THE FOOD ENVIRONMENT AND OBESITY, ARE THEY RELATED?

A CROSS-SECTIONAL OBSERVATIONAL STUDY IN THE NETHERLANDS

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July 2023

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Abstract

Background

Obesity is on the rise. In 2016 over 1.9 billion people worldwide over the age of 18 years are overweight, of whom 650 million had obesity. Obesity is characterised by excessive fat accumulation and a disbalance in energy intake and is associated with multiple different health issues. The last decades, the built environment has developed in such a way that it promotes a sedentary and inactive lifestyle. Also, the food environment, the system in which consumers buy and eat food, has changed with an increase in fast-food restaurants and the availability of ultra-processed foods. Both have been associated with increased risk of obesity. To assess the association between the food environment and obesity rates, a study will be conducted focussing on the province of Gelderland. This province has both areas with high and low rates of obesity so these can be compared. The objective of this study was to explore if there is a correlation between the food environment and obesity rates in the province of Gelderland in the Netherlands.

Methods

First, obesity rates were analysed on a national level to locate clusters of obesity using a Moran's I analysis. Based on these outcomes, further analysis was focussed on Gelderland. Secondly, the distribution of food outlets was examined. Outlets were divided into the groups healthy or unhealthy and were assigned a healthiness score. Accordingly, a food environment score was determined for each neighbourhood. A map was made with the weighted food environment score on neighbourhood level. Lastly, a Pearson's correlation coefficient (Pearson's r) was calculated for the correlation between the obesity rates and the number of food outlets per neighbourhood and the weighted food environment score with a significance threshold of $p = <0.05$.

Results

The mean obesity prevalence in the high obesity clusters was 18.6% and in the low cluster areas 11.7%. Based on the healthiness score, the mean food environment was slightly unhealthier in the low obesity rate clusters. Restaurants and fast-food outlets were the main food outlet type in both cluster types. The mean prevalence of obesity in the unhealthiest neighbourhoods was 15.5%, while the healthiest neighbourhoods had a higher mean obesity prevalence of 16.4%. Pearson's r for the correlation between obesity rates and the number of unhealthy food outlets in the neighbourhood was -0.05 ($p = 0.1478$). Pearson's r for the correlation between obesity rates and the weighted unhealthy food environment score was 0.03 ($p = 0.1563$).

Discussion

Within the scope of this study, there was no significant correlation found between the food environment and obesity prevalence. The association between obesity rates and the number of food outlets exhibited a weak negative correlation, meaning that in an area with more unhealthy food outlets obesity rates are lower. While the association between obesity rates and the weighted food outlet score exhibited a weak positive correlation. Indicating that high obesity rate areas have a healthier food environment score. Future work is needed to examine other possible influencing factors on the obesity rates.

Keywords: Overweight, obesity, food environment, fast-food, Gelderland.

Introduction

Obesity is on the rise. According to the World Health Organization (WHO) in 2016 over 1.9 billion people worldwide over the age of 18 years are overweight, of whom 650 million had obesity. (1, 2) In 2021, 50.8% of Dutch adults 20 years and older were overweight and the number of people with obesity has tripled from 5.3% in 1981 to 14.6% in 2021. (3)

Obesity is a complex condition characterized by excessive fat accumulation that impairs health and an imbalance in energy intake between consumption and expenditure of calories. (4) The WHO classifies a person to be overweight when an individual has a body mass index (BMI) between 25.0 and 29.9. A person is defined to have obesity with a BMI of 30.0 or higher (BMI= weight in kg/m² length). (1) Obesity is associated with 20 different health issues. These include cardiovascular diseases like ischemic heart disease and hypertension, diabetes mellitus, chronic kidney disease, hip and knee osteoarthritis and 13 different types of cancer, e.g., colon- and breast cancer. (5) Furthermore, obesity can cause psychological problems like stress, anxiety and depression. (2) Risk factors that can play a role in the development of obesity are physical inactivity, genetics, and social, psychological, and economic factors. (6, 7)

Moreover, the built environment has developed in such a way that it promotes a sedentary and inactive lifestyle and with an abundance of unhealthy processed foods. This is also referred to as the obesogenic environment. (6, 7) The number of fast-food restaurants has increased enormously, and the growth of the fast-food industry was almost simultaneously with the rise of the obesity epidemic. (8, 9) Also, portion sizes have increased. The meals served at restaurants and fast-food outlets generally contain more fat and calories than at home. (8) This part of the food system in which people consume or acquire their food is defined as the food environment. (10) The food environment and the availability of fast-food outlets have been associated with overweight and obesity. (9, 10, 11) There is also evidence that the local food environment influences dietary outcomes. (12) Concepts related to the food environment are food deserts and food swamps. Food deserts refer to an area that lacks sufficient; if all, access to nutritious and affordable food. Food swamps refer to areas where the amount of unhealthy food, like fast food, well exceeds the availability of healthy food. Both these concepts have been described in the literature as possible factors contributing to an obesogenic environment. (13)

The development of the fast-food industry and the increase in unhealthy food products goes hand in hand with the increasing industrialization and (highly) processing of food. (14, 15) To classify the extent of food processing the NOVA (no abbreviation) classification system is used. Foods can be assigned into one of four categories: 1. Unprocessed or minimally processed foods (e.g., eatable parts of animals and plants); 2. Processed culinary ingredients (e.g., olive oil); 3. Processed foods (dishes handmade by people) and 4. Ultra-processed food and drink products. (16) These so-called ultra-processed foods are described as *"*industrial formulations manufactured from substances derived from foods or synthesized from other organic sources. They typically contain little or no whole foods, are ready-to-consume or heat up, and are fatty, salty or sugary and depleted in dietary fibre, protein, various micronutrients and other bioactive compounds.*"* (16) The composition of ultra-processed foods, like savoury or sweet (packaged) snacks (e.g., ice cream, chips and candy) and processed meat products like sausages or hamburgers can lead to energy overconsumption. (16) A diet that is high in ultra-processed foods can increase the risk of obesity. (14, 17)

A study done in the Netherlands by the RIVM to assess the diet of the Dutch population found that the majority of the population does not meet the Dutch dietary guidelines. (18) Less than 10% of the population eats the recommended amounts of vegetables, legumes, potatoes and cereal products. Moreover, two-thirds of the Dutch people eat too many meat products and choose the unhealthy variants of which most are ultra-processed meat products. (18) Further investigation of diets and the food environment in the Netherlands has been conducted by various researchers. (11, 15, 19, 20, 21) An unhealthy food environment was not always associated with poorer dietary outcomes or obesity. (11) Two studies have investigated the food environment around schools in two Dutch cities. (20, 21) One of the studies also looked at the association between fast-food density and childhood obesity. (20) However, there is still little research on the food environment and other regional determinants in concerning the spatial clustering of obesity. One study investigated the spatial distribution of obesity rates on municipality level in the Netherlands and looked at social demographic and environmental factors that may influence clusters. (22) They found a significant variation in the spatial distribution of obesity clusters and that there is a spatial connection between regions with high and low obesity prevalence. (22) Nonetheless, these studies have not addressed the correlation between the food environment and obesity.

To study the spatial dimension of the food environment and obesity, spatial technologies can be used. The three main technologies used in obesity studies are global positioning systems (GPS), remote sensing (RS) and geographic information systems (GIS), together called the 3S technologies. The 3S technology can help to measure the distribution and patterns of obesity rates. (23) The food environment can also be examined with GIS. GIS has been used to investigate the association between the food environment and individual characteristics or behaviour. Another common use of GIS is to examine food accessibility on a neighbourhood level. (24) Examination of the food environment can be done using different measures. One way of assessing access to food in a food environment is by using the five dimensions proposed by Penchansky and Thomas. The dimensions are accessibility, availability, accommodation, acceptability and affordability. (12) In this study the first two dimensions will be of most interest since the focus will be on the location of food outlets. To examine the food availability and accessibility the density of food outlets can be measured. Density refers to the number of food outlets in a defined area. One of the most used ways to measure density is with a buffer zone. This can be a circular or network buffer. Another way to measure density is the kernel density estimation. The density of a given set of points is measured in a certain radius. (24) In this study the Kernel density estimate analysis was used because this will highlight the areas with a high density of food outlets.

The objective of this study was to explore if there is a correlation between the food environment and obesity rates for a province in the Netherlands on a spatial level. One province is selected for practicality reasons. To accomplish this, four sub-questions were composed:

1. What is the spatial distribution of obesity and where are obesity clusters and hotspots located in the Netherlands? - Based on these results, one province was chosen for further analysis.
2. What is the distribution of healthy and unhealthy food outlets in the study area?
3. How healthy are the food environments in the different neighbourhoods in the study area?
4. What is the correlation between obesity rates and the food environment in Gelderland?

The research question of the study was: what is the correlation between the food environment and the distribution of the prevalence of obesity in Gelderland in the Netherlands?

Methods

Study design and setting

A cross-sectional observational study design was used.

Materials

Neighbourhood boundaries: for the Netherlands were obtained from CBS.

Obesity: data on the prevalence of obesity in the Netherlands were obtained from the Dutch National Institute for Public Health and Environment (RIVM) for 2020. The obesity rates are based on self-reported data of length and height from adults 18 years and older who have a BMI of > 30.0 (25). These were joined with the neighbourhood boundaries data to map the spatial distribution of obesity.

Food outlets: were extracted from the Points of Interest (poi) data obtained from OpenStreetMap (OSM). A total of 4181 food outlets were obtained for the study area.

The geographical analyses were made with the software of ArcGIS Pro version 3.0. Statistical analyses were conducted with RStudio version 4.2.2 and Microsoft Excel 365.

	Source	Year	URL
Obesity in the Netherlands	National Institute for Public Health and Environment (RIVM)	2020	https://www.vzinfo.nl/overgewicht/regionaal/obesitas
Food Outlets for Gelderland	OpenStreetMap (OSM)	2023	https://download.geofabrik.de/europe/netherlands/gelderland.html
Neighbourhood boundaries	CBS	2023	https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische-data/wijk-en-buurtkaart-2022

Table 1: Data source table.

Analysis

Distribution and clustering of obesity in the Netherlands

First, the spatial distribution of obesity was examined in the Netherlands and where rates were highest. The first analysis of obesity rates was made on a national level to determine which province to focus on. A map was made with the obesity rates at a neighbourhood level. To locate clusters of obesity rates a Moran's I analysis was performed. With the Moran's I, systematic variations in obesity rates can be measured and evaluated whether patterns are clustered, dispersed, or random. The obesity rate of each neighbourhood is compared to the rates of all other neighbourhoods and accordingly assigned to one of the following categories: Neutral (0), High High (HH), High Low (HL), Low High

(LH) or Low Low (LL) (Table 2). HH means high obesity rates are surrounded by high obesity rates and LL by low rates as compared to all other neighbourhoods. HL refers to a neighbourhood with high obesity rates and LH low rates as compared to the direct surrounding neighbourhoods. In other words, these are outliers. All categories are summarised in Table 2.

Category	Abbreviation	Definition
Neutral	0	Areas with no abnormal obesity rates compared to other neighbourhoods
High High	HH	Areas with high obesity rates compared to neighbourhoods
High Low	HL	Areas with high obesity rates compared to direct surrounding neighbourhoods
Low High	LH	Areas with low obesity rates compared to direct surrounding neighbourhoods
Low Low	LL	Areas with low obesity rates compared to other neighbourhoods

Table 2: Terminology of obesity rates.

The selection criteria for the chosen province were that the province needed to have at least one or more areas with both high and low rates of obesity.

As a result of the Moran's I analysis and the criteria, the province of Gelderland was selected for further analysis.

Food environments in the study area

The second step was to determine the spatial distribution of the different food outlet types. Food outlets were assigned to the group healthy or unhealthy as seen in Table 3. This differentiation is based on similar studies (13, 26) and the healthiness score model of Thornton et al. (27)

Healthy	Unhealthy
Bakery	Café
Butcher	Convenience
Greengrocer	Fast-food
Supermarket	Food-court
	Restaurant

Table 3: Categories of food outlets.

The spatial distribution of the food outlets was examined using the Kernel density estimation. This created a map that highlighted where the density of outlets is highest. Separate maps were made for the healthy and unhealthy food environment, showing the distribution and density of food outlets and

supermarkets. A second Kernel density estimate was made of the unhealthy food outlets without the restaurants. This was done to examine the effect of the restaurants on the distribution and density of the unhealthy food outlet group. Also, a map with only fast-food restaurants was made. The food environment was further analysed by summarising the available food outlets in the study area and for HH and LL obesity categories.

Neighbourhood Healthiness in Gelderland.

The third step was to examine how healthy the food environments were in the study area. A healthiness score was determined for each neighbourhood using the Thornton et al. (27) model. In this model, they assigned a healthiness score to each of the food outlet types from -10 to +10. The plus and minus help differentiate between unhealthy (minus) and healthy (plus) (Table 4). Factors influencing the score are 1. Contribution of this store to the community regarding health risk/benefit; 2. Opening hours, this would indicate the accessibility; 3. Fraction of healthy versus unhealthy food; 4. If there is a drive-through, home delivery or takeaway option.(27) However, the model only includes take-away restaurants and does not consider full-service restaurants and cafes. In the available data, no distinction is made in different restaurant types and includes a separate category with cafes. Therefore, in this study, the score for all restaurants and cafes was based on the score of the take-away restaurants. Taking into consideration that the food in full-service restaurants and cafes can vary a lot in their healthiness and are mostly healthier than take-away food, the score was altered to a lower score (-5.0 for restaurants and -2.0 for cafes). For cafes it will be lower than restaurants since not all cafes serve full meals. Food outlets that were considered unhealthy were fast-food restaurants, restaurants, cafes and convenience stores. Food outlets that were considered healthy were supermarkets, bakeries, greengrocers and butchers. (13, 26) For the analysis the scores were rounded down. All food outlets and their healthiness score as used in this study are displayed in Table 4.

Healthy	**Score** ***Mean (SD)***	**Unhealthy**	**Score** ***Mean (SD)***
Supermarket	6.0 (2.9)	Fast-Food	-8.0 (1.6)
Bakery (bread)	5.0 (5.0)	Restaurant	-5.0*
Greengrocer	8.0 (2.1)	Convenience store	-1.1 (4.1)
Butcher	5.5 (3.2)	Café	-2.0*

Table 4: Healthiness score of healthy and unhealthy food outlets based on Thornton et al. (24)

** No SD is calculated since this score is added by the researcher based on the score of take-away restaurants from the model of Thornton et al. (27)*

A mean food environment score was created for each neighbourhood. This was done by assigning the healthiness score to each food type in the food outlet layer. This was combined with each neighbourhood to determine the average healthiness for each neighbourhood. A map was made with the weighted food environment score on a neighbourhood level.

Correlation between obesity and food environments

The last step is to determine if a correlation between the rates of obesity and the food environment exists using the software of RStudio. A Pearson's correlation coefficient is calculated for the correlation between the obesity rates and the number of food outlets per neighbourhood and the

weighted food environment score. The significance threshold is p = <0.05. To visualise the distribution of the data a boxplot and scatterplot were made.

Results

Distribution and clustering of obesity in the Netherlands

Obesity rates in the Netherlands were mapped at the national level (Figure 1A). Three obesity clusters with HH rates stand out. These include the region in the northeast, the southeast and southwest (Figure 1B). The region in the mid-west of the Netherlands, also referred to as the Randstad, has predominantly neighbourhoods with low rates of obesity. For an enlarged version of the maps see Appendix 1.

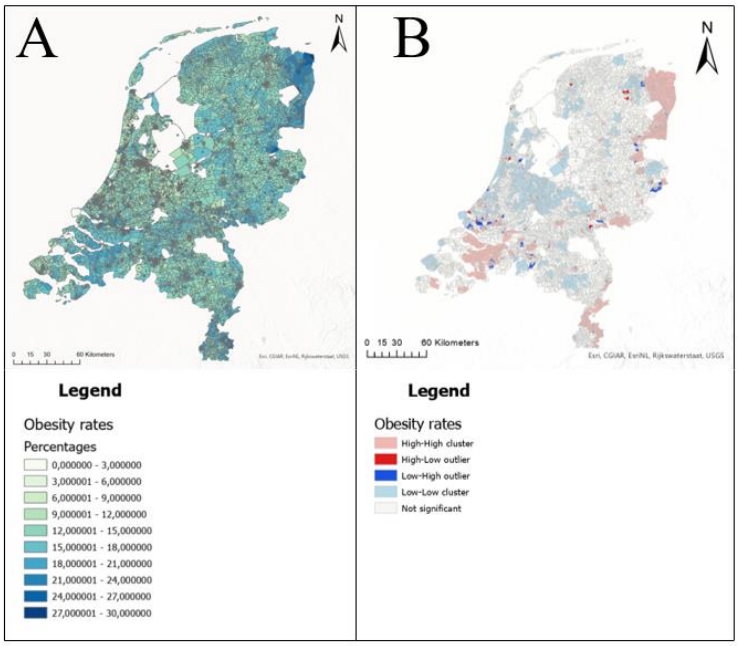

Figure 1: Map of the Netherlands. (A) Obesity rates (%) per neighbourhood. The lighter areas show lower rates and the darker areas indicate higher rates and (B) Hotspots (red) and cold spots (blue) of Obesity rates per neighbourhood.

Based on these findings the province of Gelderland was further assessed. Obesity rates in Gelderland were mapped (figure 2A). The area in the mid-west of Gelderland has predominantly clusters with low rates of obesity. The area in the middle and to the east has more clusters with high rates (figure 2B). An enlarged version of the maps can be found in Appendix 2.

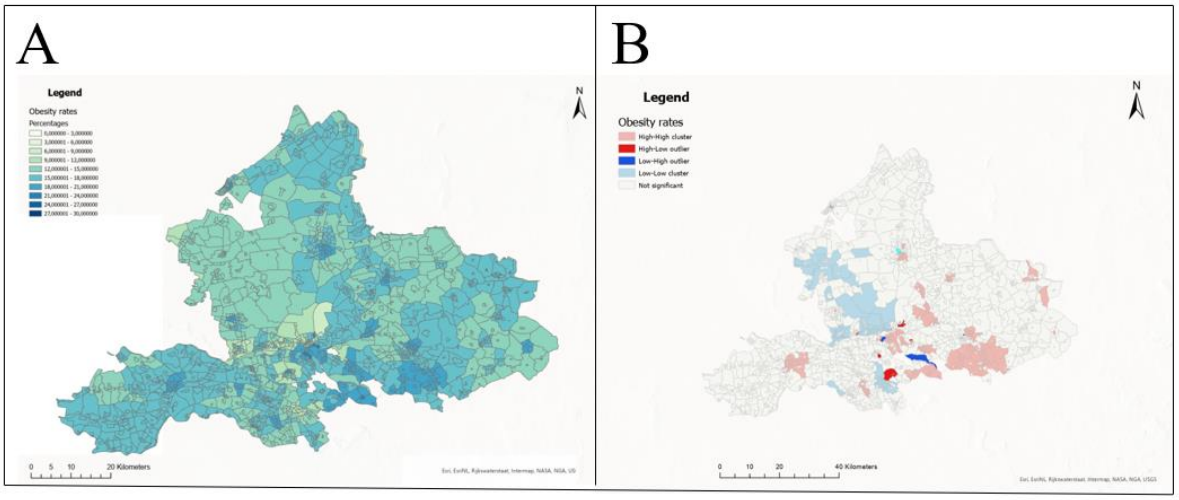

Figure 2: Map of Gelderland. (A) Obesity rates (%) per neighbourhood. The lighter areas show lower rates and the darker areas indicate higher rates. (B) Hotspots (red) and cold spots blue) of Obesity rates per neighbourhood.

Food environments in the study area

A total number of 4181 food outlets were identified with 1163 (27,8%) healthy and 3018 (72,2%) unhealthy.

The largest number of unhealthy food outlets are located around the major urban areas of Gelderland, namely Apeldoorn, Arnhem, Nijmegen, Ede- Wageningen and Harderwijk (Figure 3A). Arnhem and Nijmegen were found to have the highest densities (Figure 3B). A map of the distribution of unhealthy food outlets can be found in Figure 3A and the Kernel density estimate in Figure 3B. Enlarged version of the maps can be found in Appendix 3.

Distribution of the healthy food outlets is also concentrated around the major urban areas of Apeldoorn, Arnhem, Nijmegen, Ede- Wageningen and Harderwijk (Figure 4A). Again, Arnhem and Nijmegen have the highest densities (Figure 4B). A map with the distribution of healthy food outlets can be found in Figure 4A and the kernel density in Figure 4B. The enlarged version of the maps can be found in Appendix 4.

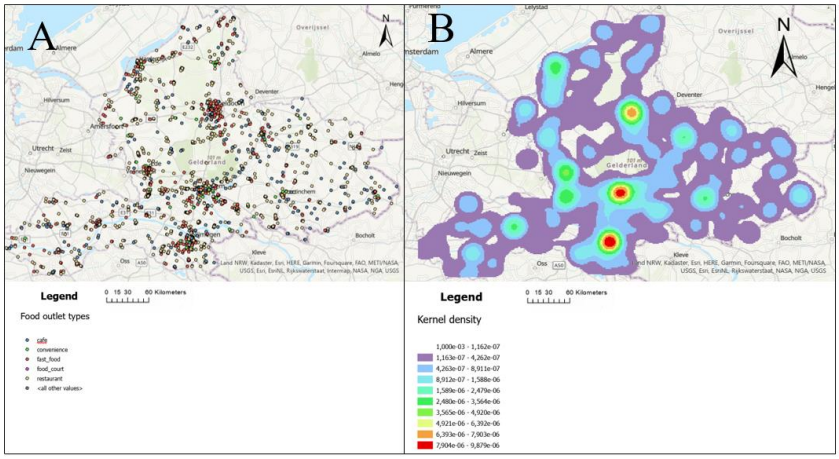

Figure 3: Map of Gelderland. (A) Distribution of food outlets in the category unhealthy (table 3). (B) Kernel density estimate of food outlets in the category unhealthy (table 3)

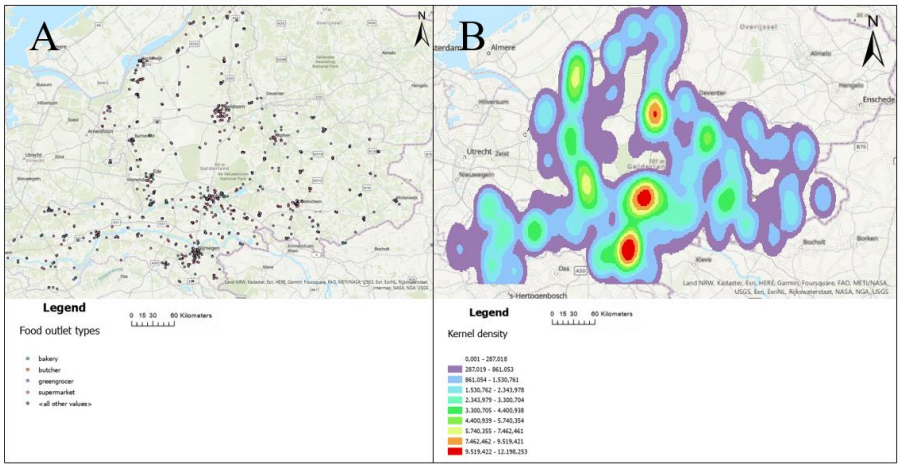

Figure 4: Map of Gelderland. (A) Distribution of food outlets in the category healthy (table 3). (B) Kernel density estimate of food outlets in the category healthy (table 3)

In Figure 5A a Kernel density distribution of the unhealthy food outlets without the restaurants can be found. The overall distribution of the food outlets looks the same. When looking at the three major cities Apeldoorn, Arnhem and Nijmegen, the intensity of the density's changes. The density in Nijmegen is highest and Arnhem lowest. The density in Apeldoorn increases compared to the first analysis including the restaurants. Moreover, it is noticeable that the density in the more rural areas decreases. In Figure 5B a map shows the Kernel density distribution with only fast-food outlets. The density in Apeldoorn increases, in Arnhem Decreases and Nijmegen stays the same. The density in the rural areas also further decreases. The enlarged version of the maps can be found in Appendix 3.

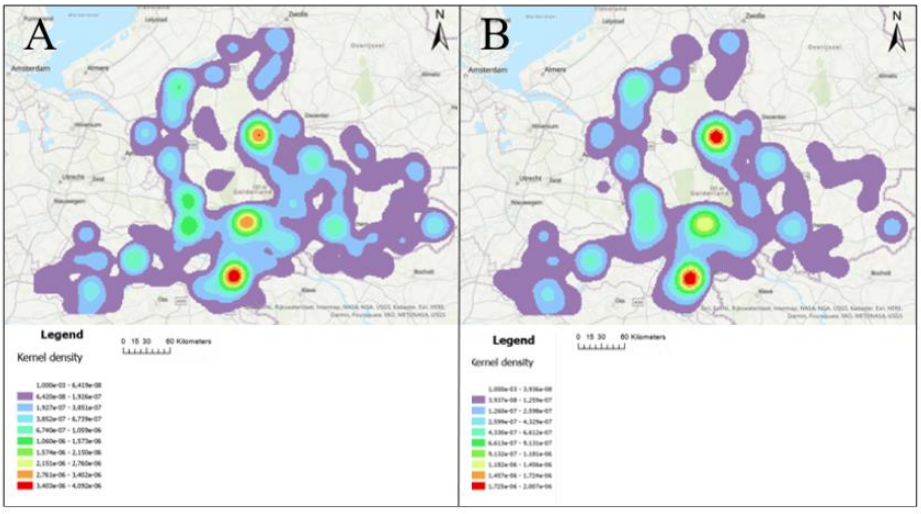

Figure 5: Map of Gelderland. (A) Kernel density estimate food outlets in the category unhealthy without restaurants (table 3). (B) Kernel density estimate of fast-food outlets only.

The main food outlets found per neighbourhood were restaurants (N=1633; mean=3.0), fast-food (N=759; mean=2.2) and supermarkets (N=580; mean=1.6) (Table 7). The least present food outlets were food courts (N= 2; mean = 2.0), greengrocers (N= 89; mean = 1.1) and convenience stores (N= 106; mean = 1.3). The average number of total food outlets per neighbourhood was 4.7. A summary of all the food outlets can be found in Table 5.

Food outlet type	Mean *(var.)*	Median	Minimum number	Maximum number	Total
Bakery	1.7 *(2.9)*	1	1	16	341
Butcher	1.3 *(0.9)*	1	1	7	153
Café	1.8 *(3.7)*	1	1	50	518
Convenience store	1.3 *(1)*	1	1	7	106
Fast-food	2.2 *(3.7)*	1	1	50	759
Food court	2.0 *(NA)**	2	2	2	2
Greengrocer	1.1 *(0.2)*	1	1	4	89
Restaurant	3.0 *(7.3)*	1	1	124	1633
Supermarket	1.6 *(1.6)*	1	1	16	580

Table 5: Summary of food outlet types by neighbourhood.

** No SD was found for food court; a possible reason is that the data only contained two food courts.*

Food environments and Obesity Rates

The mean obesity rate in the HH clusters was 18.6 (var. = 1.7) with a mean food environment score of -1.03 (var. = 7.9). In the LL cluster mean obesity rate was 11.7 (var. = 3.3) with a mean food environment score of -1.4 (var. = 5.0). In the HH cluster, a total of 200 food outlets were found in the healthy category and 410 in the unhealthy category. In the LL cluster, a total of 120 are in the healthy, and 569 in the unhealthy category. Restaurants were the main food outlet type in both HH (N=192; mean= 2.8) and LL (N=305; mean= 5.0). The food environments found in each of the clusters identified in Figure 2B are summarized in Table 6.

	Obesity rates	Food environment score* Mean *(var.)*	Food environment availability** N *(Mean)*
High High	Mean *(var.)* 18.6 *(1.7)* Min. 15.6 Max. 22.6	-1.03 *(7.9)*	**Healthy** Bakery 52 *(1.6)* Butcher 23 *(1.5)* Greengrocer 8 *(1.0)* Supermarket 117 *(1.9)* *Total 200* **Unhealthy** Café 63 *(1.8)* Convenience 16 *(1.0)* Fast-food 139 *(2.1)* Restaurant 192 *(2.8)* *Total 410*
Low Low	Mean *(var.)* 11.7 *(3.3)* Min. 6.5 Max 15.2	-1.4 *(5.0)*	**Healthy** Bakery 46 *(1.8)* Butcher 15*(1.25)* Greengrocer 10 *(1.1)*

		Supermarket 49 *(1.7)* *Total* *120* **Unhealthy** Café 98 *(3.5)* Convenience 30 *(1.7)* Fast-food 136 *(3.9)* Restaurant 305 *(5.0)* *Total* *569*

Table 6: Summary of the food environment and obesity rates for the HH and LL clusters.

**Food environment rating is the mean score of the weighted food outlets score. **Food environment availability is the total amount of food outlets available plus the mean score of the different food outlets.*

Neighbourhood healthiness in Gelderland.

The mean weighted food environment scores were mapped on a neighbourhood level (Figure 6). Most neighbourhoods had a mean food environment score between 0.0 and -4.0. (Figure 6). The five least healthy neighbourhoods had mean food environment scores between -8 and -6.5 and sum scores ranging from -24 to -39 (Table 7). The healthiest five neighbourhoods had mean scores between 6 and 7 and sum scores ranging from 24 and 13. The unhealthiest neighbourhoods had a mean obesity rate of 15.5, while the healthiest neighbourhoods had a mean obesity rate of 16.4 (Table 7). The top 5 healthiest and least healthiest neighbourhoods are captured in Table 7.

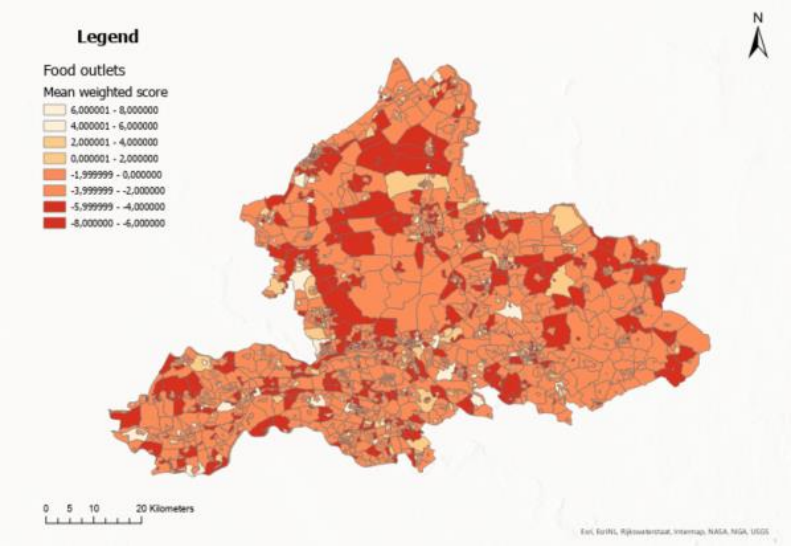

Figure 6: Map of Gelderland on the neighbourhood level with mean weighted food environment scores. The light areas indicate a healthier food environment score (plus) and the darker ones have an unhealthier score (minus).

	Mean *(var.)*	Sum	Obesity rate
Unhealthy			
Kayersmolen-noord – Apeldoorn	-8 *(0)*	-32	19
Rietgraaf – Oosterhout	-8 *(0)*	-24	15.5
Verspreide huizen Horst	-7.25 *(2.25)*	-29	NA*
Janssingel - Arnhem	-6.5 *(2.7)*	-39	12.2
Verspreide huizen – Kerkwijk	-6.5 *(6.3)*	-39	15.1
Healthy			
Latenstein – Tiel	6 *(0)*	24	20.2
Sprengenbos – Apeldoorn	7 *(2)*	14	15.4
Kern – Driel	6.5 *(4.5)*	13	16.3
Verspreide huizen Toldijk - Steenderen	6.5 *(4.5)*	13	14.8
Groessen	6.5 *(4.5)*	13	15.4

*Table 7: Top 5 neighbourhoods in the unhealthy and healthy category. * No obesity rates were available.*

Correlation between obesity and food environments

The mean weighted unhealthy food outlet scores per neighbourhood when compared with the obesity rates exhibited a slight positive correlation (higher food score with higher obesity) (Figure 7A). This indicates that a neighbourhood with a higher score has a higher obesity rate. The scatterplot shows the association between obesity rates and the mean weighted food environment score (Table 4) per neighbourhood. Most neighbourhoods have a score between -5 and 2.5.

By Cluster, the mean weighted food score per neighbourhood was close to 0 for all categories. The HL neighbourhoods had a slightly more negative score (Figure 7B). The distribution of the interquartile range (IQR) was similar for the LL and HL cluster, ranging from -3 to 0. While the IQR of HH was smaller, from 2 to 0. The IQR of the LH cluster ranged from -2 to 1,5. The boxplot and scatterplot are displayed in Figure 7.

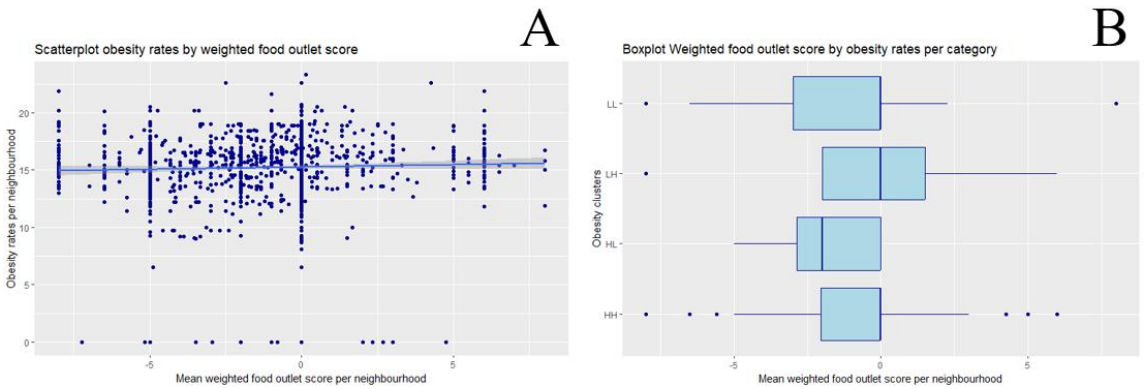

Figure 7: Scatterplot (A) and boxplot (B) of mean weighted food outlets per neighbourhood and corresponding obesity rates.(28)

A Pearson's correlation test is performed to calculate the correlation coefficient (Pearson's r) for the correlation between obesity rates and the weighted unhealthy food environment score. Results from the test show a Pearson's r of 0.03 (p = 0.1563). Meaning that no significant correlation was found.

When the number of unhealthy food outlets per neighbourhood was examined with obesity rates a slight negative correlation is presented (Figure 8A). Indicating that obesity rates are lower in neighbourhoods with a higher number of unhealthy food outlets. The scatterplot shows the association between the number of food outlets per neighbourhood and the obesity rates per neighbourhood. The distribution of the data points is skewed to the left and is not normally distributed, indicating that there is no linear correlation between the two.

The boxplot analysis by clusters showed an IQR of unhealthy food outlets between 0 and 10 in all clusters (Figure 8B). The LL and HL clusters show the widest IQR of the number of food outlets per neighbourhood. There are some outliers in the data to the right side, with most outliers in the LL, HH and 0 categories (Figure 8B). These outliers represent city centre (shopping area) neighbourhoods with a higher number of food outlets than residential neighbourhoods. The boxplot and scatterplot are displayed in Figure 8.

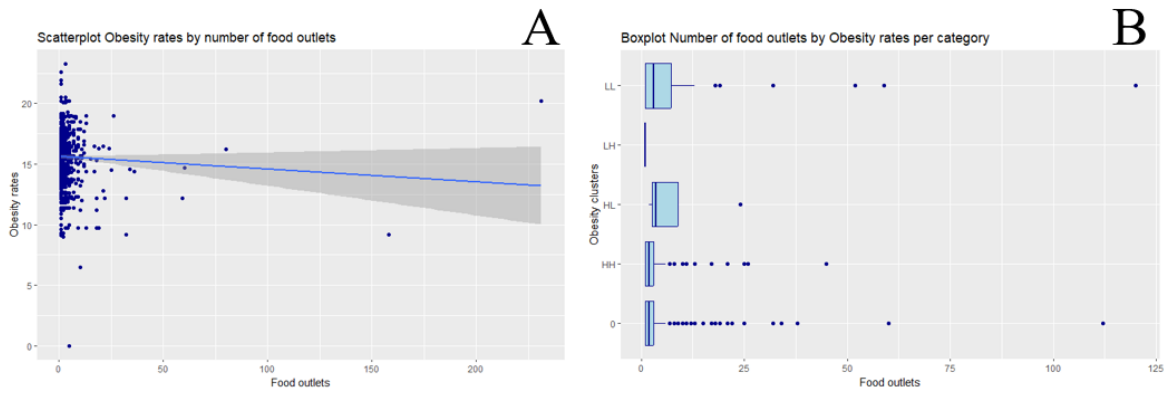

Figure 8: scatterplot (A) of obesity rate vs number of unhealthy food outlets and boxplot (B) of obesity cluster vs number of unhealthy food outlets.(28)

When Pearson's r was calculated for the correlation between obesity rates and the number of unhealthy food outlets in the neighbourhood, results show a Pearson's r of -0.05 (p = 0.1478). Meaning that there was no significant correlation.

Discussion

This study aimed to answer the question of what the correlation is between the food environment and the prevalence of obesity in the province of Gelderland in the Netherlands. The results of this study indicate that there is no significant correlation (Pearson's r) between obesity rates and the food environment in Gelderland. The association between obesity rates and the number of unhealthy food outlets exhibited a weak negative correlation. This would mean that in an area with more unhealthy food outlets obesity rates are lower. In addition, the association between obesity rates and the weighted food outlet score exhibited a weak positive correlation. Indicating that an area with high obesity rates has a higher food outlet score, and therefore being healthier. Both these findings suggest

that an unhealthier food environment, i.e., more unhealthy food outlets and a low food environment score, correlates with a lower obesity rate.

Main findings

Analysis of the food environment showed that both areas with high obesity rates (HH) and low rates (LL) have more unhealthy food outlets than healthy outlets. Unexpectedly, in the high obesity rate areas, the total number of healthy food outlets was higher and the unhealthy food outlets was lower compared to the low-rate areas. The mean food outlet availability of healthy food outlets was around the same for both cluster types, but the mean availability of the unhealthy food outlets was almost twice as many in the low-rate areas compared to the high-rate areas. Meaning that in an area with lower obesity rates there are more unhealthy food outlets. Some studies found similar results. (29, 30) However, in the existing literature, there is quite some inconsistency in study results of the effect of the food environment on obesity. (9) Other studies did find a positive association between fast-food outlets and obesity (31) or the food environment and the purchase of fast-food. (27) And there are also studies that did not find an association. (8, 32)

The top five healthy and unhealthy neighbourhoods showed that the average obesity rate was higher in healthy neighbourhoods. A possible explanation can be that fast-food and full-service restaurants are more frequently located in areas where the population is more educated and affluent. (8) In these areas the average obesity prevalence is often lower. (8, 33) The Kernel Density showed that Arnhem, Nijmegen and Apeldoorn had the highest densities of both healthy and unhealthy food outlets. The neighbourhoods with the highest amount of food outlets were all city (shopping) centres located in these areas. These areas are also visited by many people from the surrounding areas. This could explain why the number of food outlets is much higher. Besides, the higher number of unhealthy outlets does not result in a high increase in the obesity rates of these areas and sometimes even fall in the low-rate category.

Strengths and limitations

In this study, there are some limitations that affect the results of the analysis. The data obtained from OSM may not be complete as the data is based on volunteered geographic information, better known as citizen science-reported information. Therefore, the results should be interpreted with care. The missing data can lead to an underestimation or overestimation of the healthiness of a neighbourhood. A neighbourhood can look (un)healthier than it is because of food outlets that are not reported. In the correlation analysis this can result in a higher or lower correlation coefficient than it would be with the poi's present. If a neighbourhood has high obesity rates but has missing poi's, and therefore seems healthier, it can wrongfully classify it as if there is no or weak correlation, when in fact there might be a correlation.

Another potentially influencing factor is that some restaurants may be misclassified as unhealthy. Some restaurants serve exclusively healthy meals. However, in the analysis, all restaurants were classified as unhealthy. This could lead to neighbourhoods looking unhealthier than they might be. This could affect the correlation analysis in a way that if these healthy restaurants would have been left out, the correlation could be weaker or stronger. To compensate for this effect all food outlets were assigned a healthiness food outlet score and a separate analysis was made based on the healthiness score. This way, restaurants were differentiated from fast-food outlets. The ratio between restaurants and fast-food outlets can be of importance. It was found in some studies that people who live in neighbourhoods with a high ratio of fast-food outlets compared to full-service restaurants, the

risk of obesity increases.(34, 35) Areas where the ratio of full-service restaurants to fast-food was greater were associated with lower obesity rates.(35) That could suggest that the influence of full-service restaurants on obesity prevalence is seemingly less than fast-food restaurants.

The strength of this study is that it includes both healthy and unhealthy food outlets for a comprehensive examination of the food environment. This made it possible to compare healthy and unhealthy neighbourhoods and their obesity rates. Weighing the different food outlet types helped to further analyse the food environments on a detailed level, since this would give the neighbourhoods a more representative value than just healthy or unhealthy. To the best of our knowledge, no study has been conducted where weighted food outlets were used to examine the effect on obesity levels.

Future work

Obesity has often more than one attributable factor and the food environment is just one. If a neighbourhood has high or low rates of obesity is dependent on multiple factors including access to physical activity (6). Further work is needed to determine the other contributing factors to obesity within each of the neighbourhoods. Furthermore, the accessibility of food outlets could be further examined by looking at travel distance and time from residential homes to the different types of food outlets.

Conclusion

Within the scope of this study, there was no significant correlation found between the food environment and obesity prevalence. The results showed a weak association between the healthiness of the food environment and obesity rates, indicating that an unhealthier food environment correlates with a lower obesity rate. The use of the food environment score and weighing of the food outlets can help establish a more extensive analysis and help in future studies. A larger comprehensive study is needed to include more factors that play a role in obesity to determine what determinants influence obesity rates.

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Appendix 1

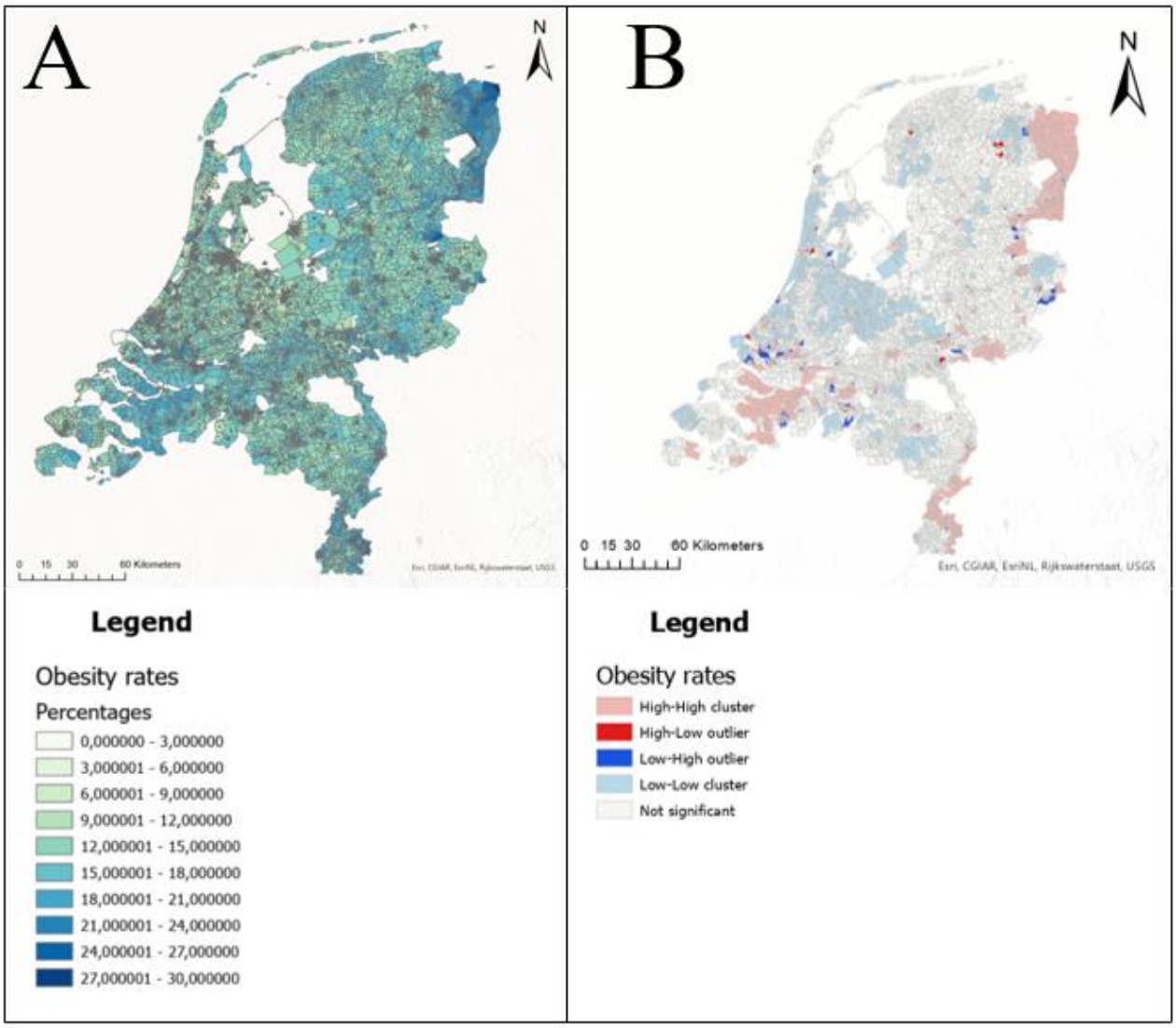

Figure 1: Map of the Netherland. (A) Obesity rates (%) per neighbourhood. The lighter areas show lower rates and the darker areas indicate higher rates and (B) Hotspots (red) and cold spots (blue) of Obesity rates per neighbourhood.

Appendix 2

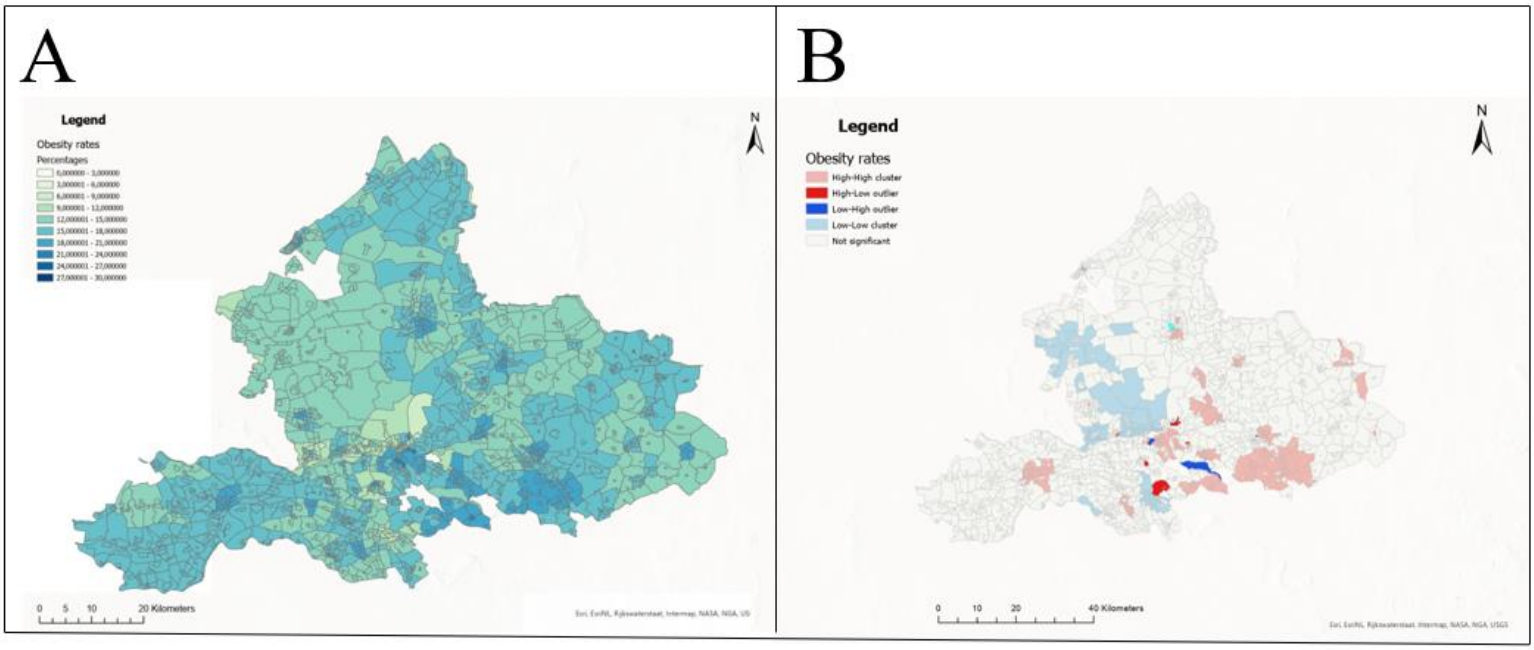

Figure 2: Map of Gelderland. (A) Obesity rates (%) per neighbourhood. The lighter areas show lower rates, and the darker areas indicate higher rates and (B) Hotspots (red) and cold spots blue) of Obesity rates per neighbourhood.

Appendix 3

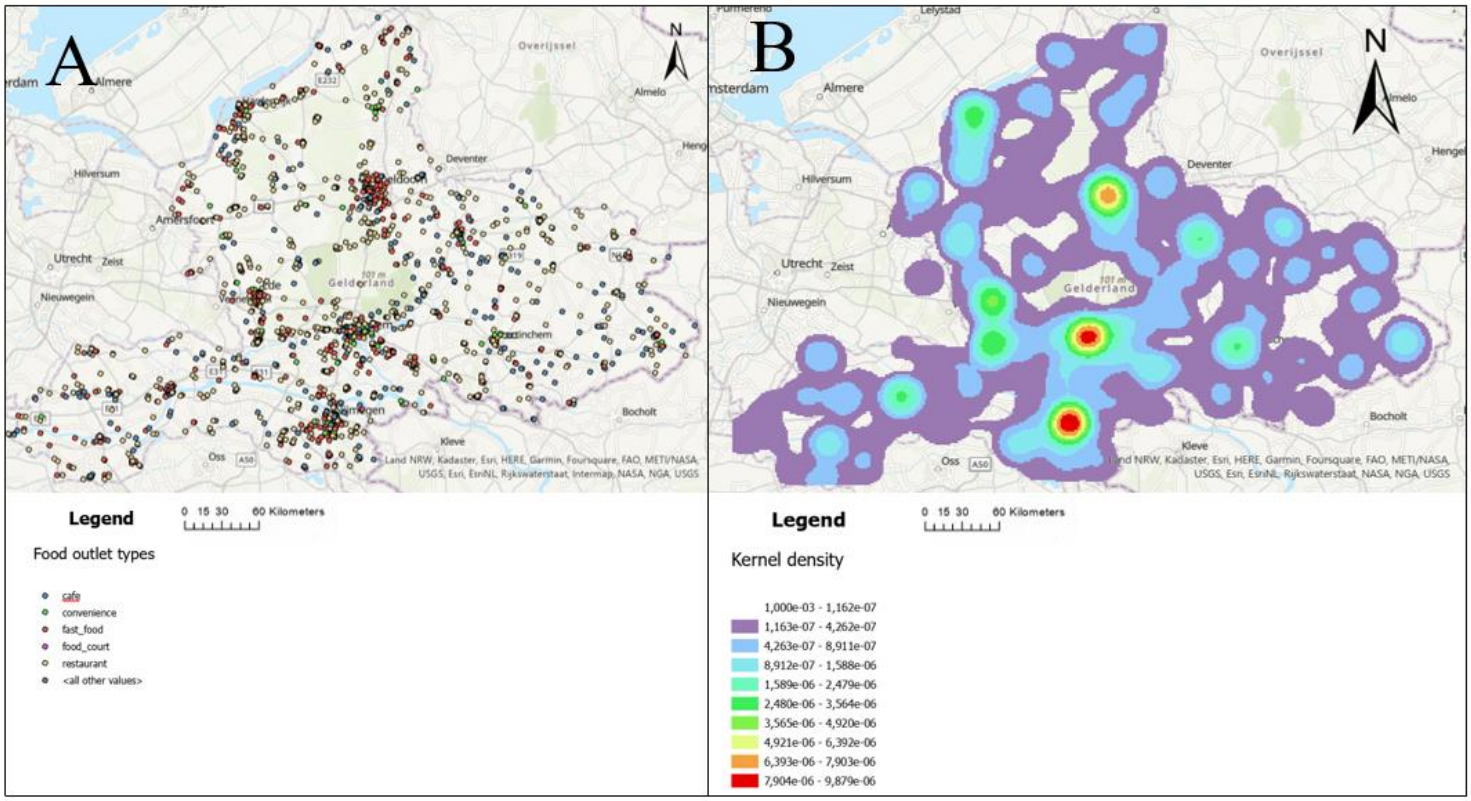

Figure 3: Map of Gelderland. (A) Distribution of food outlets in category unhealthy (table 3). (B) Kernel density estimate of food outlets in category unhealthy (table 3)

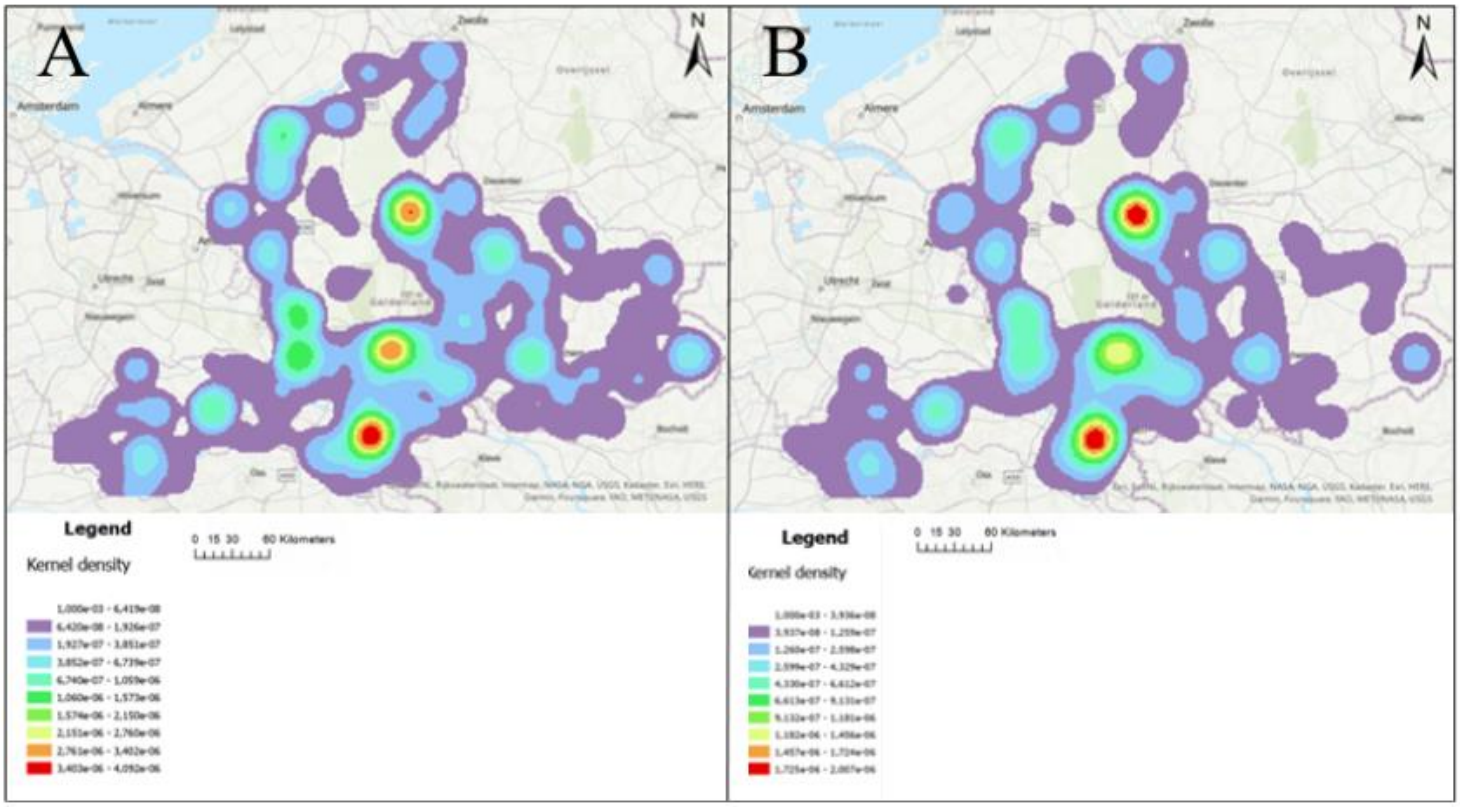

Figure 5: Map of Gelderland. (A) Kernel density estimate food outlets in category unhealthy without restaurants (table 3). (B) Kernel density estimate of fast-food outlets only.

Appendix 4

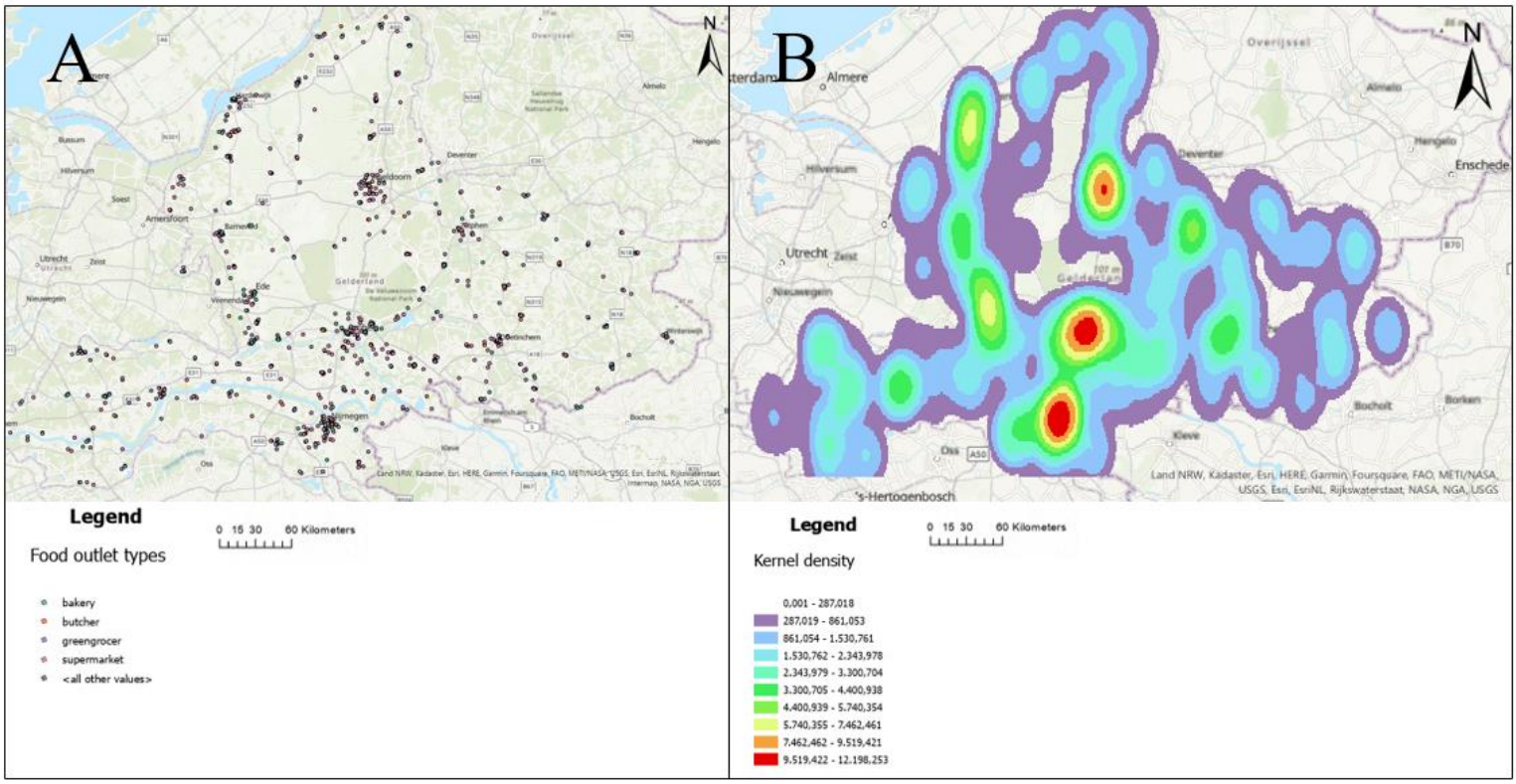

Figure 4: Map of Gelderland. (A) Distribution of food outlets in category healthy (table 3). (B) Kernel density estimate of food outlets in category healthy (table 3)