of low density of neighborhood destinations and elevated BMI.

Background and Literature Review

Body mass index as a health measure

Body mass index is a commonly used measurement of weight and nutritional status; a measurement of body weight in kilograms divided by the square of height in meters (kg/m^2). The concept of BMI was conceived by Alphonse Quetelet in 1832 and was originally called the Quetelet Index (12). The Quetelet Index was renamed as the body mass index by Ancel Keys in a 1972 paper in which BMI was presented as an appropriate population measurement that can be used for comparisons between groups, areas, or time (13).

Body mass index is used as a risk indicator of disease. A BMI in the range of 18.0-24.9 is considered normal weight, 25.0-29.9 as overweight or pre-obesity, and anything equal to or greater than 30.0 as obese. These ranges are based on the effect excessive body fat has on disease and death (14). A BMI in the range of overweight or obese is associated with an increased risk in diseases including premature death, cardiovascular diseases, high blood pressure, osteoarthritis, hypertension, some cancers and diabetes (1, 2, 14).

There are arguments for and against BMI being used as an appropriate measure of weight and nutritional status. The main criticism of BMI is that it does not take into consideration different levels of excess body fat based on age, physical activity levels and sex (15). Also, BMI is not a direct measure of body fat, unlike other methods such as skinfold thickness, bioelectrical impedance analysis, X-ray absorptiometry, or underwater weighing. However various studies using alternative methods of directly measuring body fat have been found to be correlated with BMI (15-18). Due to its inexpensiveness, non-invasiveness, and ease to calculate, BMI continues to be a common and acceptable method to measure excess body fat and nutrition.

The built environment and body mass index

There has been an increasing number of papers that focus on the built environment and its influence on BMI. The built environment is defined as the physical parts of where people live and work (e.g., homes, buildings, streets, open spaces, and infrastructure) (19). The three most commonly studied aspects of the built environment in relation to obesity are the physical activity environment (e.g. parks/open spaces, physical activity facilities), land use and transportation environment (e.g. population density, residential density, retail density, public transportation stops, street connectivity) and local food environment (e.g. the distance and density of fast food, supermarkets, grocery store, and commercial food outlets) (6).

The built environment can be divided into two categories: the objective, or the actual, environment and the perceived environment. Thus studies can be further divided into three groups: those in which the exposure is the objective environment, those in which the exposure is the perceived environment, and those in which the researchers look at both.

For the purpose of this study, the scope of the literature review is limited to studies in which the outcome is adult BMI and the exposure is the objective built environment, with focus on the physical activity, land use and transportation, and local food environments.

Physical activity environment

The physical activity environment refers to features of the built environment that promote physical activity, such as parks, trails, fitness centers, schools, and streets (20). The results of studies that investigate the relationship between different examples of the physical activity environment and BMI produce varied results.

When looking at the influence of recreational facilities, there is evidence of a negative correlation between the accessibility of recreational physical activity facilities and BMI (21); a similar relationship was seen between the number of facilities within a park and BMI (22).

A common hypothesis is that the parks and green spaces is associated with a lower BMI. Although there is evidence that support this hypothesis (6), there is also evidence to the contrary. One study showed that a high level of green spaces was associated with an increased relative risk of being overweight of 12 percent and an increased relative risk of being obese of 23 percent in England (23). A study in New Zealand shows that there is no significant difference in the proximity of parks and BMI (24).

There is also evidence that the size of parks and open spaces are a stronger predictor of BMI than just the presence of these spaces. Among persons living in New York City, those who live in close proximity to parks that are greater than 6 acres, on average, have a BMI that approximately 1.7 kg/m^2 lower than those who do not live in close proximity, but this relationship was not significant when looking at park size less than or equal to 6 acres (22).

Land use and transportation environment

A previous systematic review of the literature showed that the two factors of the built environment have a consistent association with weight status: urban sprawl and land use mix (25). Urban sprawl is the rapid urban expansion through a "complex pattern of land use, transportation, and social and economic development" (26). Land use mix is a combination of land use (e.g. residential, commercial, institutional, industrial, recreational, and agricultural) in geographically defined areas (27). What connects these two factors together is urban density, an all-encompassing term that describes population density, residential density, employment density, and other specific measurements of the population in an inhabited area.

Urban sprawl has become synonymous with low density, especially low residential density developments far from economic centers and places of employment. This distance has fostered an automobile dependence and change in health behaviors that has been attributed to elevated BMI. (28, 29) This association has been observed in different countries on separate continents. In the United States, residents of counties that are more sprawling were more likely to be obese, adjusting for demographic and behavioral characteristics. (30, 31). Among residents of metropolitan Sydney, New South Wales, Australia , an interquartile increase in sprawl (based on population density) is associated with a 26% increase in the odds of being overweight and a 47% increase in the odds of being obese, after adjusting for individual and area level socioeconomic factors (32).

Though urban sprawl may be considered a North American phenomenon, it has caused concern in Switzerland. The degree of urban sprawl in Switzerland has increased by 155% between 1935 and 2002 (33). The city of Lausanne, using a measurement of urban sprawl that takes to account the amount of built-up area, the spatial configuration of built-up areas, and the uptake of built-up area per inhabitant or job, is considered to have no urban sprawl (34). However a formal study on the impact of density on adult BMI in Lausanne specifically has not been found during a literature review.

Unlike urban sprawl, land use mix promotes high density development to accommodate the different uses of land. Land-use mix has been found to have the strong association with a BMI greater than or equal to 30 kg/m^2, with a quartile increase in land-use mix being associated with a 12% reduction in the likelihood of obesity across demographic groups (35). Similar associations of high land-use mix and lower BMI has also been observed when using different measurements that quantify land-use mix. (36) These studies, and in fact the majority of studies on land use mix and BMI, are conducted within the United States.

Like urban sprawl, there has not been a formal study found in the literature on the effects of land-use mix on the BMI of adult population in Lausanne. A study done on the regional difference of obesity and physical activity of Swiss children rated the level of land-use mix using a scale from 1 (low mix) to 5 (high mix) in the French speaking region of Switzerland where Lausanne is located as a 3.5. (37). In its master plan of urban development, the city of Lausanne has made it a priority to keep a high level of land-use mix in the city (38). The role of land-use mix on the health of the population may help support the importance of high levels of mixed use as the city continues to grow.

Local food environment

The local food environment can influence food choices and eating patterns. Two aspects of the food environment that are frequently found in the literature related to the built environment are availability and accessibility. Availability refers to the presence of stores, restaurants, and other food outlets in a defined area. Accessibility refers to the location of the food outlet and ease of getting to the location. Most studies in this area are done schools and primarily focuses on children, which is not in scope for this review. The results of studies that focus on the availability and accessibility of the built food environment and BMI in the adult population vary in study design and produced mixed results.

Studies using longitudinal data to estimate these associations are ideal. A review of the literature did not yield results of studies among adults based in Europe. Using longitudinal data from the United States, the neighborhood density of small grocery stores was positively and significantly related to obesity and BMI , and change in BMI in individuals who moved from a rural area to an urban area over a 2-year period were also associated with neighborhood supermarket density, small grocery store density, and full-service restaurant (39). In another U.S. based longitudinal study, evidence was found of 1 km increase in distance between the closest fast-food restaurant was associated with a small but significant decrease in BMI among the Framingham Heart Study cohort over a 30 year period. (40)

Cross-sectional studies have produced equivocal results. A systematic review of the relationship between the local food environment and obesity in the United States and Canada found mainly null results, with more studies finding that: 1) supermarket availability being be negatively associated with obesity than positively, 2) grocery store availability being positively associated with obesity, 3) fast food restaurant availability was more likely to be positively associated with obesity. (41). An international comparison of food environments between Seattle, U.S.A. and Paris, France saw no correlation between physical distance to supermarkets and obesity risk in either city (42).

Physical activity and the built environment

The relationship between the built environment and physical activity has to be considered when examining the relationship between the built environment and body mass index. Physical activity can be considered a mediating variable in the relationship. While there are studies that assess the association between the built environment and BMI, most research is being done on the association between the built environment and physical activity.

In terms of the built physical activity environment, studies focusing on the relationship between distance to green spaces and participation in physical activity give equivocal findings. In the Australian city of Perth, the proximity to public open space was associated with higher levels of walking (43). A comparison of two U.S. cities found no relationship between living within a 5 minute walk from a green space and meeting physical activity guidelines (44). A study on a cohort of adults in an English city of Norwich found no relationship between distance to green spaces and leisure time physical activity (45).

There are also mixed results in studies assessing land use and transportation environment and physical activity. A study across five different European countries found that residents residing in low-density neighborhoods were less physically active than those from high-density neighborhoods (46). On the hand, land use mix and distance to nearest public transport point were found to be not related to physical activity in a study conducted in 14 cities worldwide (47).

There have not been many studies that look at physical activity as a mediating variable in the relationship between the built environment and BMI. Moderate to vigorous physical activity is a mediator between the infrastructure for walking and BMI among African-Americans (48). Physical activity was found to be a mediator of the association between neighborhood walkability and BMI in Belgian adults (49). Physical activity was also found to mediate the association between high residential density and BMI among Nigerian adults. (50) Though not common in the literature, the existing evidence shows that physical activity as a mediator needs to be discussing when studying the built environment and BMI.

Spatial analysis of the built environment and body mass index

There is a growing number of studies that show distinct spatial patterns in BMI, but few examine the spatial relationships between the built environment and BMI. In Seattle, U.S.A., a cluster analysis showed that residential density and fast food outlet density were significantly lower within a two mile radius from where individuals with significantly higher BMI resided; residential density and fast food outlet density were significantly higher within a two mile radius from where individuals with significantly lower BMI resided; and significantly higher density of supermarkets, grocery stores, parks and street intersections were located within a two mile radius from where individuals with significantly lower BMI resided (51) The density of supermarkets, fruit and vegetable markets, and natural food stores within a half mile of an individual was found to be inversely associated with BMI in New York City (52). In urban Melbourne, Australia, participants living in areas of greater density of neighborhood destinations within 1200 meters of residence had lower BMIs (11).

Although there have been spatial analyses done on the relationship between the built environment and body mass index in Europe, this has been done among children (53, 54). There is one study done among adults in a European country that shows an association between the land use patterns and physical activity, though there was no significant difference in BMI (55).

Limitations of the literature

The equivocal results of the literature can be attributed to a number of factors. The most consistent aspect of the literature is the inconsistency of the measurement of the built environment. According to reviews of the built environment, the variability in the definition of "place" across studies made it impossible to perform a pooled analysis. (6, 7) The inability to compare results across studies contributes the uncertainty of the true relationship between the built environment and BMI.

Another factor is confounding. Confounding is the situation in which the association between an exposure and outcome is distorted by the presence of another variable. In regards to studies looking at neighborhood or small area effects, results are subject to structural confounding, or confounding resulting from socioeconomic processes that drive specific people to specific types of neighborhoods, which may confound the association under study. (56-60)

Another issue related to confounding is selection bias. People that are clustered within neighborhoods have similar social interaction and common exposures that differ from the people living in other neighborhoods and may produce different results than if people were randomly distributed across neighborhoods. (56) A criticism of the literature is that studies do not include controls in their models for selection bias, resulting in uncertain correlation estimates between neighborhood characteristics and the individual outcome. (61)

As mentioned in the introduction, analyses common in the literature use statistical models that assume independence among individuals even when they live in the same neighborhood; or, if location is used, data that are aggregated into an arbitrary defined space, which can introduce statistical bias. Measuring contextual factors across continuous space would be a method to account for spatial variation in health outcomes and reduce the bias introduced by traditional analytical methods. Chaix and collaborators have shown that using such spatial methods produce more information on neighborhood risk factor effects than traditional multilevel models. (62,63) Spatial analysis, though not widespread in the literature, could provide less biased estimates that describe the relationship between the built environment and BMI.

Summary of Literature Review

There is more research being done on the relationship between the built environment and body mass index. The results of these studies have not provided a clear consensus on the nature of the relationship. This type of research has mainly been done in North America and Australia, making it difficult to generalize results to other geographical areas. Also, most research has been done on children and school environments, which cannot be generalized to adults and residential neighborhoods. Issues with measurement error, confounding, and selection bias affect the results of these studies and contributes to the inconsistency of estimates of the true relationship between the built environment and BMI. Spatial analysis of the built environment and BMI may offer an alternative way to investigate the relationship that may minimize bias seen in the literature. Spatial analysis of the relationship between the built environment and body mass index have given insightful results, but are not common in the existing literature.

Methods

Data Sources

The analysis was based on data collected by CoLaus baseline and follow-up studies, the Swiss Federal Statistical Office and the Swiss Federal Office of Transport.

CoLaus and GeoCoLaus study

The CoLaus study was cohort study aimed to assess the prevalence and determinants of cardiovascular disease in the Caucasian population of Lausanne, Switzerland. (64) Lausanne is located in southwestern Switzerland with a population of 126,700 persons in 2003 and a population of 143,561 persons at the end of 2016. (65) The baseline study included 6,733 participants between the ages 35 and 75 and took place between the years 2003 and 2006. Of the participants who took part of the baseline study, 5,064 of them took part in the follow up study which took place between 2009 and 2012.

At baseline and follow-up, participants attended a study visit, which consisted of an interview and a physical examination. Weight and height were measured by healthcare professionals and BMI was calculated as weight divided by height squared (kg/m^2). Individual-level variables that were collected include self-reported information on age, sex, education level, ethnicity, marital status, receiving government benefits, physical activity, smoking status and alcohol consumption.

The GeoCoLaus study was a separate project using data collected by the CoLaus study. The aim of the GeoCoLaus study was to determine if there was spatial dependence (tendency of a variable measured in locations in close proximity to be related) of BMI over a five year period among the Lausanne adult population. (9) The postal address of CoLaus participants living in the urban areas of the city were converted to geographical coordinates through geocoding. Additionally, the GeoCoLaus study used income data from the 2009 Lausanne Census to assess the relationship between BMI and neighborhood income level.

Neighborhood destination data

Data on Swiss businesses is collected by the Federal Business Census, which is administered by the Federal Statistical Office every three years. The census is a full survey of the workplaces and enterprises of the manufacturing and service industries. This compulsory survey includes questions on the location of business, economic activity, number of employees and gender. The Geoiformation Division of the Federal Statistical Office (GEOSTAT) provides spatial data from the Business Census and other federal statistics. This data is publicly available through the GEOSTAT website (66).

The Federal Office of Transportation is the federal authority responsible for public transportation. Among its responsibilities is the collection and management of spatial data of public transportation, including public transport stops in Switzerland. This data is publicly available through the Office website. (67)

Ethics statement

The CoLaus Study was approved by the Institutional Ethics Committee of the University of Lausanne. (64) This study was reviewed by Emory University's Institutional Review Board and met the criteria for an exempt review (Appendix 3).

Variables

Outcome variable: body mass index

This analysis used BMI variables that were produced by the GeoColaus study (9). These include the raw BMI that was measured and calculated by the CoLaus study staff and estimates of BMI that were adjusted for socioeconomic and demographic variables by the GeoCoLaus study. The raw and adjusted BMI variables were used as the outcome variables for this analysis. A list of these BMI variables used in this analysis can be found in Appendix 1.

Exposure variable: destinations

Destinations were chosen based on previous studies that used places people may use active travel to access in their neighborhood. (10, 11) Examples of destinations included in the analysis are: educational facilities, food outlets, transport stops and stations, supermarkets, parks, sports facilities, art and culture establishments, and community resources. Data on destinations were abstracted at two time points: the year 2005 (middle of the baseline enrollment period) and the year 2008 (latest available year; used for analysis of follow-up data). Parks and large open spaces were geocoded at the center. Appendix 2 provides details of the destination types. All destinations were combined and merged into a single layer using ArcGIS 10.3. (68)

Deriving Kernel density estimations for destinations

Kernel density estimation (KDE) was used to calculate the density of destinations in the neighborhoods where participants live. The first step of the KDE process is starting with a continuous map surface that is divided into a grid of cells. What the KDE process does is that it applies a series of probability density functions called kernels to each point feature of interest (here destination), creating a continuous map of feature density. (69) Using the equation stated by Fortmann-Roe, Starfield and Getz, assuming a sample of n points $\mathbf{X}=\{X1,\ldots, Xn\}$ drawn from an unknown, univariate probability density function f, the kernel density estimate $\hat{f}$ of f is

$$\hat{f}(x|h) \equiv \frac{1}{n}\sum_{i=1}^{n}\frac{1}{h}K\left(\frac{x-X_i}{h}\right), \quad \text{(Eq.1)}$$

where K is a kernel function set by the user and h is the bandwidth, or smoothing parameter, set by user. (70) The radius of each kernel is set to a distance representing the area of effect of the point of interest. Each cell on the map is assigned a kernel density estimate in which cells that are closer to a kernel receive higher estimates and cells further from the kernel receive lower estimates. The smoothing parameter adds estimates of overlapping kernels for each cell (69), producing a smoothed local summary of neighborhood destinations.

The kernel density estimates were extracted using the 'extract values to points' command in the Spatial Analyst toolbox in ArcGIS. Extracted estimates were assigned to each participant's household location based on the output cell in which they resided. The number of destinations at a location was used as a weighting factor, so a building with more destinations has higher influence in the surrounding area. The values of kernel density estimates indicate the proximity and density of destinations in relation to the participant location. Kernel density estimates were calculated using kernel sizes of 200, 400, 800 and 1200 m. Because physical activity can be considered a mediating variable in the observed relationship between destinations and BMI, bandwidth distance were chosen to reflect distances that individuals are willing to walk. The distances of 200 m and 400m were used because it captures the immediate environment and serves as a proxy for high land use mix that the city of Lausanne has planned for future development. (38) Distances of 800 and 1200 m were used as they represent the distance that the average person could walk in 10 and 15 minutes, respectively.

Constructing exposure variable

Kernel density estimates were categorized into quintiles (quintile 1 representing areas of least intensely distributed destinations, and quintile 5 representing areas of most intensely distributed destinations). The use of quintiles as the exposure variable is based on previous studies using quintiles to model the distribution of destinations. (10, 11, 52, 71) Quintiles groups were created using proc rank statement on SAS 9.4 software (72).

Statistical analysis

All statistical analysis analyses were conducted in SAS 9.4 software. (72) Ten baseline participants and six follow-up participants were excluded from analysis because of missing kernel density estimates. The referent category for the exposure was quintile 1 (Q1, lowest destination clustering). Multilevel linear regression was performed using a mixed-effects model (with statistical sector (neighborhood) at level 2 and participants at level 1) to estimate the associations between each of the BMI variables and the four kernel density measures (200, 400, 800 and 1200 m). The mixed-effects model is as follows:

$$Y_{ij} = \beta_{0j} + \beta_{ij}X_{ij} + \varepsilon_{ij} \qquad \text{(Eq. 2)}$$

where:

Y_{ij} is the BMI for the ith observation in jth statistical sector;

X_{ij} is the Level 1 predictor (KDE);

β_{0j} is the intercept at the jth statistical sector;

β_{1j} is slope for the relationship in statistical sector j between KDE and BMI; and

ε_{ij} is the random error term.

For this analysis, the β coefficients will be reported. Sector-level variance and intraclass correlation coefficients (ICC) will also be reported to measure the degree of correlation among participants within the same statistical sector.

Results

Descriptive statistics

Characteristics of participants were reported by Joost et al and presented in Table 1. In summary, women made up 53% of baseline participants and 54% of follow-up participants. The mean age (±SD) of participants included at baseline and at follow-up was 52.6±10.7 and 58.1±10.5 years, respectively. The mean BMI (±SD) was 25.8±4.5 (median=25.2) and 26.2±4.6 (median=25.6) kg/m^2 at baseline and follow-up, respectively. The median annual income level at baseline was CHF 50,882 (1 CHF= US $1.69, December 2004) and CHF 51,139 (1 CHF= US $1.07, December 2010) at follow-up.

Multilevel analysis of kernel density estimation

Due to the differences in BMI variables between baseline and follow-up, only two variables were used as the dependent variable for this analysis: raw BMI and BMI previously adjusted by GeoCoLaus researchers for individual socio-economic factors (age, sex, education level, ethnicity, marital status, receiving government benefits, and physical activity) and sector-level median income. These two variables were chosen because they were the two that were calculated for both waves by the GeoCoLaus Study.

Baseline

The increasing density of neighborhood destinations was associated with increasing raw and adjusted BMI at the 200m and 800m kernel sizes. This association is statistically significant at 200m for quintile 2 compared to quintile 1 (Raw BMI: Quintile 2 β=0.61 kg/m^2, 95% CI: 0.24, 0.97; Adjusted BMI: Quintile 2 β=0.50 kg/m^2, 95% CI: 0.13, 0.86) (Table 2).

At the 400m kernel size, increasing density was associated with decreasing adjusted BMI. There was no evidence that the decrease in BMI was significant at the 5% significance level (Table 2).

There was no association between kernel density estimates and raw BMI for the 400m and kernel density estimates and raw and adjusted BMI at the 1200m kernel size.

For the model with raw BMI as the outcome, the ICC was .02 for 200m and .03 for the 400m, 800m, and 1200m kernel size. The ICC for the model with adjusted BMI was zero for all but the 1200 m kernel size, where ICC=0.01. (Table 2)

Follow-up

At 200m and 400m, there is an association between increasing raw BMI and increasing density of neighborhood destinations. This association is significant at 200m kernel size when comparing Quintile 4 to Quintile 1 (Quintile 4 β= 0.54 kg/m^2, 95% CI: 0.05, 1.04). This association does not hold when evaluating the relationship between adjusted BMI and neighborhood destination density quintiles. There is no association between raw BMI and the density of neighborhood destinations at the 800m and 1200 m kernel size. (Table 3)

At the 800m kernel size, increasing density was associated with decreasing adjusted BMI. There was no evidence that the decrease in BMI was significant at the 5% significance level. (Table 3) There was no association between neighborhood destination density and adjusted BMI at the 200, 400, and 1200m kernel sizes.

For the model with raw BMI as the outcome, the ICC was .02 at all kernel sizes. The ICC for the model with adjusted BMI was zero at all kernel size. (Table 3)

Sensitivity analysis

To determine how different values of the exposure variable might impact the outcome variable, a sensitivity analysis was performed with the exposure variable (KDE) modeled as a continuous variable. These estimates gave evidence of no significant association between exposure and outcome. The ICCs remained substantively unchanged. Results from these sensitivity analyses are reported in Tables 4-5.

Discussion

The results of this study do not give evidence to support the original hypothesis of an association between decreasing neighborhood destination density and increasing BMI. At the 200m and 800 m kernel size, results of baseline show an association between increasing neighborhood destination density and increasing BMI adjusted for socio-economic factors. However the opposite effect is observed at the 400m kernel size. In the second wave of data collection five years later, the observed associations at baseline do not hold. At follow-up, decreasing BMI and increasing density is seen a larger kernel size. These inconclusive results suggest that proximity to parks, open spaces, shops, food outlets and other services do not influence BMI as seen in previous studies (10, 11).

Further evidence of no association between BMI and neighborhood destination density is inconsistency of the direction of effect estimations over time. The use of two waves of data for this analysis was to investigate, given an association, whether there may be a possible cause-effect relationship between destination density and BMI. There is a preference to use longitudinal data to estimate causal effects. (73, 74) Given the longitudinal nature of this dataset, it is possible to further examine and estimate causal effects of other neighborhood level factors and BMI in Lausanne in future studies.

The random-effects model produced ICCs that were close to or equal to zero. This indicates that the variability of observations within sectors are independent from the variability of observations from different sectors. Because the independence assumption is met, it is possible to use simpler regression methods to estimate effects. However, because the data have a spatial component, spatial regression models should be considered as an alternative method of analysis. A suggested spatial regression model is Geographically Weighted Regression (GWR).

Briefly, GWR fits a regression model that uses the dependent and predictor variables that fall within a user defined bandwidth to every feature in the dataset. (75) This model is recommended because different distances can be used to calculate estimates, which in turn can give more insight on what distances can neighborhood level factors can affect the individual.

The risk factors for weight gain are varied and spread across biological, behavioral, and environmental domains. This complexity makes it difficult to identify specific factors for analysis. The aim of this analysis was to specifically see the extent of the influence of the built environment on BMI. Density of neighborhood destinations was chosen as the exposure variable because it has been shown that individuals living within areas of greater destination density walked more frequently, and had higher odds of being sufficiently physically active. (10) There are other aspects of the built environment that were not considered in this analysis that may influence the relationship in question. Features of the built environment that have been found to affect health outcomes include street connectivity (76), air pollution (77), and environmental noise (78), to name a few. Recommendations for future studies include see how the relationship physical activity is mediated by these neighborhood environmental factors.

Overall, this study presents evidence that there are much stronger predictors of BMI than neighborhood destination density and further research is needed to understand the mechanisms behind known spatial clusters of elevated BMI in Lausanne.

Strengths and Limitations

A strength of this study is that the exposure variable was created to be specific to each individual, rather than creating neighborhood exposures based on aggregate units of analysis. This method eliminates MAUP and produces more precise estimates.

Another strength of this study is that a comprehensive and diverse list of commercial and noncommercial destinations was used. Many studies in the literature have used kernel density estimations to examine relationships to specific environmental aspects such as park access (80), health resources (81) and the food environment. (52, 79, 82) The issue with that is that not everyone would go to those specific destinations. This study used a wider range of destinations to capture all the type of establishments that someone would use and better describes their local environment.

The data collection methods deployed by the CoLaus Study is another strength of this study. Other studies with a similar study design (10, 11) used self-reported BMI, which is subject to measurement bias. An advantage of this study is the use of measured weight and height to calculate an unbiased BMI estimate. However, the sampling for the CoLaus Study intended to recruit a representative sample of the Lausanne adult population, it is still possible that the study participants are different for non-participants, introducing participation bias.

One limitation of this study is that all participants in this study were adults, so the extent to which the results can be generalized to other populations (e.g. children, the elderly) is limited.

Another limitation is that this study only considered the home environment. Other environments, such as work and social environments may have important influences on overweight and obesity.

One final limitation to note is that individual income was not available for analysis. Individual income may have a different effect on BMI than sector-level income.

Conclusion

To the best of the author's knowledge, this is the first study that uses kernel density estimation to understand the influence of an aspect of the built environment (in this study, neighborhood destinations) and BMI in Switzerland. The analysis produced inconclusive results for both baseline and follow-up studies. The results suggest that neighborhood destination density is not an important predictor variable when investigating the association between BMI and the built environment. Future research is needed to both explain this relationship and to evaluate other possible factors for the observed clusters of BMI in Lausanne.

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Table 1. Characteristics of Sample Population

	Participants included in analysis of BMI clusters at baseline
N	6,481
Age, mean (SD), years	52.6 (10.7)
BMI, mean (SD), kg/m^2	25.8 (4.5)
Women, %	52.7
Education level, %	
Obligatory school	20.9
Apprenticeship	35.2
University entrance	11
University degree	20
Higher degree	12.9
Marital status, %	
living alone	33.4
living in couple	66.6
Social aid, %	24.6
Physical Activity*, %	
Never	35.8
Once a week	9.5
Twice a week	52.1
>= 3 times per week	1.3
Caucasian, %	91.8
Smoking, %	
former smoker	32.5
never smoker	40.4
Smoker	27.1
Current alcohol consumption, %	77.5

Table 2. Multilevel linear regression: Estimates of β coefficients for association between destination intensity and BMI at baseline.

		β coefficient estimates for change in BMI	
Kernel distance	**Quintile of the density of destinations in sector**	**Raw BMI † (95% CI)**	**Adjusted BMI‡ (95% CI)**
200 m	*Quintile 1*	Referent	Referent
	Quintile 2	0.61 (0.24, 0.97)*	0.50 (0.13, 0.86)*
	Quintile 3	0.11 (-0.28, 0.49)	0.07(-0.03,0.44)
	Quintile 4	0.27 (-0.14, 0.67)	0.22 (-0.15, 0.60)
	Quintile 5	0.40 (-0.07, 0.86)	0.32 (-0.08, 0.72)
	Sector-level variance	20.05	20.95
	ICC	0.02	0.00
400 m	*Quintile 1*	Referent	Referent
	Quintile 2	0.01 (-0.39, 0.39)	-0.09 (-0.46, 0.29)
	Quintile 3	0.10 (-0.32, 0.52)	-0.03 (-0.41, 0.29)
	Quintile 4	0.12 (-0.36, 0.59)	-0.02 (-0.42, 0.39)
	Quintile 5	-0.24 (-0.75, 0.28)	-0.14 (-0.55, 0.27)
	Sector-level variance	20.07	20.97
	ICC	0.03	0.00
800 m	*Quintile 1*	Referent	Referent
	Quintile 2	0.42 (-0.02, 0.85)	0.25 (-0.14, 0.64)
	Quintile 3	0.43 (-0.05, 0.92)	0.17 (-0.24, 0.57)
	Quintile 4	0.31 (-0.21, 0.83)	0.08 (-0.33, 0.50)
	Quintile 5	0.05 (-0.49, 0.58)	0.03 (-0.39, 0.44)
	Sector-level variance	20.06	20.97
	ICC	0.03	0.00
1200 m	*Quintile 1*	Referent	Referent
	Quintile 2	0.38 (-0.07, 0.83)	0.24 (0.16, 0.64)
	Quintile 3	0.49 (-0.01, 1.00)	0.23 (-0.19, 0.64)
	Quintile 4	0.22 (-0.31, 0.75)	0.14 (-0.28, 0.56)
	Quintile 5	-0.15 (-0.70, 0.40)	-0.09 (-0.51, 0.33)
	Sector-level variance	20.05	20.96
	ICC	0.03	0.01

† Outcome Variable is an unadjusted measure of BMI

‡ Outcome variable is BMI adjusted for age, sex, ethnicity, marital status, government benefits, physical activity, and statistical sector median income

*$p<0.05$

Table 3. Multilevel linear regression: Estimates of β coefficients for association between destination intensity and BMI at follow-up.

Kernel Distance	Quintile of the density of destinations in sector	β coefficient estimates for change in BMI: Raw BMI † (95% CI)	Adjusted BMI‡ (95% CI)
200m	*Quintile 1*	Referent	Referent
	Quintile 2	0.43 (-0.03, 0.88)	0.26 (-0.18, 0.69)
	Quintile 3	0.07 (-0.41, 0.55)	-0.23 (-0.67, 0.21)
	Quintile 4	0.54 (0.05, 1.04)*	0.31 (-0.13, 0.75)
	Quintile 5	0.43 (-0.11, 0.98)	0.22 (-0.23, 0.66)
	Sector-level variance	21.33	21.14
	ICC	0.02	0.00
400m	*Quintile 1*	Referent	Referent
	Quintile 2	0.25 (-0.24, 0.73)	0.04 (-0.41, 0.48)
	Quintile 3	0.20 (-0.32, 0.72)	-0.03 (-0.48, 0.42)
	Quintile 4	0.33 (-0.22, 0.90)	0.05 (-0.41, 0.51)
	Quintile 5	0.06 (-0.53, 0.65)	-0.01 (-0.47, 0.45)
	Sector-level variance	21.34	21.16
	ICC	0.02	0.00
800m	*Quintile 1*	Referent	Referent
	Quintile 2	-0.20 (-0.71, 0.32)	-0.18 (-0.63, 0.27)
	Quintile 3	-0.10 (-0.67, 0.46)	-0.08 (-0.55, 0.38)
	Quintile 4	0.05 (-0.54, 0.64)	-0.09 (-0.56, 0.37)
	Quintile 5	-0.01 (-0.61, 0.59)	-0.01 (-0.48, 0.45)
	Sector-level variance	21.35	21.16
	ICC	0.02	0.00
1200m	*Quintile 1*	Referent	Referent
	Quintile 2	0.26 (-0.23, 0.82)	0.24 (-0.22, 0.69)
	Quintile 3	0.29 (-0.23, 0.95)	0.13 (-0.34, 0.59)
	Quintile 4	0.14 (-0.47, 0.75)	0.08 (-0.39, 0.55)
	Quintile 5	-0.18 (-0.80, 0.44)	-0.13 (-0.59, 0.35)
	Sector-level variance	21.32	21.15
	ICC	0.02	0.00

† Outcome Variable is an unadjusted measure of BMI

‡ Outcome variable is BMI adjusted for age, sex, ethnicity, marital status, government benefits, physical activity, and statistical sector median income

*$p<0.05$

Table 4. Results for sensitivity analysis at baseline.

Kernel distance		β coefficient estimates: Raw BMI † (95 % CI)	β coefficient estimates: Adjusted BMI‡ (95% CI)
200 m	*Intercept*	25.89 (25.62, 26.15)	25.85 (25.66, 26.03)
	Change in BMI for one unit change in Kernel Density Estimate	-95.16 (-443.59, 253.26)	-123.29 (-400.92, 154.35)
	Sector- level variance	20.07	20.97
	ICC	0.03	0.00
400 m	*Intercept*	25.95 (25.66, 26.23)	25.88 (25.69, 26.08)
	Change in BMI for one unit change in Kernel Density Estimate	-243.12 (-673.36, 187.11)	-217.99 (-543.55, 107.56)
	Sector- level variance	20.07	20.97
	ICC	0.03	0.00
800 m	*Intercept*	25.97 (25.67, 26.28)	25.89 (25.68, 26.10)
	Change in BMI for one unit change in Kernel Density Estimate	-320. 73 (-847.34, 205.87)	-249.62 (-638.02, 138.78)
	Sector- level variance	20.07	20.97
	ICC	0.03	0.00
1200 m	*Intercept*	26.06 (25.73, 26.38)	25.92 (25.70, 26.14)
	Change in BMI for one unit change in Kernel Density Estimate	-562.35 (-1204.00, 79.29)	-342.36 (-805.92, 121.21)
	Sector- level variance	20.06	20.97

ICC	0.03	0.00

† Outcome Variable is an unadjusted measure of BMI
‡ Outcome variable is BMI adjusted for age, sex, ethnicity, marital status, government benefits, physical activity, and statistical sector median income
*p<0.05

Table 5. Results for sensitivity analysis at follow-up.

		β coefficient estimates	
Kernel distance		**Raw BMI †** **(95% CI)**	**Adjusted BMI‡** **(95% CI)**
200 m	*Intercept*	26.28 (25.98, 26.57)	26.27 (26.06, 26.47)
	Change in BMI for one unit change in Kernel Density Estimate	6.4 (-384.92, 397.73)	-46.00 (-354.00, 262.01)
	Sector- level variance	21.34	21.15
	ICC	0.02	0.00
400 m	*Intercept*	26.37 (26.05, 26.68)	26.31 (26.10, 26.53)
	Change in BMI for one unit change in Kernel Density Estimate	-189.05 (-653.22, 275.13)	-159.48 (509.44, 190.49)
	Sector- level variance	21.34	21.15
	ICC	0.02	0.00
800 m	*Intercept*	26.48 (25.81, 27.15)	26.44 (25.95, 26.92)
	Change in BMI for one unit change in Kernel Density Estimate	-2583.59 (-10591.00, 5423.44)	-2471.53 (-8318.80, 3375.75)
	Sector- level variance	21.34	21.15
	ICC	0.02	0.00
1200 m	*Intercept*	26.47 (26.11, 26.83)	26.37 (26.13, 26.62)
	Change in BMI for one unit change in Kernel Density Estimate	-460.31(-1127.12, 306.51)	-322.48 (-801.21, 156.25)
	Sector- level variance	21.33	21.15
	ICC	0.02	0.00

† Outcome Variable is an unadjusted measure of BMI
‡ Outcome variable is BMI adjusted for age, sex, ethnicity, marital status, government benefits, physical activity, and statistical sector median income
*$p<0.05$

Figure 1. Raster representation of kernel density estimates of baseline destination distribution using 200 m kernels, Lausanne, 2003.

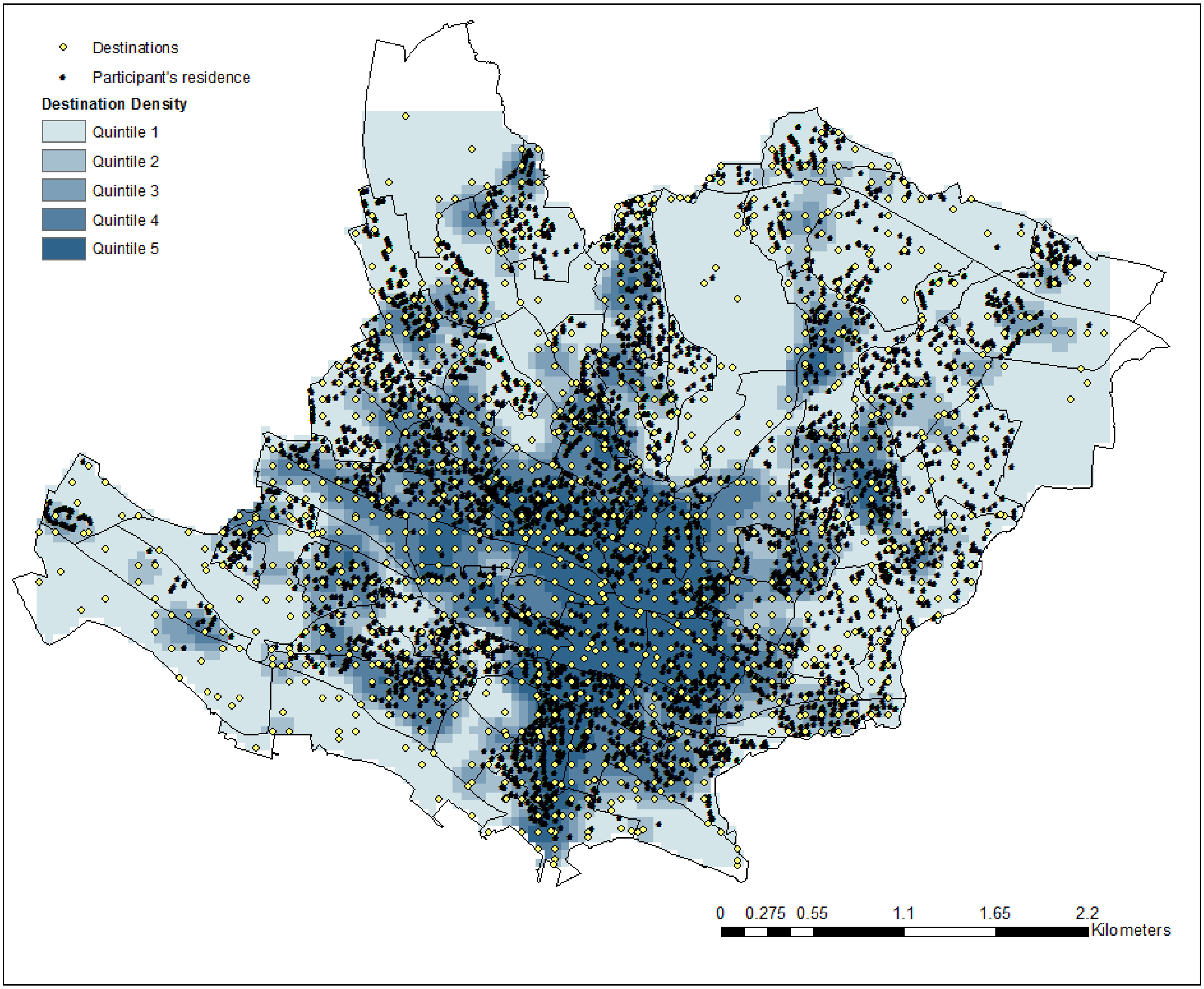


Figure 2. Raster representation of kernel density estimates of follow-up destination distribution using 200 m kernels, Lausanne 2005.

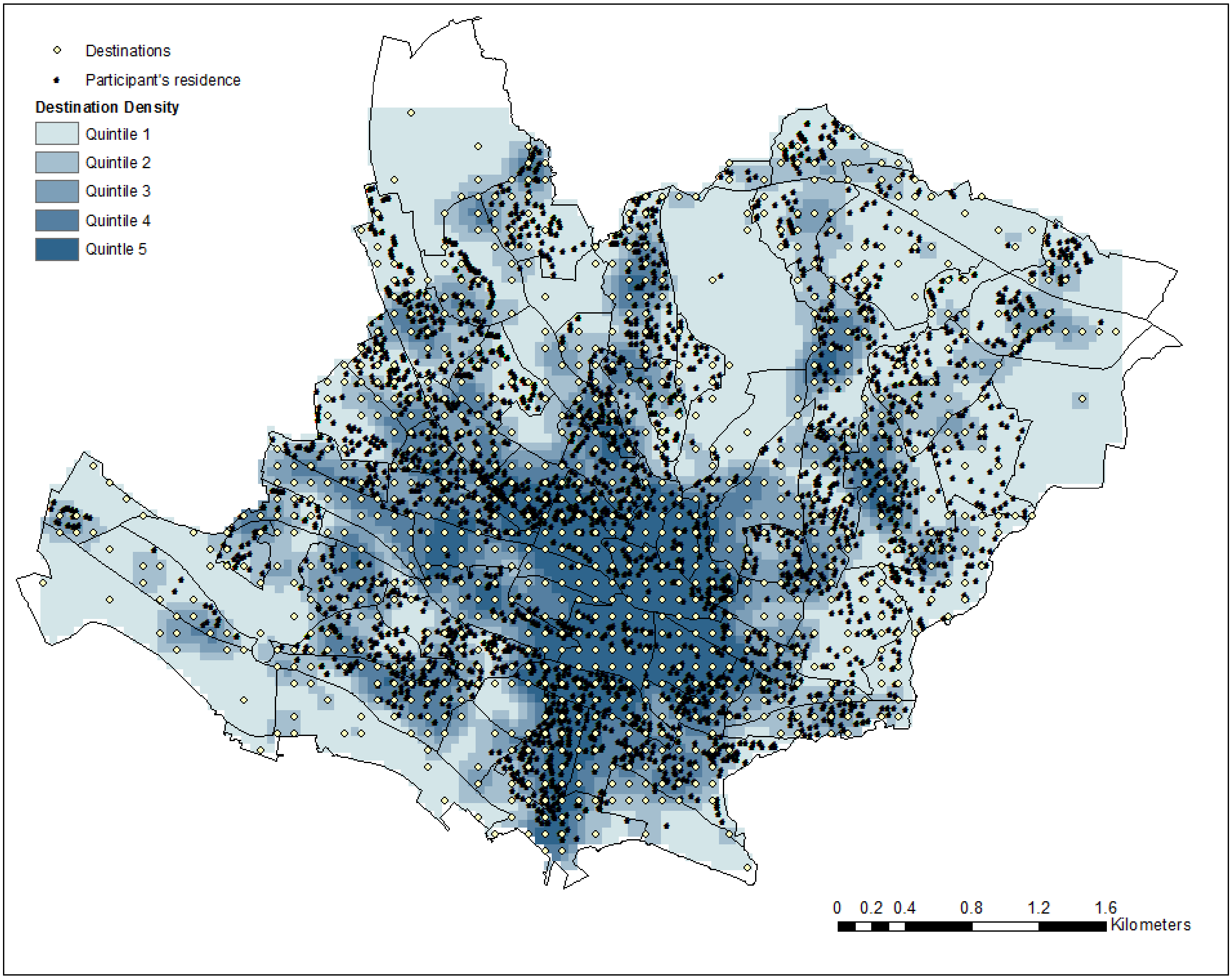


Figure 3. Raster representation of kernel density estimates of baseline destination distribution using 400 m kernels, Lausanne 2003.

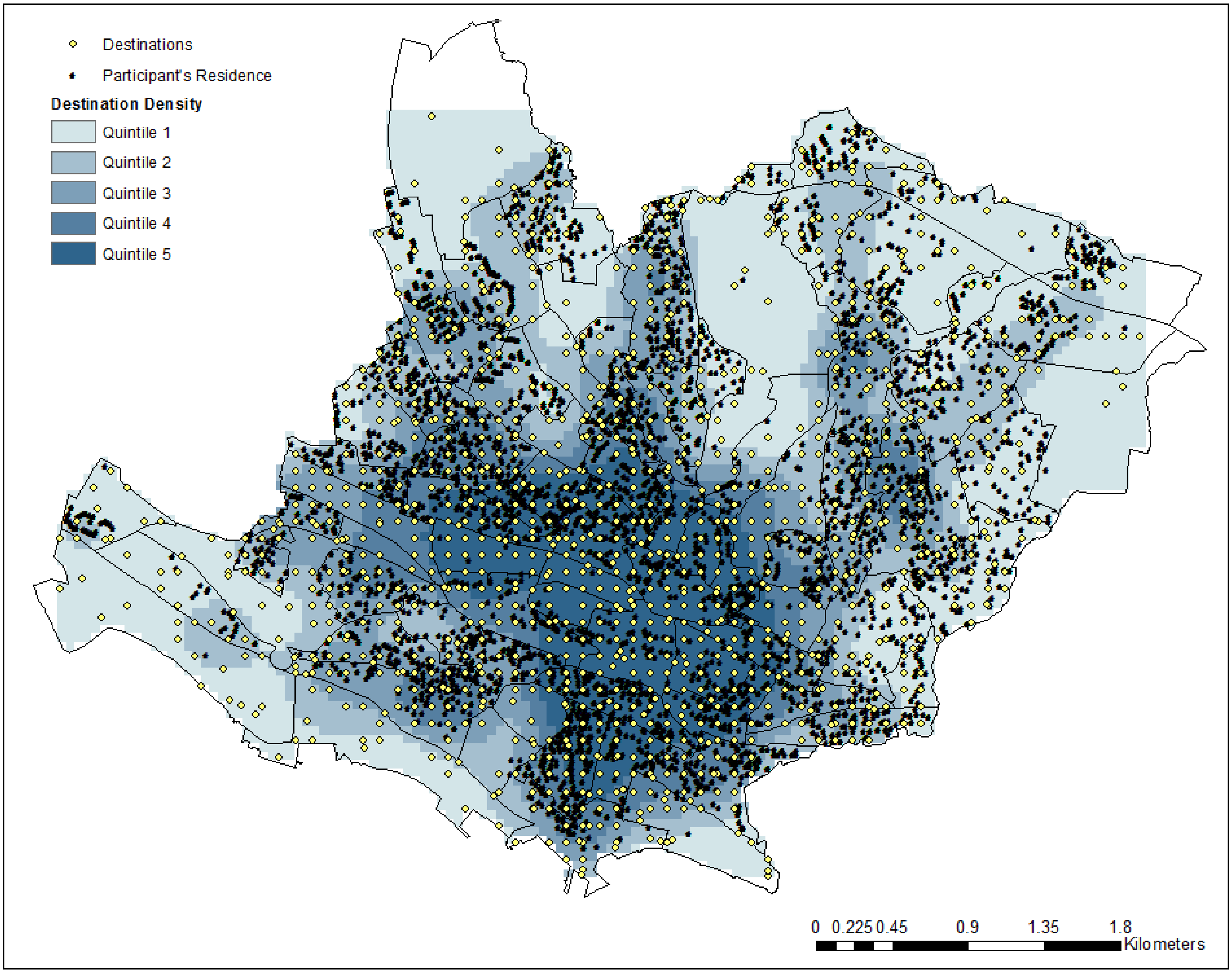


Figure 4. Raster representation of kernel density estimates of follow-up destination distribution using 400 m kernels, Lausanne 2005.

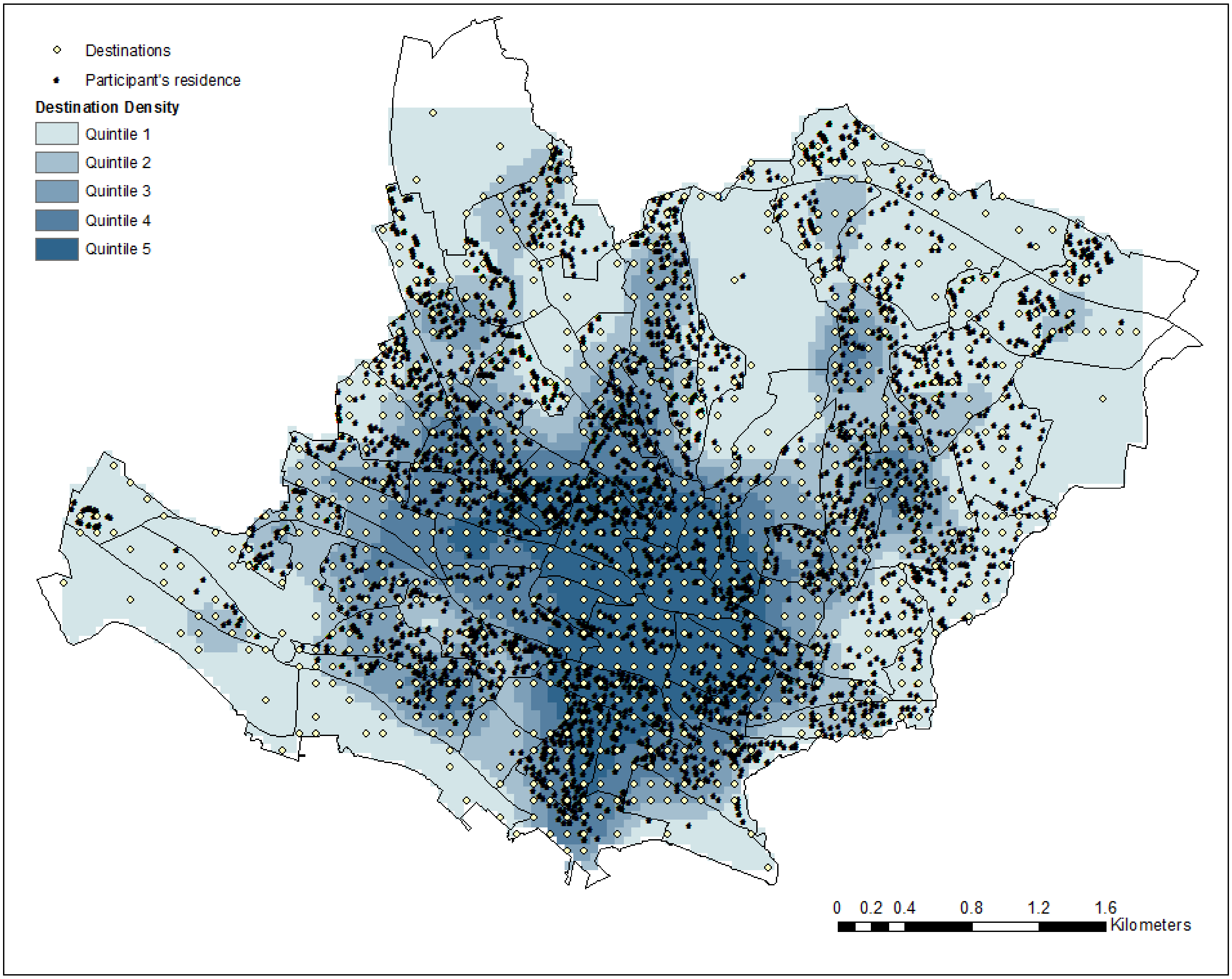


Figure 5. Raster representation of kernel density estimates of baseline destination distribution using 800 m kernels, Lausanne 2003.

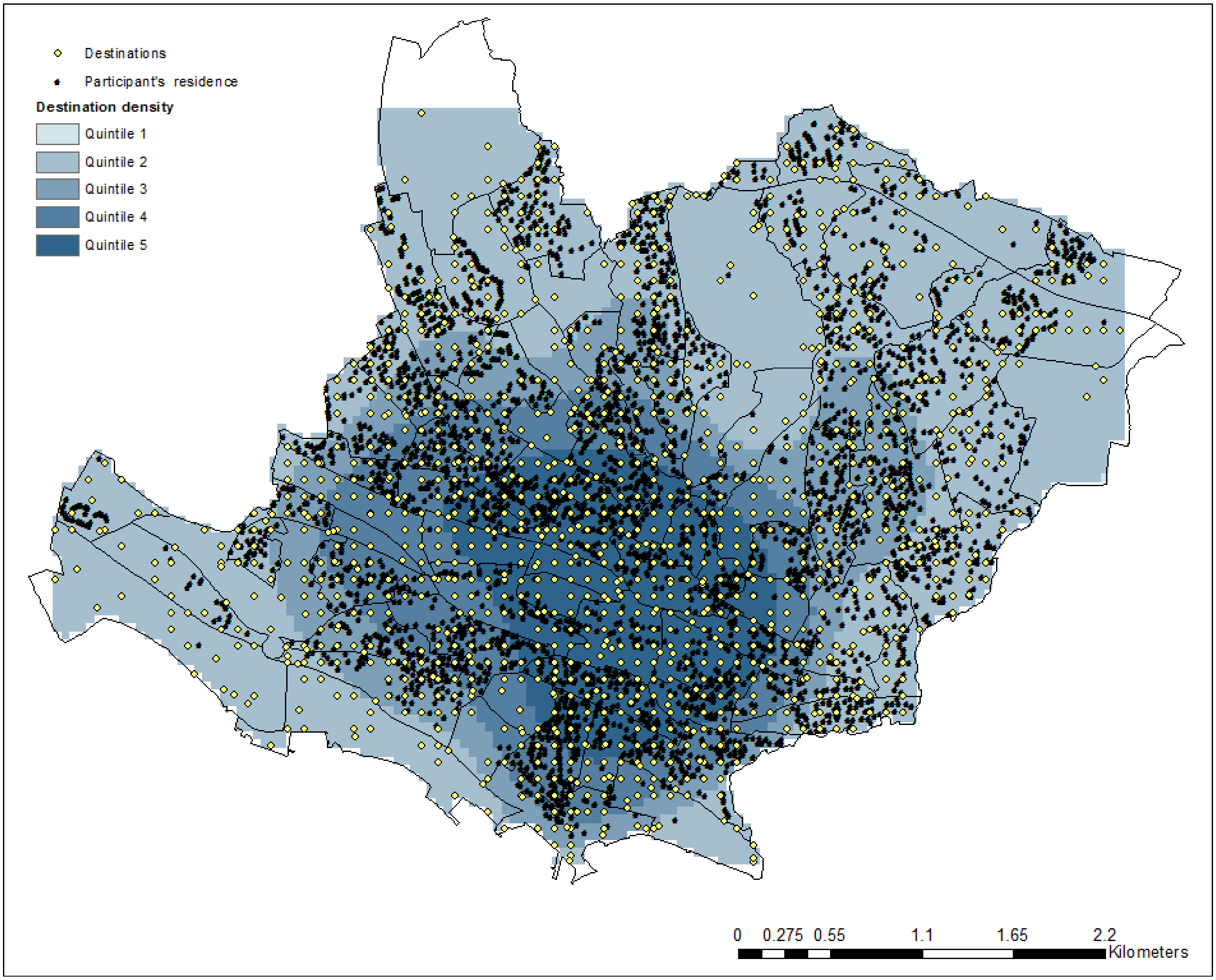


Figure 6. Raster representation of kernel density estimates of follow-up destination distribution using 800 m kernels, Lausanne 2005.

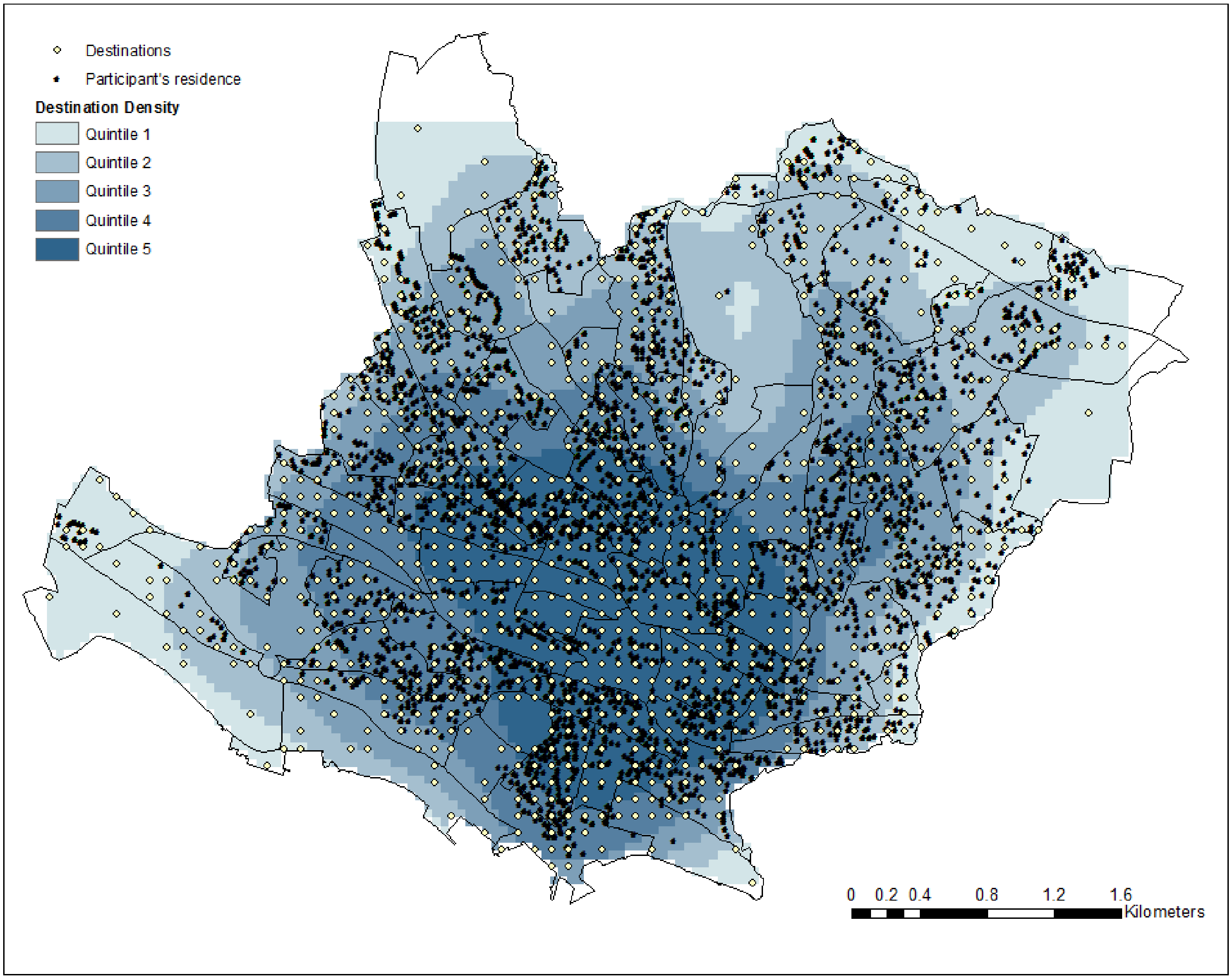


Figure 7. Raster representation of kernel density estimates of baseline destination distribution using 1200 m kernels, Lausanne 2003.

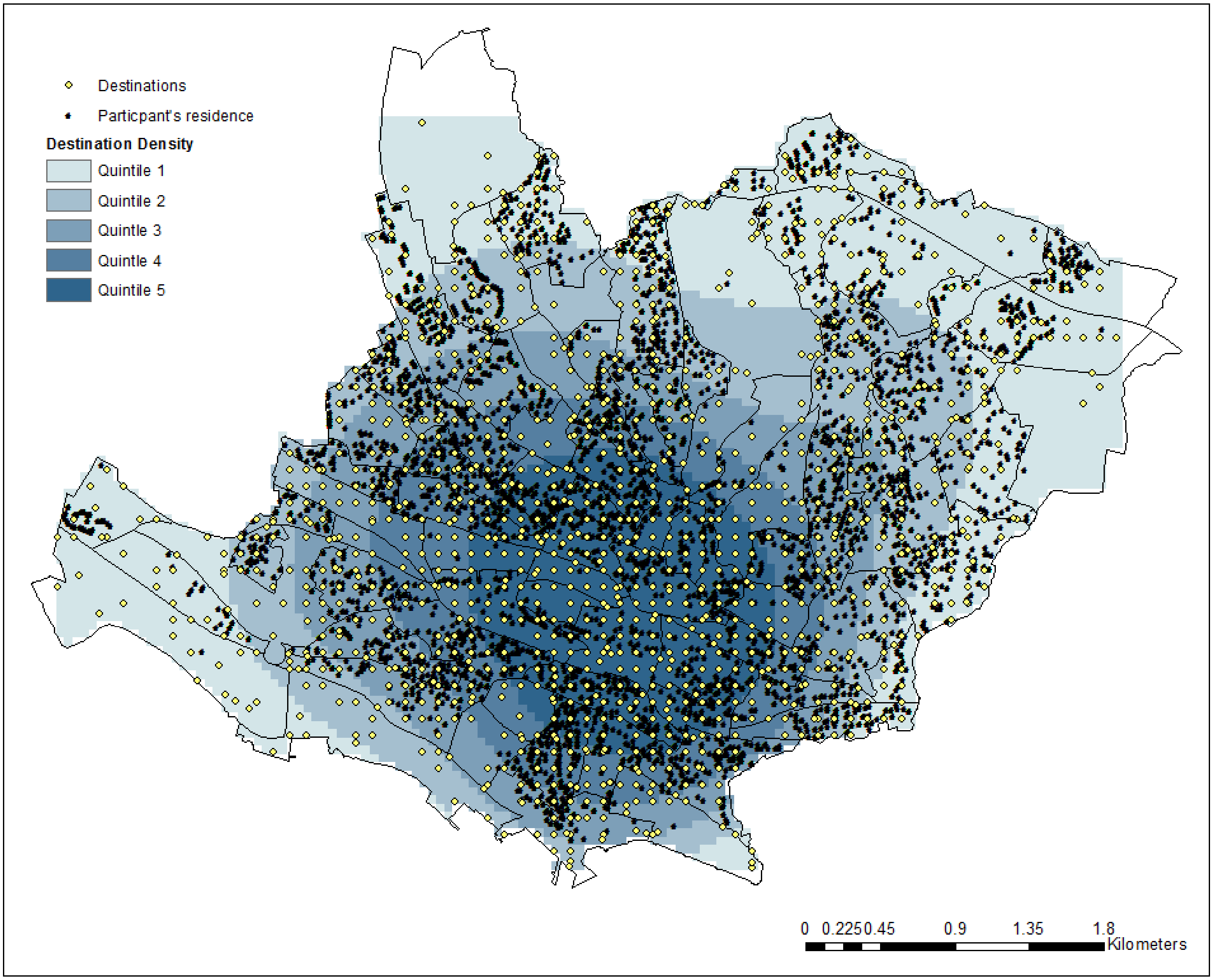
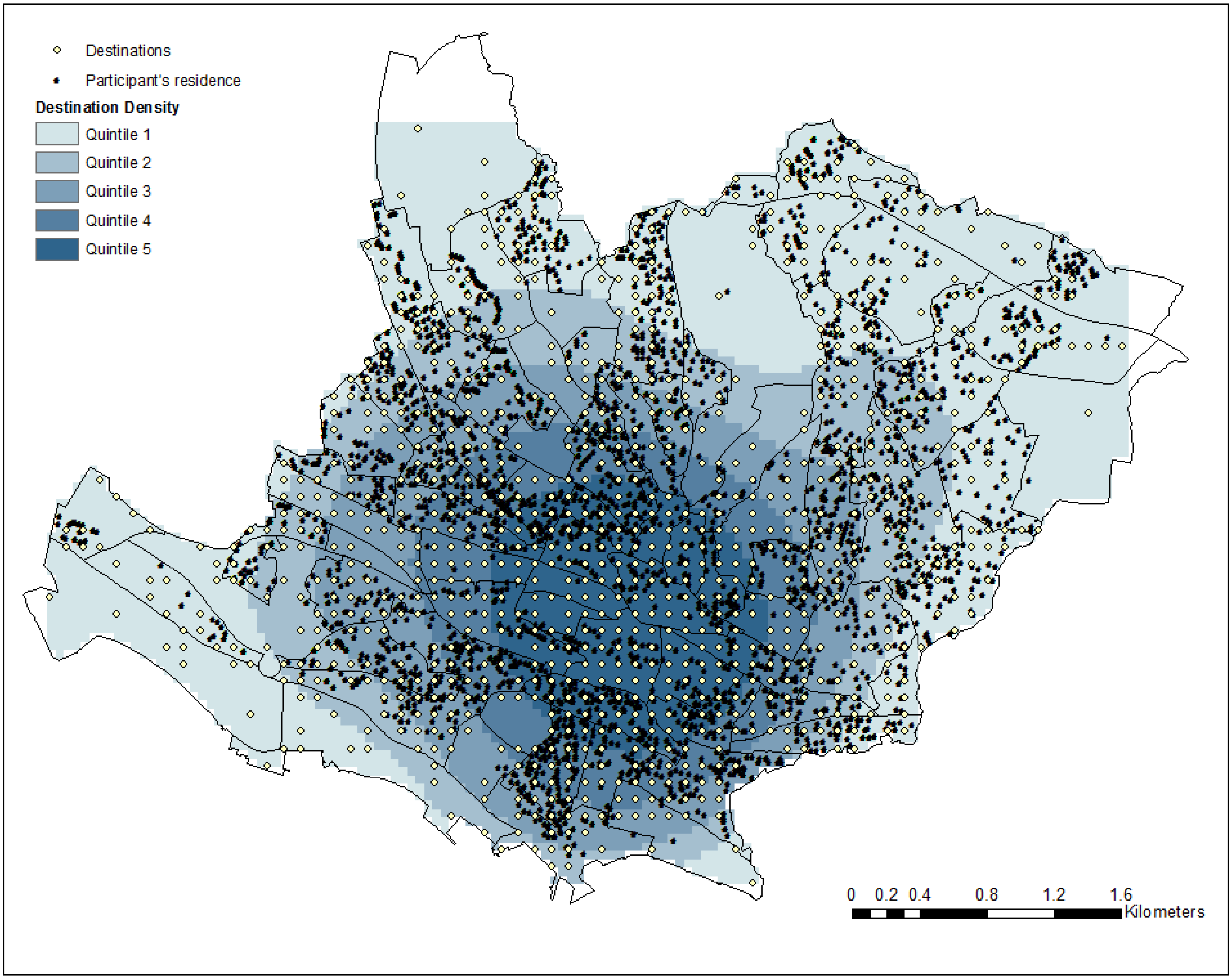


Figure 8. Raster representation of kernel density estimates of follow-up destination distribution using 1200 m kernels, Lausanne 2005.



Appendix 1. BMI variables from Joost et al., 2016

Baseline BMI variables

bsraw *	Raw BMI at baseline
bsadrv	BMI adjusted for median income
bsaded	BMI adjusted for education level
bsadjb	BMI adjusted for job
bsadedrv	BMI adjusted for education level and for median income
bsadedjb	BMI adjusted for education level and for job
bsadjbrv	BMI adjusted for job and median income
bsadedjbrv	BMI adjusted for education level, job, and median income
bsadal	BMI adjusted for all socio-economic variables
bsadalrv *	BMI adjusted for all socio-economic variables and median income
bsadalrsa	BMI adjusted for all socio-economic variables, smoking, and alcohol consumption

Follow-up BMI variables

furaw *	Raw BMI at follow-up
fuadrv	BMI adjusted for median income
fuaded	BMI adjusted for education level
fuadedrv	BMI adjusted for education level and for median income
fuadal	BMI adjusted for all socio-economic variables
fuadalrv *	BMI adjusted for all socio-economic variables and median income
fuadalrvas	BMI adjusted for all socio-economic variables, smoking, and alcohol consumption

* Used in model for analysis

Appendix 2. List of neighborhood destinations

*Note: Data available only provides for the number of establishments that fall under the categories in bold. Listed is the type of establishment that fall under each category. Not all establishments were used in analysis.

Retail Trade
Superstores (>2500m^2)
Large supermarkets (1000-2499 m^2)
Small supermarkets (400-999 m^2)
Large shops (100-399m^2)
Small shops (<100 m^2)
Large Stores
Other retail sale in non-specialized stores not classified elsewhere
Retail sale of fruits, vegetable, and potatoes
Retail sale of meats and meat-based products
Retail sale of fish, seafood, and fish-based products
Retail sale of bread, cakes, and confectionery
Bakeries and tea rooms
Retail sale of alcoholic beverages
Retail sale of tobacco
Retail sale of dairy and eggs
Other retail sale of food, beverages and tobacco in specialized stores not classified elsewhere
Pharmacy
Retail sale of medical devices and orthopedics
Hardware shops
Perfumery and other retail sale of beauty products and toiletries
Retail sale of fabrics
Retail sale of women's clothes
Retail sale of men's clothes
Retail sale of baby and infant clothes
Retail sale of furs
Retail sale of clothes and accessories
Retail sale of shoes
Retail sale of leather goods and travel items
Retail sale of furniture
Retail sale of domestic appliances not classified elsewhere
Retail sale of electrical appliances
Retail sale of radios and televisions
Retail sale of sound and film equipment

Retail sale of musical instruments
Retail sale of electrical appliances, radios and televisions, excluding household goods
Specialized retail sale of hardware
Other retail sales of hardware, pains, and construction and home improvement materials
Retail sale of books
Retail sales of newspapers and periodicals, kiosks
Retails sale of paper and office goods
Retail sale of grains, livestock feed and agricultural products
Retail sale of flowers and plants
Retail sale of pets and pet accessories
Retail sale of flowers and plants
Retail sale of grains, livestock feed and agricultural products
Retail sale of flowers and plants
Retail sale of photography equipment
Retail sale of watches and jewelry
Retail sale of office equipment and machinery
Retail sale of computers and software
Retail sale of flowers and plants
Retail sale of bicycles
Retail sale of sporting equipment
Retail sale of gifts and souvenirs
Retail sale of art items
Retail sale of flowers and plants
Retail sale of Antiques
Retail sale of occasions and occasion accessories
Mail-order selling
Stalls and markets
Other retail sales outside a store
Shoe and leather goods repair
Repair of electrical appliances for household use
Watch, clock, and jeweler repair
Repair of other personal and household goods

Hotels and Restaurants

Hotels, inns and guesthouses with restaurants
Hotels, inns and guesthouses without restaurant
Youth hostels and cabins
Campgrounds
Apartments, holiday homes
Shared accommodation (without cabins)
Other means of accommodation not specified elsewhere

Restaurants, cafes, snack bars, tea rooms, ice-cream parlors
Restaurants with accommodation
Bars & Pubs
Nightclubs, dance halls, night clubs
Canteen
Caterers

Transport
Rail transport
Urban or suburban passenger transport
Regular regional and intercity passenger transport
Funiculars, cable cars and ski lifts
Transport of passengers by taxis
Other land passenger transport
Road transport of goods
Maritime and coastal transport
Transport of passengers by inland waterways
Transport of goods by inland waterways
Regular Air Transport
Non-scheduled air transport
Space transportation

Post and telecommunications
Activities of the Post Office
Mail activities (without the activities of the Post Office)
Telecommunications without transmission of radio and television programs
Transmission of radio and television programs
Provision of Internet access

Education and training
Kindergartens and schools
Elementary Schools
Schools with Special Education Programs
Schools compulsory not specified elsewhere
Secondary schools, orientation cycles
Schools preparing for maturity, Normal schools
Graduate Schools and Other Schools of General Education
Technical or vocational secondary education
Colleges and Universities
Specialty Colleges and Universities
Other higher education
Driving Schools and Aviation Schools

Professional development, adult education
Courses of artistic expression
Language Courses
Computer courses
Other educational activities not specified elsewhere

Health
Hospitals for general care
Specialized clinics
General medical practice
Specialized Medical Practice
Dental Practice
Psychotherapy and psychology
Physiotherapy
Nursing and midwifery activities, home care
Other paramedical activities
Medical laboratories
Other human health activities not specified elsewhere
Veterinary activities
Houses for the elderly
Medical Homes
Institutions for the disabled
Institutions for drug addicts
Establishments for psychosocial treatment
Children's and young people's shelters
Educational Houses
Other social action with accommodation
Nurseries and day-care centers
Disabled day centers, sheltered workshops
Charitable organizations, charitable organizations
Other social work not specified elsewhere

Representation of interests as well as other associations
Economic and Employer Organizations
Professional organizations
Trade unions of employees
Parishes and Religious Associations
Convents
Political parties and associations
Organizations for Culture, Education, Science and Research
Health Organizations
Youth movements

Other representations of interests and associations not specified elsewhere

Cultural, sporting and recreational activities
Film and video production
Film and Video Distribution
Projection of films and videos; Movie theaters
Radio Activities
Television Activities
Theater and ballet troupes
Orchestras, choirs, musicians
Painters, sculptors and other independent artists
Other artistic and literary activities
Theaters, Operas
Other activities related to the management of cultural centers and theaters
Fairgrounds and amusement parks
Other entertainment activities not specified elsewhere
News Agencies
Freelance journalists
Management of libraries and archives
Museums and Preservation of Historical Monuments
Botanical and zoological gardens, nature reserves
Management of sports facilities
Sports associations
Other sports related activities not specified elsewhere
Games of chance, lotteries
Other recreational activities not specified elsewhere

Personal Care
Laundry and dyeing
Hair salons
Beauty salons
Funeral Services
Saunas, solariums
Fitness Centers
Other activities related to physical well-being
Other services not specified elsewhere

Appendix 3. Exemption of Human Subjects Research Approval from **Emory University Institutional Review Board**

EMORY UNIVERSITY | Institutional Review Board

Date: February 16, 2017

Natalie Rivadeneira
Principal Investigator
SPH: Career Services

RE: **Exemption of Human Subjects Research**
IRB00094778
Assessing the influence of the density of built neighborhood features on body mass index among an urban Swiss cohort

Dear Principal Investigator:

Thank you for submitting an application to the Emory IRB for the above-referenced project. Based on the information you have provided, we have determined on **2/15/2017** that although it is human subjects research, it is exempt from further IRB review and approval.

This determination is good indefinitely unless substantive revisions to the study design (e.g., population or type of data to be obtained) occur which alter our analysis. Please consult the Emory IRB for clarification in case of such a change. Exempt projects do not require continuing renewal applications.

This project meets the criteria for exemption under 45 CFR 46.101(b)(4). Specifically, you will evaluate the relationship between the distribution of destinations in the local neighborhood and body mass index (BMI) using kernel density estimation (KDE).This project involves secondary data analysis only; data provided by GeoCoLaus Study.

- IRB_thesisproposal_05FEB2017.pdf

Please note that the Belmont Report principles apply to this research: respect for persons, beneficence, and justice. You should use the informed consent materials reviewed by the IRB unless a waiver of consent was granted. Similarly, if HIPAA applies to this project, you should use the HIPAA patient authorization and revocation materials reviewed by the IRB unless a waiver was granted. CITI certification is required of all personnel conducting this research.

Unanticipated problems involving risk to subjects or others or violations of the HIPAA Privacy Rule must be reported promptly to the Emory IRB and the sponsoring agency (if any).

In future correspondence about this matter, please refer to the study ID shown above. Thank you.

Sincerely,

Anisha Easley, MPH
Research Protocol Analyst
This letter has been digitally signed

CC: There are no items to display

Kramer Michael *SPH: Epidemiology