

Spatial Patterns of Obesity in the Netherlands, and Its Association with (Un)Healthy Food Store Accessibility

Benjamin Aretz^{1,2}, Rafael Costa³, Gabriele Doblhammer^{1,4}, Fanny Janssen^{2,3}

¹ Institute of Sociology and Demography, University of Rostock, Rostock, Germany

² Population Research Centre, Faculty of Spatial Sciences, University of Groningen, Groningen, The Netherlands

³ Netherlands Interdisciplinary Demographic Institute - KNAW/University of Groningen, The Hague, The Netherlands

⁴ German Center for Neurodegenerative Diseases, Bonn, Germany

Contact: benjamin.aretz@uni-rostock.de

1. Background

Obesity prevalence has globally more than doubled since 1980 (NCD Risk Factor Collaboration 2019) and is a growing public health concern. Within Europe, obesity prevalence has almost tripled since 1980 (WHO 2022). The emergence of obesogenic (food) environments (= obesogenic environment theory) is suspected to be one of the main drivers of the rapid increase in obesity prevalence (Egger & Swinburn 1997, WHO 2022). The WHO therefore recommends creating a health-promoting environment (WHO 2022).

The obesogenic food environment (FE) can affect obesity in two ways, either at the macro level through the food laws and food technology in the country, or at the micro-level through the physical presence or accessibility of food that can influence people's diet (Egger & Swinburn, 1997). Especially the micro-level FE is assumed to be one of the most important risk and prevention factor for obesity (Giskes et al. 2011, Lim et al. 2020). That is, easy and nearby access to unhealthy food combined with limited access to healthy food may lead to supernutrition, e.g. intake of food with a high proportion of fat and a high energy-dense (Swinburn et al. 1999, Swinburn et al. 2011).

The previous research on the USA found important differences in the importance of the FE between regional subtypes (see Lam et al. 2021 for a systematic literature review). People living in disadvantaged urban (outskirt) neighborhoods, so called "healthy food deserts", are forced to travel longer distances to reach FEs that offers healthy and fresh foods, compared to people in wealthier neighborhoods, where grocery stores are easier to reach (Larson et al. 2009).

However, empirical evidence on the association between unhealthy and healthy food accessibility and obesity is rare for Europe and previous research, primarily conducted for the US, revealed mixed results (Brown et al. 2019, Morales & Berkowitz 2016). Knowing about its importance would be essential for developing policy interventions to fight against the burden of obesity.

Our ecological study aims to explore the geographic distribution of obesity and associated food environmental risk and prevention factors in the Netherlands thereby differing between regional subtypes. We have formulated three research questions that build on and may extend the existing state of research:

- 1) How is unhealthy and healthy food accessibility related to obesity prevalence in the Netherlands?
- 2) How relevant is unhealthy and healthy food supply in the a) immediate and b) the wider surrounding of people to predict obesity prevalence.
- 3) How does the effect of food accessibility on obesity prevalence vary locally in the Netherlands?

2. Data and methods

2.1 Setting

Our study was based on all adults aged 19 or older living in private households in 2016 in the Netherlands. The spatial units of interest are neighborhoods (six digits zip code, “wijken”). In the Netherlands, the municipalities are subdivided in neighborhoods, which are coherent regions without a formal status that are based on several characteristics such as age structure, geographical barriers, e.g. busy roads, having similar urban and/ or architectural features, or having similar functional, social or political characteristics (Statistics Netherlands 2017).

All spatial units with valid data on the used variables were included in our analysis. Of initially 2,960 neighbourhoods, 77 (small) neighbourhoods could not be included in this study due to missing information in obesity prevalence ($n = 30$) or a missing value in any other variable of interest ($n = 47$). The final study sample covered 2,836 neighbourhoods in total.

We explored spatial patterns for the entire Netherlands and divided additionally between regional subtypes, namely urban (≥ 1500 addresses per km^2), suburban ($500 \leq 1500$ addresses per km^2), and rural neighborhoods (< 500 addresses per km^2) in line with the definition of Statistics Netherlands (Statistics Netherlands 2022a). This resulted in 785 neighbourhoods which were defined as urban, 756 as suburban, and 1,295 as rural neighbourhoods. Urban neighbourhoods were more present in the West.

2.2 Outcome: Obesity data

The obesity data were provided by the National Institute of Public Health and the Environment (RIVM 2022a). Obesity prevalence was represented by the small-area proportion of obese (BMI ≥ 30) people.

Because there are no primary microdata data for obesity prevalence available at the neighbourhood level, we used already estimated small-area obesity prevalence from the National Institute of Public Health and the Environment (RIVM) available at their website (RIVM 2022a). RIVM calculated small-area estimators for different health and lifestyle determinants across neighbourhoods in the Netherlands in 2016, using individual-level data from the Dutch Health Monitor 2016 (“De Gezondheidsmonitor”, $n = 457,153$, age 19+, RIVM 2022b), a national survey-database to observe the public health and lifestyle characteristics of Dutch individuals every four years. Small-area estimations are necessary because the number of cases gathered from the Dutch Health Monitor are mostly not sufficient to deliver per se valid measures for small-area characteristics. To yield small-area estimations the RIVM has used generalized structured additive regression (STAR) modeling to carry out parameters via restrictive maximum likelihood (REML). 12 indicators at individual (age, sex, ethnicity, marital status), household (household type, size, capital, income, income source, and home ownership) and neighborhood (urbanisation, neighbourhood code) level were used to predict the obesity, smoking and alcohol intake prevalence data for 2016. For further information on the used methodology see van de Kasstele et al. 2017.

2.3 Exposure: Food environment data

We studied unhealthy and healthy food supply in the people’s surrounding simultaneously by focusing on accessibility to three different food environment domains, namely 1) fast food stores (including grill/ lunch rooms), which were defined as **unhealthy food supply**, 2) fresh food stores, e.g. vegetable shops, bakeries, health food shops, which were defined as **healthy food supply**, and 3) **supermarkets**, which were defined as healthy food supply in accordance with previous studies (Helbich et al. 2017, Michimi & Wimberly 2010). For the more detailed definitions of the three food

environment domains see **Supplementary Table S1** showing English translations of the Dutch definitions or see the original source (Statistics Netherlands 2017). Accessibility is here defined as the access to food stores locations operationalised by their proximity in the people's surrounding in accordance with the general understanding of accessibility (Downs et al. 2020). Proximity was measured by the average Euclidean distance to the next food facilities and measures stem from 2016.

2.4 Methods

The data base was computed by linking the used neighbourhood-level data from the different sources by their unique existing six-digits zip codes (gwb codes).

To answer our **first research question** on the global associations between (un)healthy food accessibility and obesity prevalence, we estimated multivariable (linear) spatial lag of X models (SLX) thereby controlling for sociodemographic, SES, and lifestyle confounders

$$y = X\beta + WX\theta + \varepsilon$$

We checked if the residuals of obesity, the outcome of interest, was normally distributed among the studied neighbourhoods (**Supplementary Figure S2**).

We estimated models for the entire Netherlands as well as models stratified for regional subtypes, which refers already in part to **our third research question**, namely for urban, suburban, and rural settings. Lagrange Multiplier diagnostics for spatial dependence in linear models showed coherently that SLX models would outperform OLS regressions.

To answer our **second research question** on the direct and indirect effects of (un)healthy food accessibility on obesity prevalence, we decomposed each of the yielded total effects (TE) into a direct effect (DE) showing the effect of the local food environment on the local obesity prevalence and an indirect effect (IE) showing the effect of the food environment in bordering locations (here a neighbourhood) on the local obesity prevalence. This indirect effect is also called spatial spillover effect.

To answer our **third research question** on the local variations of the food environment effects on obesity prevalence across the Netherlands in 2016 more precisely, we also estimated geographically weighted regressions (GWR)

$$y_i = \beta_{i0} + \beta_{i1}x_{i1} + \beta_{ip}x_{ip} + \varepsilon_i. \quad (\text{iii.})$$

A GWR estimates β_p at each location i , so that β_{ip} is the local realization of β_p at a specific neighborhood i , which was realised by using a kernel density estimation (Brunsdon et al. 1996). For that purpose, the specific kernel function assigning the spatial weights w_{ij} and the underlying bandwidth h have to be determined. The optimisation of the bandwidth was evaluated based on both Akaike's Information Criterion (AIC) and Cross Validation (CV), and we decided to use the GWR model showing the best fit to the data based on highest R^2 and lowest AIC, which was true for an adaptive kernel with bisquare kernel function and AIC method. To find out where exactly in the Netherlands a reduction of unhealthy food accessibility independently of healthy food accessibility would be beneficial to fight against obesity, we performed the GWR for unhealthy fast food accessibility solely (but still controlled for all confounding variables).

All calculations were conducted on R 4.1.1 and packages sp, spdep, spatialreg, spgwr.

3. Key findings

Our ecological study of the geographic distribution of obesity and its associations with (un)healthy food accessibility for the Netherlands in 2016, showed that obesity prevalence was slightly higher in urban neighbourhoods (14.61%) compared to suburban (14.19%) and rural (14.09%) settings. However, when controlled for the food accessibility, socio-demographic and socio-economic determinants, obesity prevalence was higher in suburban (+ 2.62, $p < 0.01$) and rural (+ 1.14, $p = 0.01$) than in urban neighbourhoods. Regional clusters of high obesity were observed in the North East, the South West and South East.

As regards our first research question, worse accessibility to unhealthy food was significantly related to lower obesity prevalence (entire Netherlands, urban, suburban and rural neighbourhoods). Better accessibility to fresh food stores was only relevant for obesity in urban settings. No relationships were found for supermarket accessibility. (see **Table 1, TE**)

As regards our second research question, we found important indirect effects of the food environment in bordering neighbourhoods on obesity. That is, better accessibility to healthy food in adjacent neighbourhoods was associated with lower obesity in urban neighbourhoods only, and better accessibility to unhealthy food with higher obesity prevalence (entire Netherlands, urban and suburban neighbourhoods). (see **Table 1, Direct Effects & Indirect Effects**)

And, as regards our third research question, we found that effects of unhealthy food on obesity varied across the Netherlands, and that the relationships are stronger in metropolitan regions. More precisely, we observed stronger relationships in the so-called Randstad, which is a conurbation in the central-western Netherlands consisting mainly of the four largest Dutch cities (Amsterdam, Rotterdam, The Hague and Utrecht) and is one of the largest metropolitan regions in Europe. (see **Table 1, Figure 1**)

4. Discussion of the findings

Our finding that food accessibility is relevant for obesity has already been shown in previous studies conducted for the US, which used either BMI (Chen et al. 2019) or obesity (Huang 2021, Mazidi et al. 2017, Michimi & Wimberly) as outcomes. Our results indicate that this association might be important for European countries as well, at least for the Netherlands.

Our finding that food accessibility plays a more important role in regions with a higher degree of urbanity, - which was also found for the USA before (Michimi & Wimberly 2010) - might be explained by the existence of a certain threshold distance, beyond which the distance to healthy food locations no longer impacts obesity. The reason for this could be that there are differences in transportation infrastructure and travel behaviour (Pucher & Renne 2005) - urban residents make the most trips, but their trips have the shortest durations and spend less time in traveling. The opposite is the case for people from rural regions, which have to travel longer distances when they do their daily activities, e.g. claiming medical services (Probst et al. 2006). The relative time costs would then not weigh so heavy when the rural population has to travel longer distances to an appropriate food location, especially when cars for transportation were used which is more common in rural landscape (Zijlstra et al. 2022).

Another finding of our study was that the indirect effects (= wider food environment) contributed more to the total effects compared to the direct effects (= immediate food environment), and this was true for the healthy as well as the unhealthy food environments and independently of the regional subtype. The food environment (healthy or unhealthy respectively) in bordering neighbourhoods so may be more important for developing obesity than the food environment in the direct, immediate surrounding of people. This was already shown in a study for the US, which showed that the average distance between the food establishments and homes was 2.6 miles and only 34% of the visited food establishments were within participants neighbourhood census tract (Liu et al. 2015). One pathway explaining this finding could be that residential areas are usually away from commercial areas, where food locations are more present. This would indicate that people usually travel abroad administrative borders to buy most of their daily food. Furthermore, most people do not work in the same neighbourhood in which they live in. More than 20% of the Europeans commute at least 90 minutes daily (SD Worx 2018). The Netherlands Environmental Assessment Agency found that Dutch commute on average 19 kilometers per day (Netherlands Environmental Assessment Agency 2020). This would explain why people have to necessarily travel between neighbourhoods in their daily live, and may then purchase food on their way home.

We also found that, in the univariate analysis, obesity prevalence was slightly higher in urban neighbourhoods (14.61%) compared to suburban (14.19%) and rural (14.09%) settings. This, however, was not the case anymore in the multivariate model controlled for the food accessibility, socio-demographic and socio-economic determinants, where obesity prevalence proved stat. significantly higher in suburban and rural than in urban neighbourhoods. This finding could be explained by different population compositions in urban and rural regions. We know that in high-income countries, those with higher SES were less likely to be obese (McLaren 2007) and that the prevalence of obesity increases by age (Statistics Netherlands 2022c) and differs between men and women (= generally higher for men) (Schokker et al. 2007) in the Netherlands.

5. Conclusion

The findings of our ecological study for the Netherlands warrant that Dutch public health policies and urban planners may focus more on reducing unhealthy food supply in their policy making than on expanding healthy food supply. Attention is especially demanded in urban regions. When interventions are elaborated the focus should not only lie on people's immediate food surrounding, but also on their wider living environments. This calls for a superordinate policy strategy abroad municipal administrative borders in fighting against obesogenic food environments and thus the burden of obesity.

6. References

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Table 1. The relationship between healthy and unhealthy food accessibility and obesity prevalence at the ecological level among study participants ages 19 and older in the Netherlands in 2016: results from spatial lag of X models

Variable	Netherlands			Urban			Suburban			Rural		
	DE ^b	IE ^c	TE ^d	DE ^b	IE ^c	TE ^d	DE ^b	IE ^c	TE ^d	DE ^b	IE ^c	TE ^d
<i>Food environment</i>												
Average distance to next fast food store, km (urban)	-0.13	-2.31**	-2.44**	-0.98**	-1.94**	-2.94**	-0.09	-0.56*	-0.65*	-0.04	-0.08	-0.12*
Average distance to next fresh food store, km (urban)	1.10**	3.20**	4.30**	1.17**	2.54**	3.71**	-0.36	0.23	-0.13	-0.08	0.07	-0.01
Average distance to next supermarket , km (urban)	0.02	-0.22	-0.20	-0.21	0.17	-0.05	-0.27	0.36	0.09	0.02	0.03	0.04
<i>Confounders</i>												
Males, %	-0.09**	-0.04	-0.13**	-0.08**	<0.01	-0.08*	-0.05	-0.04	-0.09*	-0.03	-0.08**	-0.12**
People ages 45 to 64, %	0.12**	0.12**	0.24**	0.15**	0.07**	0.22**	0.12**	0.05*	0.16**	0.07**	0.13**	0.21**
People ages 65 and older, %	0.06**	0.01	0.07**	0.05**	0.04*	0.09**	0.03**	0.01	0.04**	0.08**	0.01	0.09**
Population density ^a , no. of inhabitants/ km ²	3.91*	-12.81**	-8.90**	-1.14	-4.82	-5.97**	4.04	-1.08	2.97	43.81**	-27.65	16.17
Non-western immigrants, %	-0.01	-0.01	-0.02*	-0.02	0.02	<0.01	0.01	-0.03	-0.02	-0.04	-0.09	-0.12**
Social welfare recipients, %	0.20**	0.10*	0.30**	0.43**	0.30**	0.73**	0.24**	-0.08	0.17*	0.14**	0.13*	0.26**
Yearly net income [*1,000 euros]	-0.10**	-0.08**	-0.18**	-0.10**	-0.05**	-0.15**	-0.19**	-0.06**	-0.25**	-0.09**	-0.06*	-0.15**
Low alcohol consumption, %	0.17**	0.02	0.19**	0.24**	-0.05**	0.19**	0.14**	0.02	0.16**	0.12**	0.06**	0.18**
Smokers, %	0.30**	0.01	0.31**	0.20**	-0.02	0.18**	0.22**	0.09**	0.31**	0.45**	-0.06	0.39**

Regional subtype, ref.				
Urban				
Suburban	1.36**	1.25*	2.62**	
Rural	1.15**	-0.01	1.14*	
<i>Food environment × regional subtype</i>				
Average distance to next fast food store, suburban	0.10	0.99	1.10	
Average distance to next fast food store, rural	1.15	2.22**	2.34**	
Average distance to next fresh food store, suburban	-1.19**	-3.55**	-4.74**	
Average distance to next fresh food store, rural	-1.18**	-3.14**	-4.32**	
Average distance to next supermarket , suburban	-0.39	1.21	0.83	
Average distance to next supermarket , rural	-0.02	0.30	0.28	
R²		0.6903	0.8182	0.6964
				0.5983

Abbreviations: No, number; sd, standard deviation; km, kilometre(s).

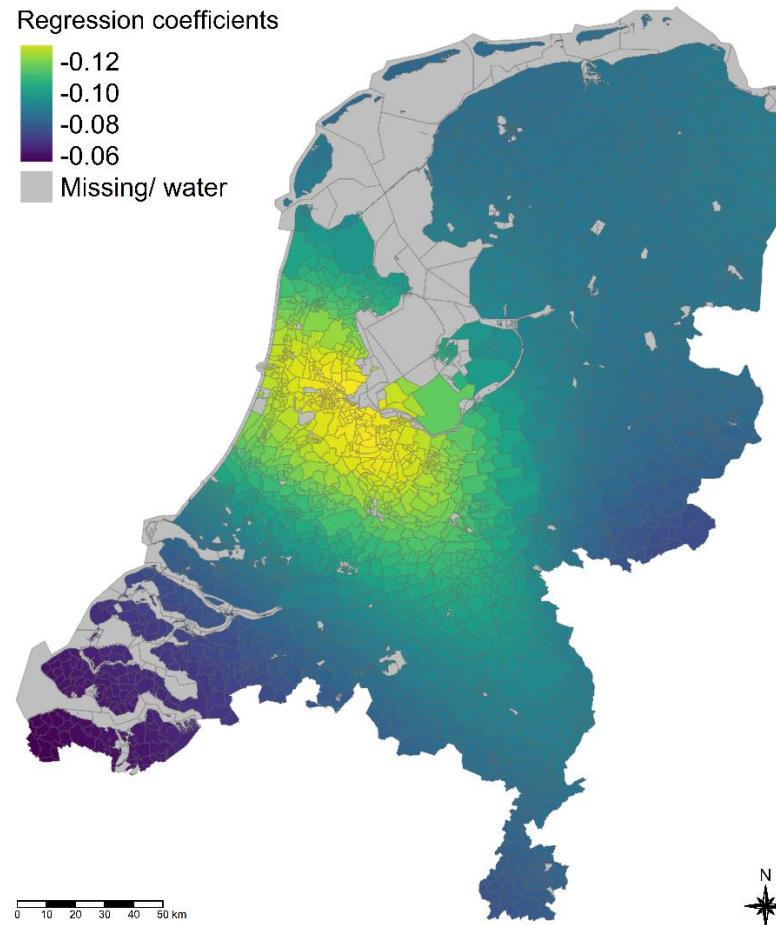
Footnote: Significant results are denoted with * $p < 0.05$, ** $p < 0.01$. ^aPoint estimators $\times 10^{-5}$.

^bDE = direct effect, which is the effect of the local food environment on the local obesity prevalence (immediate food surrounding effect).

^cIE = indirect effect, which is the effect of the food environment in bordering locations (here a neighbourhood) on the local obesity prevalence.

^dTE = total effect, which is the sum of the direct and indirect effect.

Figure 1. The spatial effect variations for fast food accessibility on obesity prevalence in the Netherlands in 2016 (GWR)



Footnote: The map shows the regression coefficients for fast food accessibility (measured in average distance to the next fast food store) on obesity prevalence (in %) across the Netherlands. Coefficients were estimated by a geographically weighted regression (GWR) model using a bisquare weighting function and an adaptive bandwidth evaluated by using Akaike's Information Criterion (AIC).