Enabling an Efficient Lockdown by Assessing Proximity to Essential Amenities in Amsterdam, the Netherlands

by

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Wednesday, June 2nd, 2021

Science major with Focus on the Environmental Sciences

Word Count: 6336

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Abstract

Contemporary research into the spread of COVID-19 stresses the importance of enabling efficient lockdowns as a method to reduce infections. However, limited access to essential amenities diminishes the ability to introduce an efficient lockdown. Using Amsterdam as a case study, I conducted a GIS analysis that assesses a neighbourhoods' proximity to essential amenities based on three measures. 1) The average distance to the nearest essential amenities, 2) the number of essential amenities that are within walking distance of a neighbourhood, and 3) The average number of customers per supermarket within walking distance of a neighbourhood. Results of the GIS analysis were used to identify areas in Amsterdam that are under-provisioned in essential amenities and therefore less prepared to implement an efficient lockdown. Large clusters of under-provisioned neighbourhoods were found in the Amsterdam districts of Noord and Zuidoost. Inhabitants of these areas may be unable to effectively socially distance, putting them at higher risk of contracting or spreading COVID-19.

<u>Keywords:</u> *COVID-19 Pandemic*, *Proximity Analysis, Lockdown Strategies, Essential Amenities, Sustainable Urban Design*

1) Introduction

Infectious diseases have long played a significant role in the development of urban planning. The high population density and connectivity characteristic for cities can exacerbate the spread of diseases among their inhabitants (Matthew & McDonald, 2006). During the early 20th century, modernist urban planning championed the idea of decentralizing urban areas, moving further away from the high density and congestion found in city centres (Batty, 2020). A famous example of this concept can be seen in Le Corbusier´s "Ville Radieuse", itself formed as a response to the spread of tuberculosis in the cities of the time, which was supposed to provide all the necessities needed in everyday life within the immediate surroundings of its inhabitants (Campbell, 2005; Fishman, 2019). However, the modernist ideals did not prevail, and over the course of the 20th century, urban policies made cities increasingly bigger and more centralized, with a strong emphasis on connectivity (Batty, 2020). While Le Corbusier´s utopian urban plans ultimately failed, some of his ideas have seen a resurgence, repackaged in emerging urban planning strategies like the polycentric city and, more recently, the 15-minute city concept.

The 15-minute city takes its name from its defining feature: necessary amenities should be reachable by the inhabitants within a fifteen-minute walk or cycle (Pozoukidou & Chatziyiannaki, 2021). Modelling neighbourhoods after this concept provides a myriad of potential benefits that are supposed to improve the inhabitants' overall quality of life. These benefits include providing them with easy access to all the essential urban social functions, reducing pollution and energy consumption, and promoting healthier lifestyles through walkability (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021). This concept has experienced increased popularity with urban planners around the globe in the wake of the COVID-19 pandemic and the lockdown strategies implemented as a response (Pozoukidou & Chatziyiannaki, 2021). When countries worldwide enacted lockdowns and travel restrictions to curb the spread of COVID-19, the aim was to reduce mobility and social interactions to reduce transmissions and prevent the spread of the virus into other regions (Cartenì, Di Francesco, & Martino, 2020). During these lockdowns, travel activities are strongly reduced to only include necessary travel, such as grocery shopping and visiting other essential amenities (Fatmi, 2020). Ensuring that these amenities are in close proximity to all citizens, like the 15-minute city envisions, could further reduce the need to travel to other neighbourhoods to fulfil one´s basic needs during a lockdown, thereby decreasing mobility and the number of interactions where a potential transmission could occur. In fact, recent research into the spread of COVID-19 showed that inadequate access to essential services and infrastructure strongly increases the difficulty of maintaining social distancing to prevent transmissions (Sharifi & Khavarian-Garmsir, 2020). Therefore, designing cities with easily accessible lockdown amenities could prove valuable in creating better strategies to combat the spread of diseases in urban areas. This strategy gains additional importance when considering the possibility of lockdowns becoming more commonplace in the future. This might occur in the case of COVID-19 becoming endemic and the emergence of new epidemics, which is increasing in likelihood due to human activity continuously encroaching on natural environments (Connolly, Keil, & Ali, 2021).

In this paper, I conduct a GIS-based amenity proximity analysis of Amsterdam to assess how well different neighbourhoods in the city provide essential lockdown amenities to its inhabitants. I am using a GIS-based proximity analysis to assess how far inhabitants of a neighbourhood need to travel to reach their essential amenities, whether they have all their essential amenities within walking distance, and how many customers visit the supermarkets that are reachable from a neighbourhood. Through this, I am able to identify neighbourhoods in Amsterdam that are comparatively under-provisioned with the infrastructure needed for an efficient lockdown. Identifying such areas could inform spatial planners about how and where to improve neighbourhood access to the studied amenities, thereby improving lockdown preparedness and potentially limiting the spread of diseases in future lockdown scenarios. Beyond enabling efficient lockdowns, improving under-provisioned neighbourhoods can also increase the general amenity equality across Amsterdam and provide the additional benefits of a 15-minute city.

2) COVID-19 in Urban Environments

With the rapid spread of COVID-19 after its emergence in Wuhan, the international scientific community started to research different strategies of containing the virus. In addition to understanding the biological characteristics of the disease to develop pharmaceutical response measures, many researchers stressed the importance of non-pharmaceutical interventions like the design of built environments to combat the spread (Lai, Webster, Kumari, & Sarkar, 2020). This section reviews contemporary research to gain insight into how mobility patterns and spatial characteristics of urban areas drive the spread of COVID-19 and how provision of essential amenities can reduce this spread. In the Methods section I use these insights to create a framework that assesses how well neighbourhoods in Amsterdam are provisioned with essential amenities that enable implementing an efficient lockdown.

Cartenì, Francesco & Martino (2020) provide a case study into the relationship between mobility and the spread of COVID-19 during the first wave in Italy. Their linear regression analysis identifies mobility habits as the most significant variable on the emergence of new cases, far ahead of other factors like population density and the amounts of tests conducted (Cartenì, Di Francesco, & Martino, 2020). Their results make a strong case for decreasing mobility to avoid further spread. Countries worldwide achieved this reduced mobility through implementing lockdown measures, during which travel behaviour declines and shifts to mostly essential trips. De Haas, Faber & Hamersma (2020) investigate the impact of lockdown on travel behaviour in the Netherlands and found that while the number of trips conducted per day decreased from 8 to 3.6, the share of the remaining trips devoted to grocery shopping increased compared to pre-lockdown. Similar results are presented by Fatmi (2020), who found that travel behaviour decreased by more than 50%, with routine shopping constituting the largest share of remaining trips. Both studies indicate the shift in behaviour during lockdown situations, where reduced mobility pushes people towards mainly conducting essential activities while avoiding longer travel times.

Beyond the research into the impact of lockdown strategies on COVID-19 transmission rates and everyday travel behaviour, a significant body of research was dedicated to understanding the interplay of COVID-19 and the spatial characteristics of urban environments. As established, urban environments possess several spatial characteristics that exacerbate the spread of infectious diseases, leading to a high reproductive number R. This reproductive number is determined by the contact rate, which measures the number of interactions among individuals where the disease can be transmitted (Stier, Berman, & Bettencourt, 2020). High population density has a significant influence on the contact rate by virtue of many susceptible individuals clustering together in a small area (Merler & Ajelli, 2010). Similarly, larger cities have been shown to experience more severe outbreaks of COVID-19 due to the higher number of susceptible individuals present and those individuals having more extensive contact networks than ones in smaller cities (Stier, Berman, & Bettencourt, 2020). However, when trying to contain the spread of a disease in a city, reducing population density or decreasing the number of inhabitants is not a feasible option as it would mean displacing the inhabitants. Therefore, the most crutial factor in responses to disease outbreaks is addressing the number and spatial distribution of interactions among the inhabitants. Aguilar et al. (2020) show that, following the implementation of mobility restrictions, the effective reproductive number of COVID-19 strongly decreases in the same pattern across US cities of varying sizes and densities. This presents mobility restrictions and stay-at-home orders as an effective measure for reducing the contact rate, independent from a cities population characteristics. Furthermore, these measures have been shown to lead to the containment of COVID-19 spread within smaller sub-regions of urban areas, with limited influence on other sub-regions (Aguilar, et al., 2020). Keeping outbreaks locally contained within these sub-regions could prevent large-scale outbreaks in urban areas. However, enacting an efficient lockdown that allows inhabitants to stay within their respective neighbourhoods requires reducing their need to leave their neighbourhoods for fulfilling their basic needs.

The importance of ensuring close proximity to essential amenities is supported by a large number of current researchers. Lai et al. (2020) stress the importance of utilising intelligent urban planning to increase the resilience of cities against pandemics. They argue for optimizing the use of transport and amenities in urban spaces to minimize the number of interactions and potential transmissions (Lai, Webster, Kumari, & Sarkar, 2020). The authors' call for improving the liveability of local neighbourhoods mirrors the concept of a 15-minute city, where necessary shops and spaces are provided in the immediate surroundings of the inhabitants. Similarly, Sharifi & Khavarian-Garmsir (2020) highlight the issue of how limited availability of necessary amenities can promote the spread of COVID-19 in cities and stress the importance of access to public health infrastructure. Even though the researchers identify a lack of studies exploring the relationship between different urban designs and the infection rate of COVID-19, they strongly advocate for urban design to improve the ability to socially distance within cities (Sharifi & Khavarian-Garmsir, 2020). Connolly, Keil & Ali (2021) come to a similar conclusion, emphasizing the importance of effective lockdown strategies while calling for more research into urban patterns and the distribution of healthcare services and other important amenities needed during a lockdown.

Despite the general consensus on the importance of access to essential everyday amenities to prevent increased transmissions, a lack of research exists in the current field. This becomes more apparent with the call for more research into the spatial aspects of lockdowns and COVID-19 being reiterated in recent literature (Connolly, Keil, & Ali, 2021; Sharifi & Khavarian-Garmsir, 2020). The gap is even more pronounced when it comes to spatial analysis studies into the provision of amenities and services during lockdown. While there exists a significant amount of literature conducting proximity analyses on urban spatial indicators, none of them study the density and proximity of amenities in relation to the spread of COVID-19. This likely relates to the still recent emergence of the pandemic. To create a framework that can assess the spatial distribution of essential amenities needed during a lockdown, I am conducting a literature review of previous studies that conduct GIS-based proximity analyses. My approach is synthesized from the methods presented in the studied literature that are most relevant to my research focus. The results of my literature review can be found in section 3.2).

3) Methods

Everyday life under COVID-19 lockdown is, by definition, a stripped-down version of the normal situation and is characterized by reduced travel activity, especially to high-contact businesses and public spaces. Therefore, this proximity analysis only includes amenities that are essential in this lockdown scenario. To assess the provision of these essential amenities, the first step concerns identifying which amenities can be considered essential and where they are located. As there is no precedent for a proximity analysis of a lockdown situation, essential amenities are synthesized from previous proximity analysis studies, research into lockdown travel behaviour, and the Dutch lockdown regulations that apply to Amsterdam. Once these amenities have been identified and mapped in the

ArcGIS software, their provision can be calculated. In creating the framework to assess the provision of essential amenities, multiple approaches from existing proximity analysis studies were reviewed and synthesized. Additionally, insights from section 2) into the importance of reduced mobility and close access to essential amenities were used to decide which amenity proximity characteristics are most relevant. The result is a framework that evaluates amenity provision based on three measures: average distance to the nearest amenity from each category, whether a neighbourhood is within walking distance to all amenity categories, and the average number of people who use a given amenity. Finally, these results are used to identify neighbourhoods that score low in all three measures and can therefore be considered under-provisioned. My analysis is was carried out in the case study area of Amsterdam, but the general framework can be applied to any high-density urban area.

3.1) Selection of Relevant Amenities and Data Collection

Important factors that are analysed in existing literature generally encompass the travel distance to doctors, pharmacies, shops, and greenspaces (Beames, et al., 2018; Kim, Burnette, An, Lee, & Cho, 2020). The relevance of including these amenities in a lockdown situation is corroborated by research into Dutch lockdown behaviour, which shows the relatively high frequency of grocery shopping trips and recreational walks in public greenspaces (de Haas, Faber, & Hamersma, 2020). Additionally, the increase in online shopping behaviour and the corresponding trips undertaken to retrieve online orders show the importance of proximity to postal facilities (Fatmi, 2020). Access to postal facilities is often disregarded in amenity proximity studies and is therefore a rare case of an amenity increasing in importance during lockdowns. The Dutch lockdown regulations indicate which amenities can be excluded in my analysis due to them being considered non-essential. These include restaurants, bars, non-essential retail like clothing and books, and other public meeting places that would otherwise be assessed in an amenity proximity analysis (Ministerie van Volksgezondheid Welzijn en Sport, 2021). Furthermore, as my primary concern is the provision of neighbourhood services to the inhabitants, this analysis also excludes places of employment and schools. Similarly, I also exclude the location of doctors. While they can be considered essential, they are not frequented on a regular basis and can become places of high transmission risk during a pandemic.

For this analysis, five categories of amenities that can be considered necessary were identified, namely supermarkets, convenience stores, pharmacies, post offices, and public parks. These five categories were chosen as they provide essential commodities or services to inhabitants and are frequented on a regular basis during a lockdown. I decided to consider five distinct categories to be able to represent travel behaviour during lockdown more realistically, compared to only studying supermarkets. The location data of these amenities and general topographic and population data of Amsterdam have been sourced from the German company Geofabrik and the Dutch Centraal Bureau voor de Statistiek (CBS). Apart from public parks, which are displayed as polygons, all amenities are given as point data. The population dataset contains a shapefile of 100 by 100-meter square polygons, which provides the number of inhabitants within each square rounded to the nearest multiplication of five. Therefore, squares that contain less than three inhabitants are shown as being uninhabited. A table detailing the datasets used in my analyses and their sources is shown below (Table 1).

Table 1: Included datasets and their sources

Data	Source	Extent	Format
Relevant Amenity Points (Supermarkets, Convenience Stores, Pharmacies, Post Offices)	(Geofabrik, 2021)	Province of North Holland	Shapefile, amenities as points
Topography of Amsterdam (Water Bodies, Public Parks)	(Geofabrik, 2021)	Province of North Holland	Shapefile, polygons
Population Square Statistics	(CBS, Kaart van 100 meter bij 100 meter met statistieken, 2021)	National	Shapefile, 100x100m square polygons
Neighbourhood Boundaries (Buurten)	(CBS, Wijk- en buurtkaart 2021, 2021)	National	Shapefile, administrative boundaries as polygons

3.2) Approaches to Determining Proximity to Amenities

The existing literature presents many possible approaches to using Geographic Information Systems to determine proximity to amenities. In identifying methods that can be used in my research, I was mostly interested in the use the geographic locations of amenities to study proximity. However, to add an additional dimension to my research, it was important to also include the quality of amenities. The quality most relevant to my research focus of efficient lockdowns, is the number of people that share a specific amenity. Many inhabitants frequenting a single location increases the contact rate, resulting in a higher number of interactions where a disease can be transmitted (Stier, Berman, & Bettencourt, 2020) Therefore, it was important to find an approach that allows for the inclusion of population density in my analysis.

A critical value needed to determine an inhabitant´s proximity to amenities is their travel distance to the nearest facility. A tool frequently used to derive this distance is the Euclidean distance tool (Dache-Gerbino, 2018). This tool enables the researcher to create a raster dataset that spans the entire study area, with every cell containing the distance to the nearest facility. Unfortunately, the Euclidean distance to the nearest amenity is prone to inaccurately portray travel behaviour as it does not account for the presence of physical barriers (Rokseth, Manum, & Nordström, 2019). The large number of canals present in Amsterdam creates physical barriers that could lead to an underestimation of travel time. Furthermore, Euclidean distance only informs the researcher of an area´s distance to the nearest amenity and makes it difficult to account for the population density or how many amenities are located near the area.

To avoid the underestimation of travel distance which the Euclidean distance approach is prone to, researchers can calculate the travel distance along street networks (Burgoine, Gallis, Penney, Monsivais, & Benjamin Neelon, 2017). While this proximity measure provides a more accurate way of quantifying accessibility, it also has the underlying assumption that residents travel to the nearest amenity (Beames, et al., 2018). In a real situation, this might not be the case, as individual behaviour can be dictated by other preferences, such as visiting a specific supermarket chain. Additionally, the same issues of the Euclidean distance tool persist, as this approach is not able to include population density and number of facilities in the analysis.

As previously mentioned, high population density and large amounts of people sharing single facilities can increase transmission of infectious diseases. Therefore, it is essential to include these factors in the assessment of amenity proximity. One possible approach is creating a buffer with a radius of maximum travel distance around a household and count the number of relevant locations included within it (Carr, Dunsiger, & Marcus, 2011). This allows to relate the number of reachable amenities to the local population density and derive the provision per inhabitant. Unfortunately, this method is mainly suited for analysing unique points of interest that the buffer can be constructed around. Applying it to every residential building in the whole urban area of Amsterdam would be severely inefficient.

To make an analysis of a large area more feasible, it is possible to increase the scale and study larger areas of multiple households by aggregating them into zones. These zones could be based on geographic shapes but also administrative regions like Zip-code areas. Schafft, Jensen, & Hinrichs (2009) utilize Zip-code areas to measure the amount of accessible grocery stores in the US state of Pennsylvania. By creating population density weighted centroids within those areas, they are able to count the number of stores that are accessible from a given Zip-code by placing a travel time buffer around the centroid (Schafft, Jensen, & Hinrichs, 2009). Unfortunately, this measure of amenity proximity is also prone to methodological errors. Large numbers of individuals are aggregated into areal units with a centroid. The bigger this area is, the higher is the risk of creating aggregation errors and encountering the Modifiable Areal Unit Problem (MAUP) (Hewko, Smoyer-tomic, & Hodgson, 2002). While using centroids of large zones like Zip-code areas might be feasible in large-scale case studies like US states, much smaller zones would need to be created for the study of smaller, high-density urban areas like Amsterdam.

Beyond measuring the number of amenities within travel distance, centroids of aggregated zones can also be used to derive the travel distance to the nearest amenity from a neighbourhood. This approach is used by Lakhani (2020), who identifies priority areas of people at high risk of Covid-19 in Melbourne and uses centroids to derive which areas need the longest to travel to healthcare facilities. However, using centroid as points of origin for distance measurement is liable to overestimating actual travel distance, as a large proportion of inhabitants is likely situated closer to the studied location than the centroid (Bateman, Jones, Lovett, Lake, & Day, 2002). Again, this further supports the use of small areas with centroids to avoid distance bias and improve accuracy, especially when studying small, high-density cities.

Each of the described approaches has its own strengths and weaknesses, so choosing a specific approach should depend on which amenities are studied and what type of environment is chosen as a case study. In my analysis, I combined different aspects of the amenity approaches that are best suitable to study travel distance, number of amenities reachable from a neighbourhood, and the average number of people that use a given amenity. The resulting framework is presented in the following section.

3.3) Framework for Assessing Amenity Proximity in High-density Urban Areas

By evaluating the methods mentioned in the previous section, I developed a framework for assessing amenity proximity that combines the methods most suitable for my case study. The framework was developed with the case study of Amsterdam in mind, but it is general enough to be applied in any urban area that possesses a high population density. It encompasses the study of amenities in urban areas according to three measures: the average walking distance to the nearest amenity from each category, whether a neighbourhood is within walking distance to all amenity categories, and the average number of people who use an amenity in a neighbourhood.

To avoid the MAUP and to make my analysis as accurate as possible, I used the highest resolution population dataset available to me. This is the 100 by 100-meter polygon dataset sourced from the CBS. These cells were used as observation units, with their geometric centre being the starting point for distance calculation. To be able to relate population data to distance values, all my results were calculated at a resolution of 100 by 100 meters. Having detailed results was of high importance for my case study of an urban area, as neighbourhood characteristics can vary widely over a small space. Additionally, the detailed results can be used in further research to pinpoint exact locations were new amenities should be located.

3.3.1) Average Walking Distance to Nearest Amenity of Each Category

To approximate the distance that inhabitants of a zone need to travel to reach essential amenities, the Euclidean distance tool was used to create raster data that displays the distance to the nearest location for each of the five amenity categories. Using the Raster calculator tool, the resulting datasets were added together and divided by the total number of categories to derive the average distance among all categories. This approach does not represent actual travel behaviour as inhabitants can plan routes to efficiently access amenities of multiple categories in a single roundtrip. Furthermore, the Euclidean distance tool cannot account for natural barriers like the travel distance along the street network, which can result in an underestimation of travel distance (Bateman, Jones, Lovett, Lake, & Day, 2002). Therefore, this measure acts not as the actual travel distance but rather as a characteristic distance value that can be used to assess which zones are located further away from essential amenities than others. Only travelling short distances to fulfil basic needs is especially important during a pandemic as it allows the inhabitants to reduce the number of interactions that can lead to the transmission of an infectious disease. Identifying neighbourhoods whose inhabitants need to walk long distances to reach their essential amenities indicates where people may be at higher risk of contracting or spreading COVID-19.

3.3.2) Number of Amenity Categories in Walking Distance

Inhabitants being able to reach all their essential amenities by walking is a guiding principle of the 15-minute city concept (Pozoukidou & Chatziyiannaki, 2021). Therefore, it is vital to assess the number of essential amenity categories that are accessible on foot from each zone. To achieve this, density rasters that count the number of amenities within a maximum walking distance radius were created. The maximum travel distance was set at 1 kilometer. Given an average walking speed of 5km/h, the distance of a 15-minute walk would be 1,2 kilometers. However, for simplification purposes and to counteract the underestimation of walking distance that Euclidean distances are prone to, the maximum walking distance was rounded down to 1 kilometer.

Calculating the number of reachable amenity categories disregards the number of individual amenities of a category that are within walking distance. Therefore, the density value had to be transformed into a dummy variable. If a zone has one or more locations within walking distance, its value was set to 1. If no locations were reachable on foot, its value was 0. This was repeated for the density maps of all five amenity categories. The dummy variable datasets were then added together to calculate the total number of amenity categories reachable within walking distance from each zone. If a zone has a score of five, it can be considered complete, as its inhabitants can reach all their essential amenities on foot. When no essential amenities can be reached on foot, a zone´s score is zero.

Having access to all essential amenities in walking distance improves the liveability of a neighbourhood and reduces the inhabitants' need to travel beyond their local areas (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021). During a pandemic, this can enormously reduce the transmission rates of infectious diseases by creating local clusters of infections that have limited influence on other areas (Aguilar, et al., 2020).

3.3.3) Average Number of People per Amenity in Walking Distance

To include the quality of amenities in the analysis, it is not only important to assess the number of amenities that are in proximity to the inhabitants of a zone, but also how many inhabitants visit a given amenity. In my analysis, this value was only calculated for the amenity category of supermarkets. The focus was placed on supermarkets as they have been shown to be the amenity visited at the highest frequency during lockdowns (de Haas, Faber, & Hamersma, 2020). Calculating the approximate number of visitors that frequent an individual supermarket can be done by relating population density values to the supermarket density. To do this, the number of inhabitants per 100 by 100-meter zone was divided by the number of supermarkets that are within walking distance from the zone. This provides the number of people per reachable supermarket. Using the Focal statistics tool, a raster with the sum of people per supermarket in a radius of 1 kilometer from each cell was calculated. This value was then assigned to the individual supermarket data points by means of extracting the raster value to the point data, which yields the number of people who use a specific supermarket.

Calculating the number of customers that visit the unique supermarkets allowed me to assess the busyness of the average supermarket that can be reached from a zone. To do this, a point density raster using the customers per unique supermarket point data was created, which contains the total number of people that use supermarkets within walking distance of a zone. Next, the Raster Calculator tool was used to divide this value by the number of supermarkets that are within walking distance of a zone. The resulting raster contains the average number of customers for supermarkets within walking distance. Sharing a supermarket with a large number of other customers can lead to an increased risk of transmission due to the higher amount of potential interactions that can occur. Therefore, people living in areas with few available supermarkets and high population density might have a higher risk of contracting an infectious disease when visiting a supermarket.

3.4) Identifying Under-provisioned Neighbourhoods

The results of the analysis are given in raster cells at a resolution of 100 by 100 meters. This makes it difficult to identify specific areas that are under-provisioned with essential amenities. To increase the comprehensibility of the results, raster values were aggregated into neighbourhoods. To minimise the loss of accuracy and resolution that occurs with aggregation, the smallest available administrative neighbourhoods recognised by the Dutch government were used. Shapefiles displaying these neighbourhoods, named “Buurten”, were provided by the CBS. Aggregating into neighbourhoods means sacrificing some of the detail provided by the raster data. However, the aggregated raster neighbourhoods still possess more accuracy, and are less susceptible to the MAUP, than an analysis using the neighbourhood centroid as a starting point.

Aggregation was achieved by using the Zonal Statistics as Table tool to calculate the average value for the raster cells that fall within the overlaying neighbourhood polygon. Once all the results were aggregated into neighbourhoods, areas that can be considered under-provisioned were identified. Under-provisioned implies that an area has low provision relative to the other areas. An approach to identifying such areas of interest is presented by Lakhani (2020), who uses statistical analysis to identify priority areas vulnerable to COVID-19 based on whether they have both a high number of aging population and inadequate access to healthcare facilities. Similarly, my approach to identifying under-provision entailed using statistical analysis software to identify neighbourhoods that achieved a low score on the three different measures. Neighbourhoods that score worse than the third quartile, placing them in the lowest 25 percent of neighbourhoods, in all three measures were considered under-provisioned. The third quartile threshold values, beyond which scores were considered low, were more than 881 meters average travel distance, less than 4 reachable amenity categories, and more than 5290 customers per reachable supermarket. This definition of under-provisioned is somewhat arbitrary and a different threshold can be chosen according to the research purpose. For example, if the number of amenity categories in walking distance is seen as the most important measurement, any neighbourhoods that score lower than five could be considered as having a low score.

4) Results

The results of the amenity proximity analysis, aggregated into Amsterdam neighbourhoods, were used to create maps. While the resulting maps only display the extent of the Municipality of Amsterdam, it should be noted that amenities outside of the municipal borders were still included in the analysis. When visiting shops or parks, it is unlikely that the choice of location is influenced by the municipal boundaries.

Figure 1 displays the neighbourhoods' average distance to the nearest amenity from each category. A clearly observable pattern is that average travel distance increases further away from the city centre. People living in Centrum and in the neighbourhoods of West, Zuid, and Oost, which are adjacent to Centrum, generally travel less than 800 meters to reach any of their essential amenities. Smaller clusters of high scoring neighbourhoods also exist in Noord, Nieuw-West, and Zuidoost. Meanwhile, inhabitants of Westpoort, and the more distant areas of Noord and Zuidoost are required to travel further to fulfil their basic needs. This pattern is likely due to the high density of amenities available in the more populated areas near the city centre.

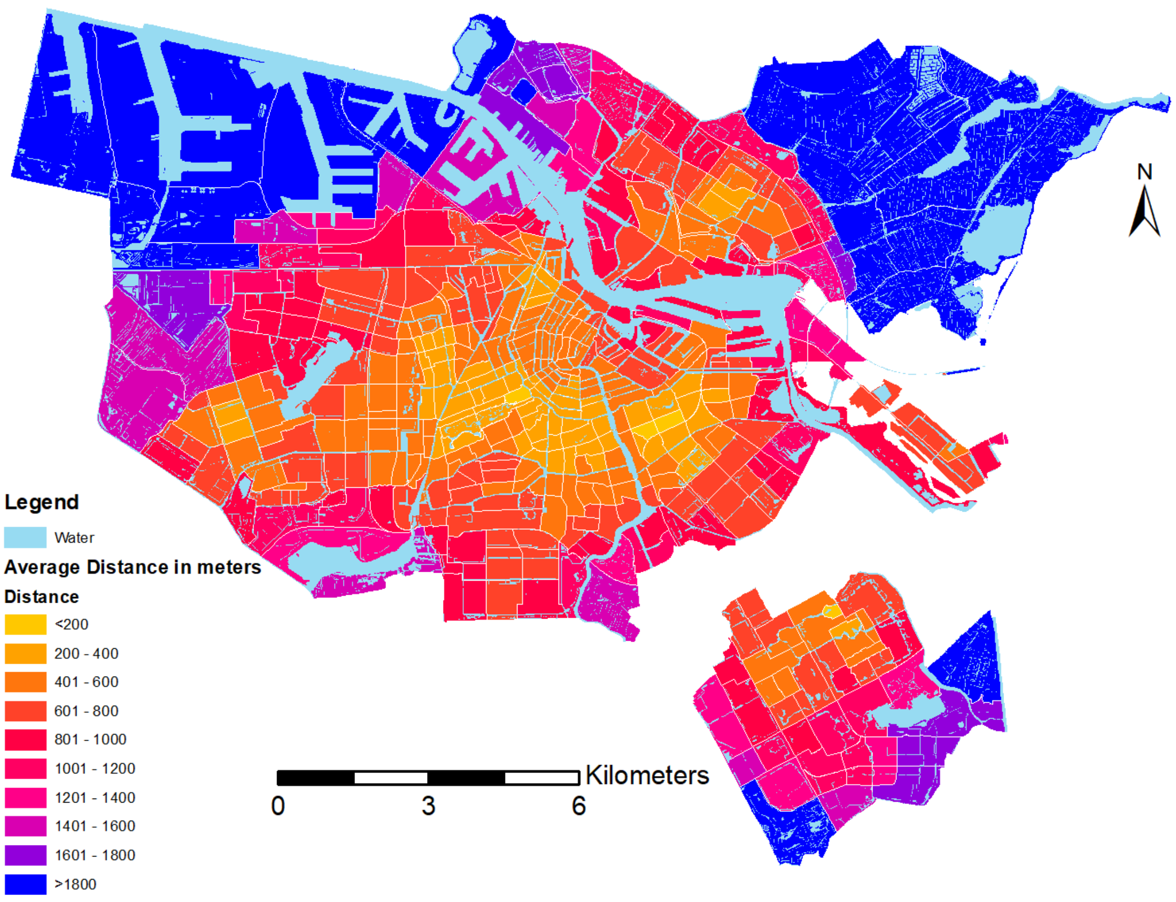

Figure 1: Average travel distance to the nearest facility from each amenity category

A similar pattern can be observed in Figure 2. Neighbourhoods near the city centre have a higher number of essential amenity categories within walking distance than those on the outskirts. The patterns being similar was to be expected, as having few amenities close by would mean that inhabitants need to travel further outside their local neighbourhood. Complete neighbourhoods, where all amenity categories can be reached within walking distance from any point in the neighbourhood, are marked in dark green. Interestingly, Centrum has only a few complete neighbourhoods. This is due to the absence of public parks in the historic city centre. The phenomenon that the value decreases at the outskirts is not observed in Nieuw-West, where neighbourhoods near the city limits are adequately provided with essential amenities.

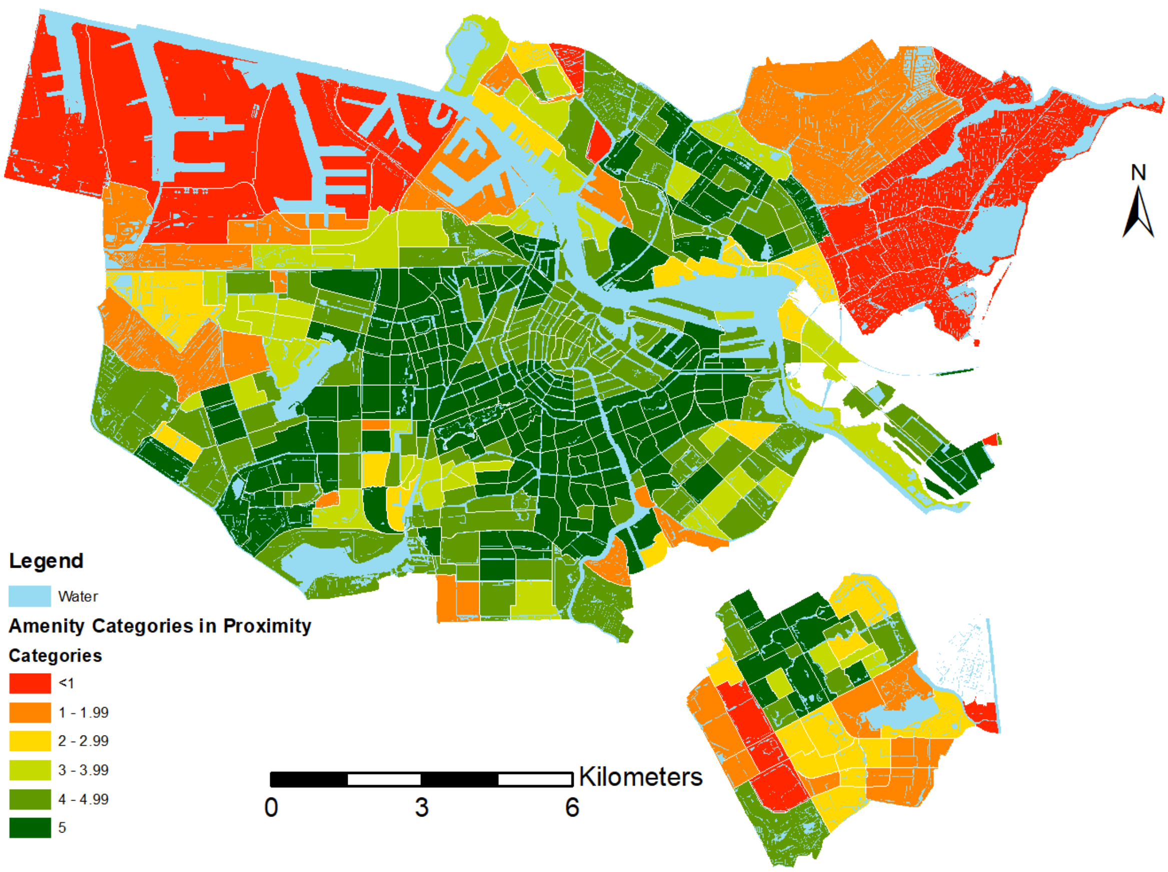

Figure 2: Average number of amenity categories in walking distance

The average number of customers that use a supermarket within walking distance from a neighbourhood is shown in Figure 3. This map shows somewhat different results than the previous two. Most neighbourhoods in Centrum, Zuid, and Oost still score very high. In contrast, supermarkets located in West are shown to have a high number of customers per location. This suggests that, unlike the other central areas, neighbourhoods in West do not have as many supermarkets relative to the high population density. The low customer values observed in the historic city centre might be misleading. These areas have a low number of registered inhabitants but a high number of temporary visitors in tourists which are not accounted for in my dataset. The actual number of customers that use supermarkets is likely higher. However, during a lockdown this can be disregarded due to only few tourists being present in the city.

Noord, Nieuw-West, and Zuidoost generally have very busy supermarkets. An exception is the presence of some high scoring areas in Noord, where inhabitants share facilities with only a small number of people. No values could be calculated for some neighbourhoods in Westpoort and Noord due to no supermarkets being reachable in walking distance from those areas.

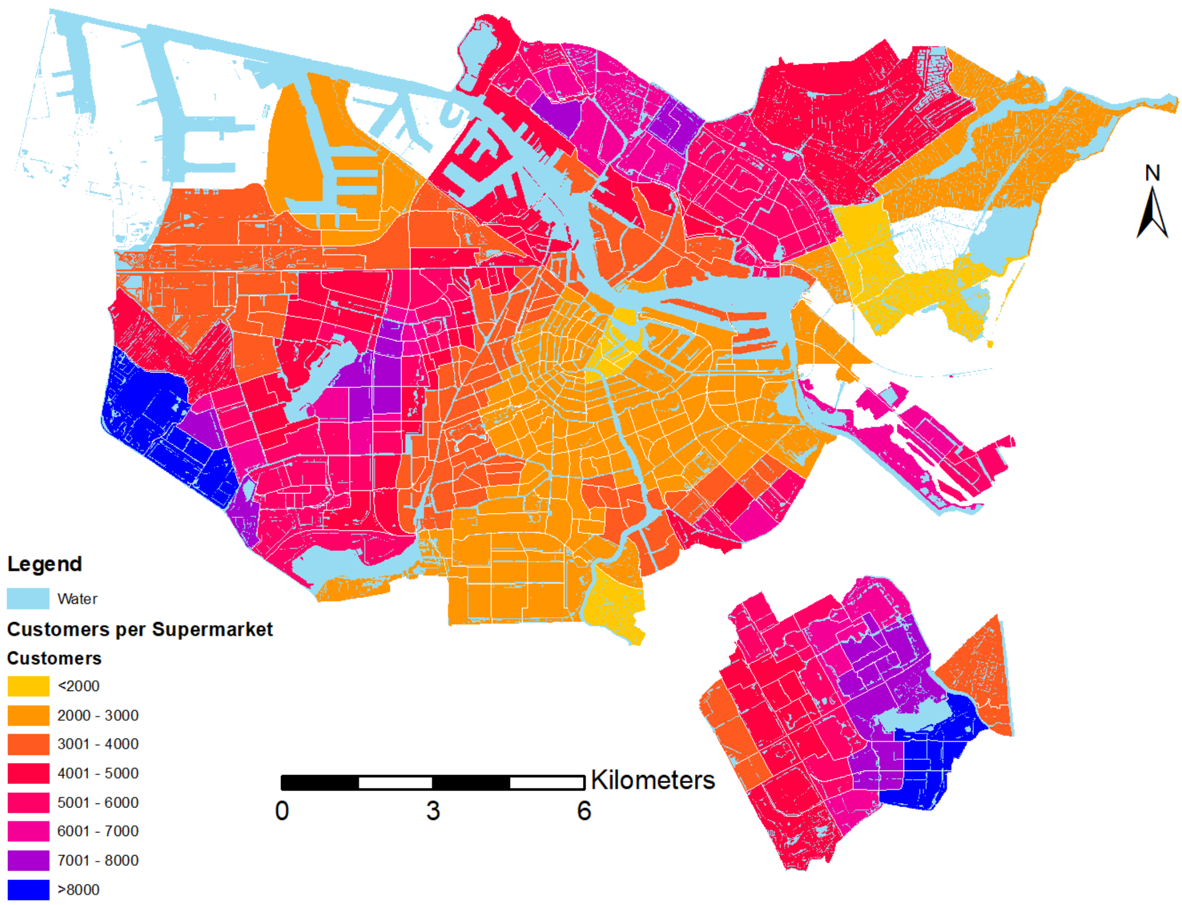

Figure 3: Average number of customers for supermarkets in walking distance

Neighbourhoods that are considered under-provisioned in essential amenities are shown in Figure 4. The map also includes neighbourhoods that could not be assessed, which are marked in grey. An area had to be excluded from the analysis if no data was available for any of the three measures of travel distance, number of amenity categories, or customers per supermarket. This mostly occurred due to no supermarkets being within walking distance of the neighbourhood.

Neighbourhoods considered under-provisioned are colour-coded by city district. The map shows two large clusters of under-provisioned neighbourhoods, one in Amsterdam Noord and one in Zuidoost. Both clusters are located at a significant distance from the city centre, bordering the city limits. Apart from the clusters, two additional under-provisioned neighbourhoods were identified. Noorderstrook West is located in Noord, not too far away from the cluster. The other neighbourhood, Park Haagseweg, is located in Nieuw-West. Interestingly, Park Haagseweg is the only under-provisioned neighbourhood outside of Noord and Zuidoost.

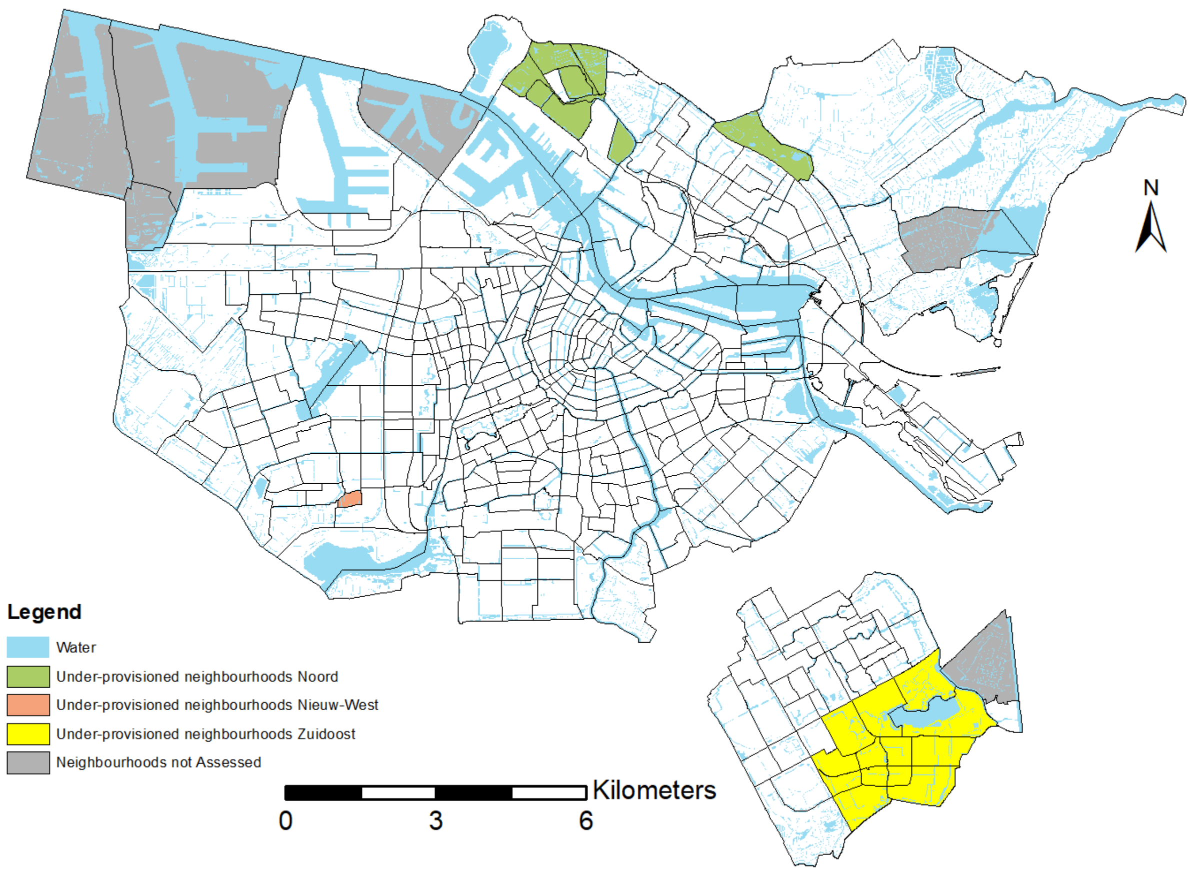

Figure 4: Neighbourhoods determined to be under-provisioned in essential amenities, colour-coded by city district

Table 2 displays the names and scores of the under-provisioned neighbourhoods shown in Figure 4. Like in Figure 4, neighbourhoods were colour-coded by city district. The information in Table 2 can be used to investigate why Park Haagseweg is the only under-provisioned neighbourhood in the area. It shows that the neighbourhoods scores slightly above the third quartile threshold in both the average travel distance (897 meters at threshold of 881 meters) and customers per supermarket measures (5437 customers at threshold of 5290 customers). This led to Park Haagseweg being classified as under-provisioned while adjacent neighbourhoods were not.

Table 2: Under-provisioned neighbourhoods and their scores, colour-coded by city district

Neighbourhood (Buurt)	Average Travel Distance (in meters)	Number of Amenity Categories Present	Number of Customers per Supermarket
Tuindorp Oostzaan West	1818.461	3	6965.176
Tuindorp Oostzaan Oost	1544.29	3.802817	7916.132
De Bongerd	950.1934	0.822222	6393.648
Oostzanerdijk	1772.097	1.285714	5445.037
Walvisbuurt	1673.611	2.302326	5440.558
Twiske West	1555.647	0.364865	6105.278
Molenwijk	1633.644	3	6105.278
Noorderstrook West	1147.3	3.913043	5750.426
Park Haagseweg	897.2083	1.130045	5436.993
L-buurt	1165.251	1.564706	7712.326
Gaasperpark	1234.494	1.253968	7915.959
Gaasperplas	1691.115	2.057143	8731.667
Reigersbos Noord	1002.446	2.363636	5692.854
Holendrecht Oost	1028.212	2.192308	5818.514
Gaasperdam Noord	1139.012	2	7150.641
Gaasperdam Zuid	1199.405	2	7400.3
Reigersbos Midden	1154.934	1.987342	5889.11
Reigersbos Zuid	1479.287	2.722222	6882.898
Gein Noordwest	1326.424	2.294118	7591.269
Gein Zuidwest	1383.185	1.734375	7450.555
Gein Noordoost	1651.08	1.987342	8731.667
Gein Zuidoost	1673.953	1	8404.321

5) Discussion

The amenity proximity analysis of Amsterdam identified a total number of 22 neighbourhoods that are under-provisioned in the essential amenities needed to enable an efficient lockdown. The inhabitants of these neighbourhoods may be at a higher risk of contracting COVID-19 during a lockdown due to multiple factors. Cartenì, Francesco & Martino (2020) identify travel behaviour as having the most significant impact on infection rates. As the inhabitants need to travel longer distances to reach their essential amenities, they are more likely to contract or spread the disease during their visits to an amenity. Furthermore, as these neighbourhoods are not provided with all the essential amenities needed during a lockdown, its inhabitants' ability to effectively socially distance themselves within their local areas is severely diminished. This increases the difficulty of containing the spread of infectious diseases (Sharifi & Khavarian-Garmsir, 2020). Lastly, the supermarkets they frequent have a significantly high number of customers, which increases the contact rate and thereby raises the chance of contracting or transmitting COVID-19 (Merler & Ajelli, 2010).

To improve these neighbourhoods, new amenities should be placed in areas where they serve the most significant number of under-provisioned inhabitants. Doing this would reduce the number of interactions that can lead to transmissions and enable an efficient lockdown (Lai, Webster, Kumari, & Sarkar, 2020). The areas that should be prioritized when developing improvement strategies are the two large clusters in Noord and Zuidoost, shown in Figure 4. Even small interventions, such as placing a single additional amenity in those clusters, could provide strong benefits to many inhabitants. Particular emphasis should be placed on ensuring that inhabitants are provided with all of the essential amenities within walking distance. Doing this can help improve the neighbourhood´s ability to contain the spread of COVID-19 locally, thereby also protecting other neighbourhoods throughout the city (Aguilar, et al., 2020). Furthermore, doing this would also reduce the average travel distance to the nearest amenity.

The framework used to derive these results comes with some limitations. The average distance measure is susceptible to multiple inaccuracies. Using the Euclidean distance value makes it prone to underestimating the actual travel distance (Bateman, Jones, Lovett, Lake, & Day, 2002). Furthermore, it cannot account for spatial barriers between the amenity and the inhabitants, such as the large number of canals and rivers flowing through Amsterdam (Rokseth, Manum, & Nordström, 2019). The measure of average number of customers per supermarket can also be improved. A more accurate assessment would be the average number of customers per square meter of supermarket. Larger supermarkets can accommodate more people and improve the ability to socially distance. In its lockdown guidelines, the Dutch government sets the number of customers allowed in a shop at 1 per

10 square meters (Business.gov.nl, 2021). Unfortunately, I was unable to find data on the capacity or size of supermarkets which would be needed to improve the results. Finally, it is uncertain whether improving these under-provisioned neighbourhoods would have any impact on the transmission rates of COVID-19 in Amsterdam.

Additional inaccuracies may have been introduced by the datasets used. The locations and names of all the essential amenities were sourced as OpenStreetMap data from Geofabrik. While the dataset is updated on a regular basis, it is possible that it includes locations that no longer exist. Furthermore, OpenStreetMap data is generated by many independent contributors. It is possible that the list of amenities is incomplete or that locations were mapped inaccurately.

For additional research, my results can be used to investigate linear relationships between amenity provision and other spatial characteristics (Kim, Burnette, An, Lee, & Cho, 2020). One potential use would be to search for a correlation between the low provision of neighbourhood amenities and an increased spread of COVID-19. Finding a correlation between neighbourhoods being under-provisioned and increased COVID-19 infections would make a strong argument for providing additional essential amenities to those neighbourhoods. To carry out this regression analysis, data on infections at the neighbourhood level would be required. This kind of high resolution COVID-19 dataset was unavailable to me.

Beyond the scope of COVID-19 and efficient lockdowns, my framework identifies general spatial inequalities that occur in Amsterdam. Improving those disadvantaged neighbourhoods would improve the general quality of life of its inhabitants like the 15-minute city concept envisions (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021). Furthermore, my framework is highly adjustable according to the research purpose. Other types of amenities can be selected and analysed. The framework can be applied to any case study areas characterized by high-density of population and amenities. Possible applications range from comparing provision of day-care facilities for children in different neighbourhoods to identifying areas of high demand best suited as a location for a new shop.

6) Conclusion

In this paper, a framework for the assessment of proximity to essential amenities needed to enable efficient lockdowns was developed based on research into COVID-19 spread and common proximity analysis approaches. This framework was then applied to the case study of Amsterdam. The results identify multiple areas that can be considered under-provisioned with essential amenities needed during COVID-19 lockdowns. Two clusters of under-provisioned neighbourhoods, one in Amsterdam Noord and one in Amsterdam Zuidoost, deserve particular attention. Improving these two areas by supplying additional amenities would enable inhabitants to more efficiently socially distance and limit the spread of COVID-19. This information can be used by spatial planners to improve Amsterdam´s resilience to pandemics.

Despite some possible inaccuracies, the developed framework provides a comprehensive method of identifying spatial differences in amenity provision and quality. The method is highly adaptable and can be used to uncover unequal provision of any type of amenities. Such an approach is valuable for a wide range of purposes as it uncovers spatial inequalities and can be used to identify optimal locations where new amenities should be placed.

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