Linking Covid-19 prevalence to measures of residential density: Does Covid-19 thrive in denser areas?

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Abstract: This research examines the effects of residential density on the prevalence of Covid-19 in the Netherlands. A new measure of residential density is introduced, integrating three components of density into a sole, all-embracing density indicator and therefore expanding the proxy for urbanity. The components include the density of residential addresses, public green space and indoor space within people's homes, respectively measured by the number of addresses within a square kilometer, green space per inhabitant in squared meters and squared meters residential space per inhabitant. Regression analysis is used to assess the relationship between residential density and the number of Covid-19 infections. The main results indicate that there indeed exists a significant positive relation between the measures of residential density and the observed Covid-19 cases. No significant relation can be found between residential density and other often-used indicators such as hospital admissions or deaths resulting from Covid-19.

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1 Introduction

The Corona shock led to an unexpected change in the use of space. This change involves the lower use of public spaces and reallocation of daily activities such as working, leisure and physical activity towards private spaces. In this context, public spaces include places mostly internal to buildings such as cafes, offices, restaurants, sports clubs, universities and bars. Government measures such as lockdowns have had a severe effect on the use of these locations. On the one hand, public spaces had to decrease their capacity or were even temporarily shut down. On the other hand, there was a non-binding governmental advice to restrict travelling and to stay indoors. The combination of these two factors for avoiding public spaces resulted in a general shift towards a situation in which people have relocated their daily activities[1]. Observations suggest that in general people have spent substantially more time in private residential space or the neighbourhood centering around it. The ability to relocate daily activities, however, depends on the characteristics of a certain municipality's supply of indoor and outdoor residential space and this supply is not quite evenly spread

[1] Some countries, such as France and Spain, even prohibited people to travel beyond the borders of their residential municipality (Europese landen in lockdown: deze maatregelen nemen landen om ons heen, 2020).

across the highly urbanized Netherlands. The question now arises to what extent urban areas are 'pandemic-resistant' in terms of their composition of land and housing for residential use. This study therefore examines to what extent a pandemic such as Covid-19 may create pressure on people's quality of life, given the availability of residential space – now that people are, in part by public policy, restricted to their home environment.

Several studies have been researching the relationship between urbanity and health with the use of multiple density indicators. For example, prior quantitative research found that the presence of green space is positively related to people's health in urban areas (Maas et al., 2006) (Mitchell and Popham, 2007). Another more recent research based on a survey conducted on students in Milan shows that there is a relationship between living in small spaces and mental health (Amerio et al., 2020). Preliminary findings from a longitudinal study based on cumulative Covid-19 infections propose that urbanity is related to the prevalence of Covid-19 in terms of city size for the U.S., using data on metropolitan population numbers or the size of the metropolitan area in squared meters as predictors for size (Angel, S. & Blei, A. M. ,2020). However, the relationship between health and urbanity in the Netherlands has only been limitedly considered.

Stokols, (1972) has brought the distinction between crowding and density to the table, proposing that although these concepts are used interchangeable, there is a clear distinction between the two. Density is a rather abstract parameter and crowding arises through the perception of density, considering social, spatial and personal factors. High density does not imply crowding on a 1:1 basis and therefore high-density areas do not immediately have to bear the negative effects of crowding. Angel builds on to the broader concept of density with his 'anatomy of density' by decomposing his proposed measure of urban density -persons per hectare- into six factors of density and accordingly proposing density strategies (UN Habitat, 2020). Clearly, density across places, density is not shaped the same.

This study will shed new light on the definition of residential density by proposing three separate indicators for urbanity which thereafter are examined as being related to Covid-19 infections per capita at the municipal level in the Netherlands. The separate indicators that are taken into account in this research are: squared meters green public space per inhabitant, squared meters indoor living space per inhabitant and the number of addresses within a square kilometer. As proposed by Stokols (1972), a broader definition of density is all-embracing and two additional measures besides the density of residential addresses are taken into account to bring the two concepts of crowding and density closer together. In doing so, I draw on the official indicator for urbanity in the Netherlands which is referred to as the OAD: density of residential addresses, measured in terms of addresses per square kilometer. (CBS, 2020). According to the official definition, the density of residential addresses reflects urbanity on a 1:1 basis and therefore the two concepts can be used interchangeable.

After looking at the separate indicator relationships, the three density indicators will be combined in order to create a composed indicator that takes multiple density dimensions into account. To find out if there exists a relationship and whether it is significant, a regression analysis will be done with the help of statistical software. In addition to the regression analysis, a visual representation will be added of a map of the Netherlands in order to create a clear visual view of troublesome municipalities in terms of density and Covid-19 cases. The final step of this research is to link the composed density indicator to Covid-19 cases and to show this in a final map of the Netherlands. Based on the outcomes of the regression analysis and the visual representations, implications can be made for future housing demand.

By quick overviewing the data, it cannot be kept unnoticed that when the Covid-19 cases are sorted descending, municipalities such as Rotterdam, Amsterdam, Utrecht and 's Gravenhage are on top of the list. However, when the relative Covid-19 cases are composed, there seems to be no clear relation between high density cities and Covid-19 prevalence. The regression analysis however does show a significant and strong relation between high scores in terms of density indicators and Covid-19 cases. The composed indicator for density also shows a significant and positive relation between Covid-19 infections and overall measured density. No meaningful relation is found between density indicators and hospital admissions or deaths.

2 Theoretical framework

2.1 The scarcity of space

The basic mechanism that the research is based upon is the scarcity of space. This attribute makes the housing market a very rigid one which cannot easily adapt to changes and demand in the market. Difficulties arise in particular with higher levels of urban density, where space is scarcer. In urban dense areas, changes on the demand side cannot be anticipated directly on the supply side by building more houses and therefore an increase in demand is most likely partially reflected by a rise in prices (Paciorek, 2013). To relate this to the importance of density measurements, other mechanisms also take place to increase urban housing supply. In the short term, apartments will be shared with more people. In the long term, changes can happen in terms of an increase in address density. Housing shortage will be partially reflected by either increased household composition, decreased indoor space per person or substitution of green spaces by housing. The formerly discussed mechanisms plea for urban density measures besides solely the address density in order to create an all-embracing measure.

2.2 Real-world example

To concretize the mechanism, this will be supported by an example. Let's say for example that we have a three-floor apartment building. If we add three extra floors to the apartment and therefore double the number of addresses, the number of addresses within the squared root the building is built on, will double as well. Note however that the per capita amount of indoor space will remain unchanged. Yet the area has become denser.

Now, assume a similar apartment building. Because of housing shortage, the inhabitants decide to share the apartment and thus foster double the number of inhabitants. Even though the address density remains unchanged, the amount of indoor space per inhabitant is halved. The example above clearly illustrates that, by considering only a singular measure of density, important information can be left unnoticed and density change is not necessarily understood from the number of addresses per squared kilometer alone, despite that Dutch policy analysts tend to rely on this metric (CBS, 2020).

Considering the mechanism in which housing space is created such as in the examples above, under the assumption that no additional green space is created, the amount of green space available per capita will decrease when more people are registered within the municipality. In addition to this, green space can be considered as being on the surface, that is to say, in contrast to multi-level apartments, green spaces cannot be expanded vertically. Therefore, the possibility to create green space as a counterpart of increased housing stock is limited. While open space comes in many forms, here I focus on public green space as this is perhaps the most dominant form of open space that is both part of the compositional outlay of residential neighborhoods as considered by urban planners and likely the subject of increased use under the Covid-19 pandemic.

In addition to the mechanism of changing density components, compensation between 'domains' of density is possible (Sijtsma et al., 2012). Different forms of residential density can be experienced by the same number of people in the same amount of space. To illustrate this, a deficit in one density component could cancel out a surplus in another component, resulting in a balanced value for the composed residential density. For this study, increased address density does not have to be a problem if density level in the post-hoc situation is sufficient in terms of the indoor space, and the nearby open spaces are large enough to facilitate the needs of additional inhabitants.

2.3 Additional measures for residential density

Prior academic research on green spaces also substantiates this mechanism and stresses the importance of sufficient amounts of green public areas, proposed as a minimum of 9 m2 being sufficient 50 m2 being optimal (Russo, A. & Cirella, G. T., 2018). The general findings are relatively straightforward in terms of the positive effect it has on people, however there are different views on the way these effects are reached. In the light of this research, the relevant relation is that between exposure to greenery and health, which is found to be positive during the Covid-19 pandemic (Dzhambov et al., 2020). Other mechanism that might logically foster positive health effects are stress reduction, social interaction, physical interaction and perception of closeness to greenery, however data supporting this assumption is lacking (de Vries, van Dillen, Groenewegen and Spreeuwenberg, 2013).

Effects of public green space are argued to rather depend on perceived quality instead of the quantity and that that the quantity measure needs to be supplemented by a perceived quality measure (Zhang et al. (2017). This research assumes that when very limited green public space is available, in the situation of high-density cities, green public spaces will be preserved better, and quantity is a more important measure than quality.

It is known that there is a relationship between living in small spaces and mental health as living in small spaces has additional negative effects on physical health (Amerio et al, 2020). As Covid-19 spreads through human interaction or through the air, the major safety requirement is keeping distance from each other to prevent the spread of Covid-19. As the possibility to keep distance decreases with small indoor space, living in small spaces is added to the composed density indicator and we conclude that living in small spaces has a negative influence on mental as well as physical health.

To elaborate further on the safety requirements that are taken, such as minimizing social interaction as much as possible and staying home, these are quite in contrast with the basic elements that form the important foundation for the existence of cities. While cities represent an interaction hub, and productivity gains are obtained by the concentration of people, this makes cities more vulnerable given the spreading of Covid-19 (Sharifi, A. & Khavarian-Garmsir, A.R., 2020). In addition to this, a second attribute that make cities attractive is the quality that cities represent connectivity and decrease the travelling costs from work to home (Krugman, 1996). When minimized social interaction and working from home rather is the rule during the Covid-19 pandemic, the question arises whether concentration of people still is required for a professional environment and to what extent cities are too dense to be healthy.

If urban municipalities indeed are too dense to be healthy, people need to deviate towards other less dense municipalities. The question than arises what the optimal residential density levels are, how they can be determined, and which measure of residential density is the most important. The solution to this optimal density problem is far from straightforward and the debate on city structure has not yet settled.

3 Method

3.1 Measures of residential density

To examine the influence of residential density on Covid-19 prevalence, I introduce a composite measure of residential density. The variables included in the composite indicator are private indoor space, green public space and the density of residential addresses and these are operationalized as follows.

First, the density of residential addresses is the official measure used to determine urban density for policy analysis by the national statistical organization in the Netherlands (CBS, 2020). This measure divides the number of addresses that lie within the radius of one kilometer around an address by the area of this circle. The values for address density are transformed using the logarithmic scale in order to control for any outliers. The relation between address density and Covid-19 infections per capita will be examined through descriptive analysis.

Second, private indoor space is measured by the number of aggregate squared meters per inhabitant. Private indoor space includes the residential area people have at their disposal. The data is divided into three subgroups and there is data on the aggregate of all households. The three divisions include couples with kids, couples without kids and single households. For model simplification, solely the aggregate indoor space of all households is used in this research. The aggregate of all types of household composition is most suitable as the relation between overall density and Covid-19 prevalence and is most in line with the goal of this research to create an all-embracing composite measure. The space per person irrespectively of household composition controls for the attribute that the distribution of household type within municipalities may differ. The tool produces all-embracing values that are most suitable to use across all municipalities in the Netherlands.

Third, the relationship between green public spaces and Covid-19 cases will be examined through descriptive analysis. There is a strong inverse relation between green public space and urban density and therefore this is added as an indicator for urban density (Gaston & Fuller, 2009). The data on green spaces is transformed using the logarithmic scale, as there are large differences between the top and bottom of the list and these may cause biases in the results section. In case that after the logarithmic transformation, some municipalities show negative values, these are changed into zero, as negative values will harm the validity of the indicator.

Eventually, the results of the previous descriptive analyses are combined into a fourth and final indicator for urbanity which can be used to evaluate municipalities and indicate pressure points in terms of density. Figure 1 illustrates the method for computing the composed indicator. A composite indicator can summarize multi-dimensional realities into one value and could therefore be easily interpretated (OECD, 2008). To create the density indicator, the values needed normalisation in order to prevent ‘comparing apples with oranges’ and to be able to combine the components into one indicator. Normalisation is done by converting the density values into density indicators on a scale from 0 to 1, with 0 standing for no density presence and 1 as being most dense. Note that the relation between density and green public spaces as well as density and indoor space is inverse. To arrive at a situation in which 1 represents high density and 0 represents no density, the densities corresponding to indoor space and green public space are converted into:-(density index = 1- density indicator)- and -(green space index = 1- green space indicator)-. This research assumes that all three components capture equal weights in the composite residential indicator. Comparable methods are used by the United Nations Development Programme (UNDP) in composing the Human Development Index (HDI), which is a regularly published index that measures the three key dimensions on human development. As the HDI is a respected, common-used measure, similar methods of computing a density index will be

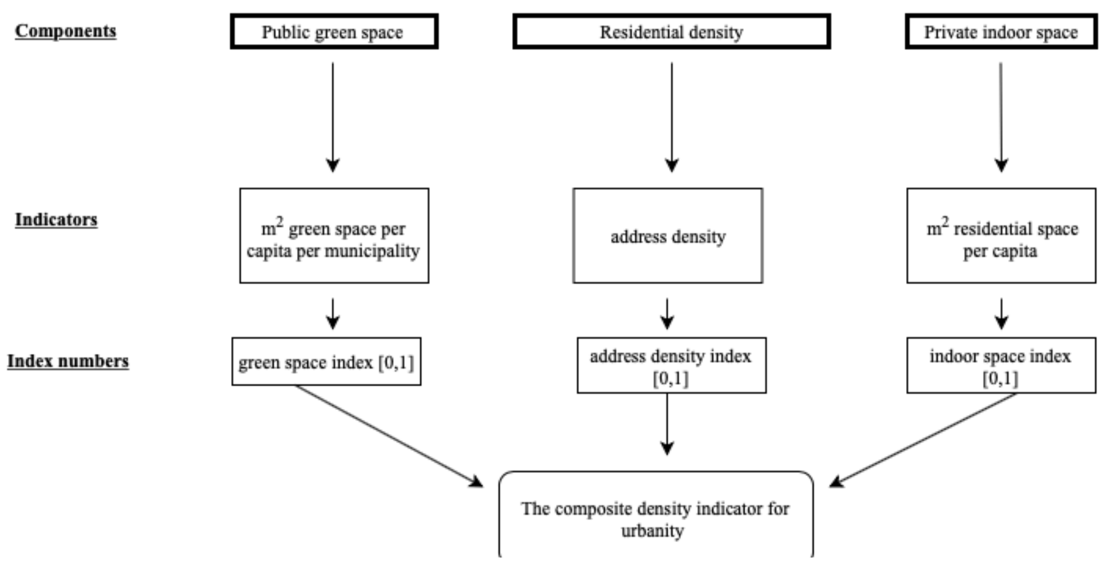

Figure 1: Creation of the composite density indicator for urbanity

repeated in order to capture a broader definition within a singular indicator for density = (Green space index * Indoor space index * Address density index) ^1/3.

3.2 Data description

This will be fully based on secondary data retrieved from the National Institute for Public Health and the Environment (RIVM) and from the Centraal Bureau voor de Statistiek (CBS). The CBS is a Dutch independent organisation that produces and publishes reliable open-source data on different, scale levels and variable time periods for the Netherlands CBS, 2020). The RIVM is an independent Dutch organisation, that produces open-source data and delivers data to the Dutch government. As the decision is made to look at the Netherlands as the research area, this research solely relies on the database of the CBS and the RIVM (CBS,2020) (RIVM,2020). The data on Covid-19 infections is published by the RIVM at country and municipality level. This study is conducted at municipality level as this research examines the differences within the Netherlands. An advantage of analyzing spatial patterns at the municipal scale is that this is quite granular and also the scale at which spatial planning is crucially organized by public planning processes. Alternative levels for this research include the lower scale neighbourhood level or the higher scale provincial level. Doing this research at a lower or higher scale influences the results in terms of vagueness and reliability in terms of outcomes.

Misallocation of Covid-19 infections can occur if people divert to testing locations that are not within their home municipality. The probability of misallocation is smaller at the higher scale than at the municipality scale as the possibility that people divert to a testing location farther away -outside their home region- is smaller. In addition to this, the probability of misallocation is higher at the lower scale than at the municipality scale. However, even though a higher scale leads to more reliable results in terms of allocation of Covid-19 infections, the higher scale makes it hard draw consistent conclusions as there might exist large differences within provinces. In defense of using a lower scale, the reliability of results could be harmed as a result of misallocation of infections. Therefore, in order to arrive at reliable results and to make implications for Dutch residents, a municipality level scale is most suitable.

The data used on Covid-19 cases consists of cumulative absolute numbers on Covid-19 cases, hospital admissions and deaths at the municipal 2020 level. The dataset used includes data starting from the 13th of March 2020 and ends on the 25th of November 2020 (RIVM, 2020). Note that the starting date of the dataset deviates slightly from the first Covid-

19 infection in the Netherlands, which was officially reported on the 27th of February. However, as cumulative numbers count up over a relatively long timespan and testing for Covid-19 happened sporadically in the first months, this does not explicitly harm the data. The broadest view on Covid-19 prevalence is reflected by a dataset that covers data from the first infection onwards. When looking at the data, it is important to keep in mind that infections often go in waves. The infection of one inhabitant will most likely cause the infection of a broader group of people, which is referred to as a 'Corona outbreak'. Showing data for a single month might shed light on a singular Corona outbreak and therefore result in a biased outcome. Therefore, the decision is made to take the cumulative number of infections instead of infections in a shorter, more recent timeframe to somewhat cover the rate of infections. The cumulative number of infections mitigates the outliers that are produced by singular Corona outbreaks and rather measures the amount and severeness of outbreaks in a longer time span. To control for the assumption that the cumulative absolute number of Covid-19 cases increases as a direct result of size as well as the indirect effects of urbanity, the reported Covid-19 cases are weighed by the municipality size in terms of inhabitants, that is, Covid-19 cases are measured in terms of observed infections per capita.

It may be noted that not each Covid-19 case is reported, as it is highly thinkable that a large percentage of the population does not engage in testing when they are experiencing symptoms and in fact are infected with the virus. This study assumes that the percentage of people refraining from testing is equal across municipalities and therefore 'non-testers' have no influence on the outcomes. Especially in the first months that the virus emerged, testing capacity was lacking and therefore influenced the testing policy that was executed by the Dutch government. Currently, testing capacity has increased and testing material has improved and is still improving. Testing has become more advanced and accessible for everyone and therefore the more recent Covid-19 infections are more likely to reflect actual infection rates. Testing policy might influence the values for Covid-19 cases, however as testing policy is pursued nationally, this does not harm the reliability of the outcomes.

In contrast to Covid-19 infections, hospital admissions might arguably be a more accurate criterion for the early months of the Covid-19 crisis than for the following months. As knowledge on Covid-19 is increasing, hospital admission can be prevented in several cases. The same holds for deaths. Both hospital admissions and deaths will be measured in terms of value per capita, in the same way infections are measured. To see whether there are differences in data between these three measures of Covid-19 effects, all three measures are plotted against the composite indicator in an additional sensitivity analysis.

3.3 Data merging methods

The data on the individual measures are merged into one dataset on the basis of municipality codes. Municipal reorganization has been implemented in the previous time period which has provoked inconsistencies in the datasets with regards to municipality names. The datasets for address density and indoor space per capita stem from 2015, the data on green spaces stems from 2017 and are retrieved from the CBS (CBS, 2020). The data on Covid-19 prevalence stem from 2020 and are retrieved from the RIVM (RIVM, 2020). In the time-period 2015-2020, municipal reorganization has caused the number of municipalities to decrease from 393 to 355 (CBS, 2020). In order to be able to combine the data from different years, the upcoming municipality mergers are calculated manually by weighing the values by the number of inhabitants. In this way, a representative image of the future-existing municipalities is created. The result is a dataset with municipality names, linked to address density, squared meters indoor space per inhabitant and the amount of green public space per inhabitant.

3.4 Empirical strategy

Regression analysis is chosen as the most suitable choice to examine the relation between Covid-19 prevalence and the various measures of residential density. In the regression, Covid-19 cases are taken as the dependent variable and the (components of the) composed density indicator as the independent variable. The correlation across the individual density components is examined by the use of bivariate analysis. Thereafter, three separate regressions are drawn with regards to the components of the residential density indicator and one regression with the residential indicator. In addition to this, a multiple linear regression is performed using enter in order to find out whether there exists a relation when the three proposed components of residential density are inserted in the model. For simplification matters, there are no control variables in the model, and we assume that solely the three components influence Covid-19 prevalence.

4 Results

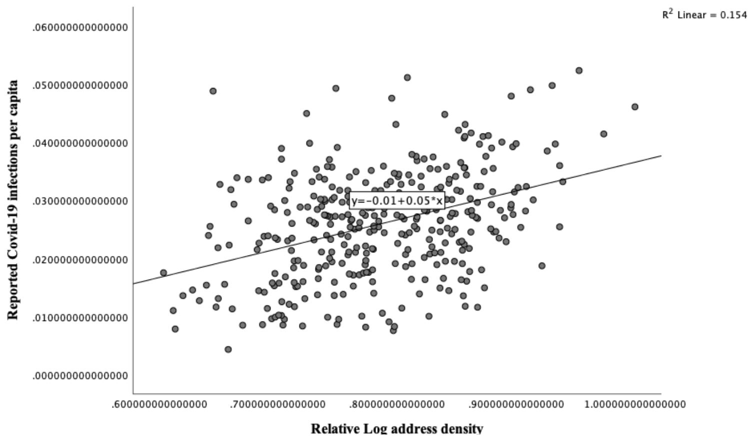

Figure 3: Regression on the relation between the address density indicator and Covid-19 prevalence

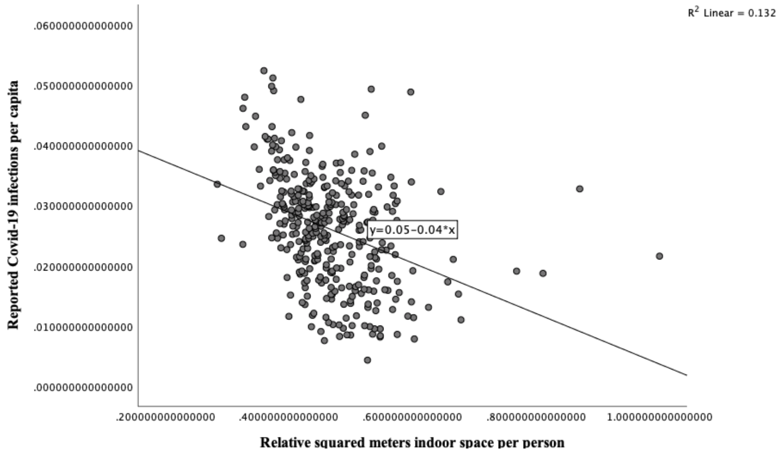

Figure 2: Regression on the relation between the indoor space indicator and Covid-19 prevalence

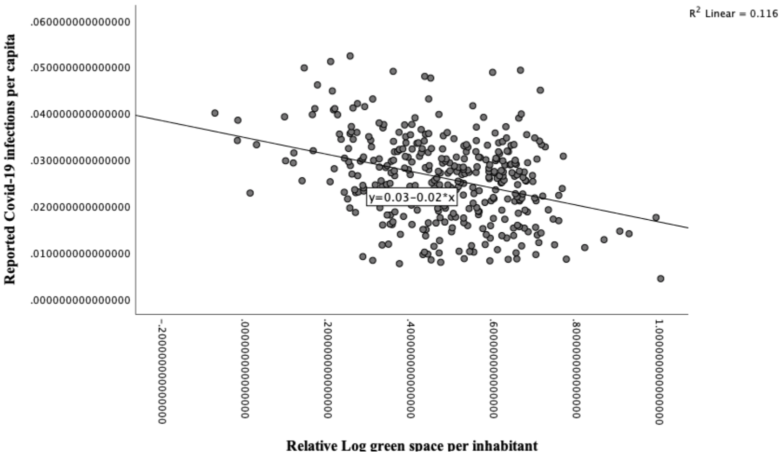

Figure 4: Regression on the relation between the green public space indicator and Covid-19 prevalence

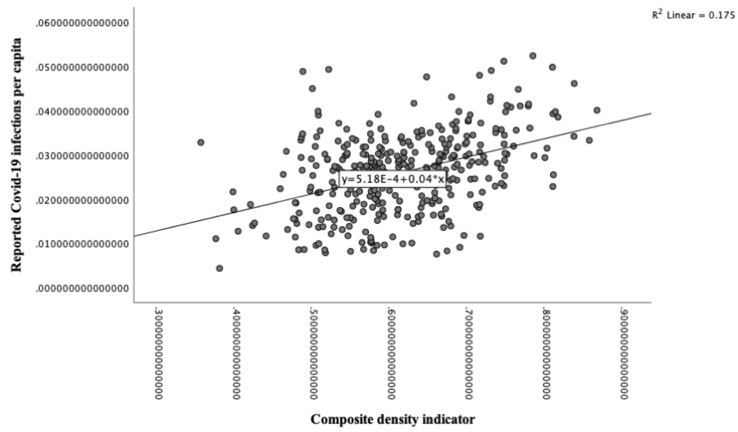

Figure 5: Regression on the relation between the composite residential density indicator and Covid-19 prevalence

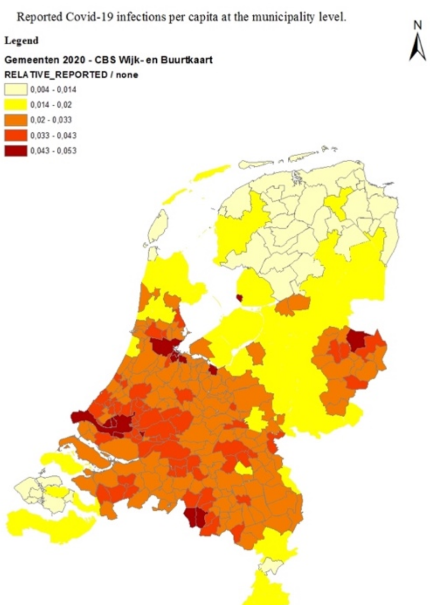

Figure 6: Covid-19 infections per capita

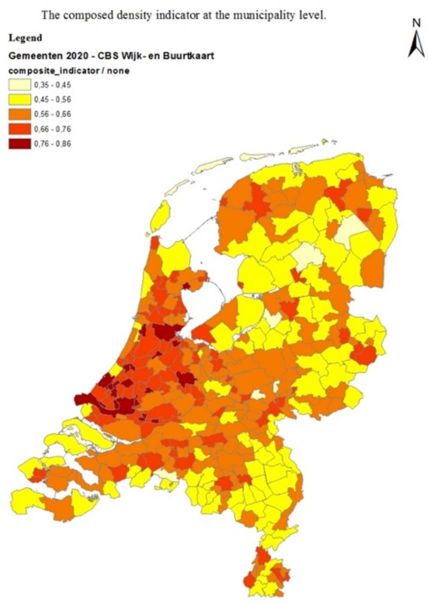

Figure 7: Composite indicator for residential density at the municipality level across the Netherlands

By comparing the list of absolute and relative Covid-19 cases, it is remarkable that the sequence changes largely when ranking the cases ascendingly. The logical order of large urban areas with high amounts of infected people seems to be affected randomly. Even though the municipalities that contain large cities are on top of the list, other municipalities that do not explicitly contain large cities rank high on infections as well.

Figures 2 t/m 4 show the relations between the components of residential density and Covid-19 infections per capita. All graphs have the measures of residential density on the X-axis and the current number of Covid-19 infections per capita measured on the Y-axis. The points depict the different municipalities. These plots show to what extent Covid-19 infections can be explained by residential density and what happens if green public space is taken as a proxy for urban density and then related to Covid-19 cases.

It becomes clear from figures 6 and 7 that there is some similarity between Covid-19 infections and residential density. However, there exist large differences between the two maps. Figure 6 depicts a clear focus of Covid-19 prevalence in the southern part of the Netherlands whereas the residential density indicator clearly shows peaks of residential density in municipalities within the Randstad or municipalities that contain large cities, such as the municipality of Groningen which has a density value of 0.712 and a corresponding value of 0.019 infections per capita.

4.1 Bivariate analysis

Performing a bivariate analysis, we find that the components of the composed indicator are correlated ($p<0.01$), with respectively Pearson correlations of. There is a strong relation between the individual predictors of density, and it is highly likely that there exist municipalities with extreme density levels pointing in the same directions. As the multicollinearity assumption for multiple linear regression does not hold, we will not perform a multiple linear regression.

4.2 Components of density

By plotting the singular address density against Covid-19 infections per capita, we find respectively a significant relation at the $p<0.01$ significance level and a Beta of 0.393 showing a positive relation.

By plotting the green public space measure against Covid-19 infections per capita, we find respectively a significant relation at the $p<0.01$ significance level and a Beta of -0,340, showing a small negative relation.

By plotting the indoor space indicator against Covid-19 infections per capita, we find respectively a significant relation at the $p<0.01$ significance level with a Beta of -0.364 showing a small negative relation.

The relation between the density indicator and Covid-19 infections per capita is significant at the $p<0.01$ significance level. The standardized Beta is 0.418, showing a positive but rather small relation between the density indicator and relative Covid-19 cases. An increase in density will result in an increase in Covid-19 cases per inhabitant. The relation is shown in figure 5.

4.3 Sensitivity analysis of alternative dependent variables

Compared to Covid-19 infections, numbers for hospital admissions and deaths are much less than those measuring the infections per capita, with respectively maximum and minimum deaths being 0.000

When plotting the composed residential density indicator against hospital admissions or deaths, there cannot be found a significant relation between density and Covid-19 prevalence measured in terms of deaths or hospital admissions.

5 Conclusions

This research has looked at the relation between residential density and the prevalence of Covid-19 in the Netherlands at the municipal level. Residential density is expanded by adding green public spaces and indoor space in order to get a broader view on the rate of urbanity across the Netherlands. With the use of statistical software, a regression analysis is performed in order to get better knowledge on the factors driving Covid-19 in the Netherlands. The most important findings include an overall positive relation between residential density and Covid-19 infections per capita. This positive relation between density indicators and Covid-19 prevalence is found to be significant for the composite indicator as well as for each proposed individual component of the composed indicator. In addition to this, there is no clear relation found between residential density and hospital admissions or between residential density and deaths. From the results, we can conclude that with increasing residential density, urban areas feed upon the prevalence of viruses such as Covid-19 and that urban areas are not as pandemic resistant as less dense, rather rural areas. Therefore, this can provoke a shock on the housing market and change housing demand on rather short notice. If certain municipalities are facing alarming residential density levels, policy implications might be needed in order to mitigate the effect of lacking space and to counteract the negative consequences such as spread of Covid-19.

Even though academic research does not arrive at consistent conclusions, there is reason to believe that certain components of residential density cause Covid-19 to thrive in urban areas. Angel & Blei (2020) find that it is rather size than density of urban areas that matters in terms of Covid-19 prevalence. Boterman (2020) arrives at similar results for the Netherlands by using the population density as a measure for density. Even though these findings are in contrast with the findings of this study, there are some important lessons that can be learned. Firstly, the density measure used by Angel & Blei (2020) as well as by Boterman (2020) is population density. This density is related to the composite residential indicator which this research relies on, however it is not part of it. In addition to this, there are large differences in terms of city structure between the Netherlands and the U.S. Rewriting the general conclusion of both studies, we find that there is supporting evidence that Covid-19 prevalence is higher in cities than in rural areas, which brings us back to the ancient question on optimal city structure.

In general, the results of this research are consistent with the line of thought that urban density can be harmful and is not solely a good thing. This is consistent with the findings of Dzhambov et al. (2020), who performed a similar study focusing on the relation between greenery and mental health and found that the prevalence of mental health issues is negatively related to the presence of nearby greenery. Additionally, the findings of this study are in line with those of Amerio et al (2020), concluding that living in small spaces can have severe consequences for health. Living in small spaces is harmful for mental as well as for physical health. The negative effects of living in small spaces can be mitigated by sufficient amounts of other density components, and sufficient green public spaces have an additional positive health effect (Sijtsma, 2012)(de Vries, van Dillen, Groenewegen and Spreeuwenberg, 2013). However, as the former introduced studies take Covid-19 into account, they rather examine the side-effects measures such as a lockdown have instead of the direct relation between Covid-19 prevalence and urbanity.

5.1 Limitations

There are limitations to this study. It is important to note that the conclusions of this study are highly generalized and based upon aggregate values which thereafter are computed to arrive at a composed indicator. Land is heterogenous within municipalities and large differences within municipalities can exist in terms of housing composition, Covid-19 prevalence, availability of green space or indoor space availability. Compensation between density indicators as proposed by Sijtsma (2012) is beneficial in terms of the flexibility for policy making, however discrepancies may appear in the use of a singular indicator. If there exist alarming values for the composed residential density indicator, such as for the municipality of Capelle aan den IJssel, the individual components of residential density need to be considered. Therefore, the results of this research are general conclusions and further, smaller scale, research is needed to examine and mitigate the effects of residential density.

5.2 Recommendations for further research

Even though the relation between Covid-19 prevalence and urbanity is a rather recent subject of research, given the relevance of this subject, there exist multiple studies that dive deeper into the relation between urbanity and Covid-19. Comparable studies have been published on the relationship between Covid-19 and variable factors, of which some can be related to residential density. It can be concluded that the concept of density is far more complex than solely can be measured by a single indicator and in order to arrive at more conclusive and comparable results, the presence of a common-used measure is highly recommended. Further research might expand on the extended measure of density and rely on a more recent, shorter time frame to control for discrepancies in the data on early months of the Covid-19 outbreak which might have biased the data.

Reference list

Angel, S. & Blei, A.M. (2020). COVID-19 thrives in larger cities, not in denser ones. Available at SSRN: https://ssrn.com/abstract=3672321

Amerio, A., Brambilla, A., Morganti, A., Aguglia, A., Bianchi, D., Santi, F., Costantini, L., et al. (2020). COVID-19 Lockdown: Housing Built Environment's Effects on Mental Health. *International Journal of Environmental Research and Public Health*, *17*(16), pp. 5973.

Bertram, C. & Rehdanz, K. (2015). The role of urban green space for human well-being. *Ecological Economics,* 120(1), pp. 139-152.

Boterman, W. Urban-Rural Polarisation in Times of the Corona Outbreak? The Early Demographic and Geographic Patterns of the SARS-CoV-2 Epidemic in the Netherlands. (2020). Available at **https://doi.org/10.1111/tesg.12437**

CBS. (2021). Gemeentelijke indeling per jaar. Retrieved from https://www.cbs.nl/nl-nl/onze-diensten/methoden/classificaties/overig/gemeentelijke-indelingen-per-jaar

de Vries, S., van Dillen, S., Groenewegen, P. and Spreeuwenberg, P. (2013). Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Social Science & Medicine*, 94, pp. 26-33.

Dzhambova, A. M., Lercher, P., Browning, M.H.E.M, Stoyanov, D., Petrova, N., Novakov, S. Dimitrova, D. (2020). Does greenery experienced indoors and outdoors provide an escape and support mental health during the COVID-19 quarantine? *Environmental Research,* Available at: https://doi.org/10.1016/j.envres.2020.110420

Europese landen in lockdown (2020, 1 november). Geraadpleegd op 2 januari 2021, van https://www.nu.nl/coronavirus/6087481/europese-landen-in-lockdown-deze-maatregelen-nemen-landen-om-ons-heen.html

Gaston, K.J. & Fuller, R.A. (2009). The scaling of green espace coverage in European cities. *Biology Letters,* 5(3), pp. 352-355.

Krugman, P., (1996). Urban Concentration, the role of increasing returns and transport costs, *International Regional Science Review,* 19(1-2), pp. 5-30.

Maas, J., Verheij, R.A. & Groenewegen, P.P. (2006) Green space, urbanity, and health: how strong is the relation? *Journal of Epidemiology & Community Health*, 60(1), pp. 587-592.

Mensah, C.A., Andres, L., Perera, U., & Roji, A. (2016). Enhancing quality of life through the lens of green spaces: A systematic review approach. *International Journal of Wellbeing*, 6(1), pp. 142-163.

Mitchell, R., Popham, F. (2007). Greenspace, urbanity and health: relationships in England

Journal of Epidemiology & Community Health, 61, pp. 681-683.

OECD, (2008). Handbook on Constructing Composite Indicators: Methodology and User Guide. available at https://www.oecd.org/sdd/42495745.pdf

Paciorek, A. (2013). Supply constraints and housing market dynamics. *Journal of Urban Economics,* 7, pp. 11-26.

RIVM, cumulative numbers for Covid-19 https://data.overheid.nl/dataset/11508-covid-19-aantallen-gemeente-cumulatief Retrieved on 15/12/202.

Russo, S. & Cirella, G. T. (2018) Modern compact cities, How much greenery do we need? *International Journal of Environmental Research and Public Health*, *15*(10), 2180

Sijtsma, F. J., de Vries, S. van Hinsberg, A. & Diederiks, J. (2012). "Does 'Grey' Urban Living Lead to More 'Green' Holiday Nights? A Netherlands Case Study." *Landscape and Urban Planning* 105(3) pp. 250–257.

Sharifi, A. (2016). From Garden City to Eco-urbanism: The quest for sustainable neighborhood development. *Sustainable Cities and Society* 20, pp. 1-16

Sharifi, A. & Khavarian-Garmsir, A.R., (2020) The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. *Science of the Total Environment* 749

Stokols, D. (1972). On the distinction between density and crowding: Some implications for future research. *Psychological Review, 79*(3), 275–277. https://doi.org/10.1037/h0032706

UN Habitat. (2020). *The anatomy of density*. Shlomo Angel. https://unhabitat.org/the-anatomy-of-density-shlomo-angel

Van Herzele, A. & de Vries, S. (2012). Linking green space to health: a comparative study of two urban neighbourhoods in Ghent, Belgium. *Population and Environment*, 34(1), pp. 171-193.

Woods, M. (2011). *Rural*. London, England: Routledge.

Zhang, Y., van den Berg, A.E., van Dijk, T. & Weitkamp, G. (2017). Quality over Quantity: Contribution of Urban Green Space to Neighborhood Satisfaction. *International Journal of Environmental Research and Public Health*, 14(5), pp. 535.

https://www.rivm.nl/monitoring-sterftecijfers-nederland

CBS

Preparing for the Next Pandemic Michael T. Osterholm, Ph.D., M.P.H.

United nations Population Division. 2014. *World Urbanization Prospects: The 2014 Revision*. new York: United nations Department of Economic and Social Affairs. Tables available at http://esa.un.org/unpd/wup/.

Woods, M. 2011. *Rural*. London, England: Routledge.