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Cycling to get my vaccination: how accessible are COVID-19 vaccination centers in the Netherlands?

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Abstract. Ensuring populations can easily access testing and vaccination centers is important during a pandemic to minimize future infection risks. Many factors can affect accessibility to such vital health services. Of these, physical accessibility and the ease in which people can get to a center are important. In this study, we examined accessibility to COVID-19 vaccination centers in the Netherlands using a common mode of transportation, the bicycle. Our study utilized data available in the public domain. Accessibility was determined using cumulative opportunities measure to identify variations in accessibility by bicycle at the height of the vaccination campaign (N=193 vaccination centers) and as centers were closed (N=99). Initially, 45% of the population had access to a vaccination facility by bicycle. However, after some centers closed, this number fell to 28%. The elderly (> 65 years) were the most affected age group. Our study shows how open data and a GIS-based approach can provide accurate and timely information to the general public and public health officials and aid in critically assessing infrastructure needs.

Keywords. geohealth, accessibility, open-data, spatial data science, service area, health centers, bicycles

1 Introduction

In 2020 the COVID-19 pandemic affected populations around the world. By the end of 2021, more than 290 million people were infected, and 5.5 million lost their lives (Worldometers, 2023). In response, several vaccines were developed in 2021 (He et al., 2021). Countries developed mass vaccination campaigns (He et al., 2022) using a variety of vaccination strategies (Cadeddu et al., 2022; ECDC, 2022; Wouters et al., 2021) to inoculate populations. Given the nature of the virus and its ability to mutate to multiple variants (Ramos et al., 2021), it was also expected that each center would need to be used several times to enable booster shots to be administered (Burki, 2021) To enable for mass vaccinations and vaccinate the population as efficiently as possible, vaccination centers were set up in locations to enable for large numbers of the population to be vaccinated efficiently.

In the Netherlands, vaccinations were rolled out based on risk, vulnerability, and age (Rijksoverheid, 2020). The Dutch government, represented by the Dutch municipal health services (Gemeentelijke Geneeskundige Dienst (GGD)), prioritized vaccinating people with risky medical conditions, the elderly (60 years and older), and health workers. Many vaccination centers were set up in large sports halls and parking lots (NU, 2020; Van Gameren, 2021). Once a large proportion of the population was vaccinated and vaccination numbers decreased, the GGD gradually closed vaccination centers (van Annemieke, 2021).

1.1 GIS for health

GIS and spatial analysis are useful for evaluating the location of healthcare services (Alemdar et al., 2021; Ouma et al., 2021). That includes measuring accessibility to healthcare facilities using different modes of transportation (Blanford et al., 2012; Ouma et al., 2021), examining facilities coverage and usage (Hernandez et al., 2021), and evaluating inequalities in the distribution of vaccinations (Cromley and Lin, 2022). Accessibility to vaccination centers can be measured using cumulative opportunities measure (Geurs and van Wee, 2004). Based on predetermined travel distance or time, the measure can draw contour lines or isochrones around the health facility to show areas within a defined accessibility range. When compared to other accessibility measures, cumulative accessibility measure demands less data, are simpler for stakeholders to interpret, and can be easily applied to large-scale national projects.

Since the vaccination campaigns started, several studies examined the impact of COVID-19 vaccination rates on access to critical care for persons fully-vaccinated versus those not fully-vaccinated(Cromley and Lin, 2022); evaluated methods for assessing accessibility to Intensive Care Units (ICU) for COVID-19 patients (Bauer et al., 2020; Ghorbanzadeh et al., 2021); assessed inequalities in accessibility in rural areas compared to urban areas for different ethnicities (Kim et al., 2021) and vulnerable populations (Whitehead et al., 2021) and examined inequalities in spatial accessibility to COVID-19 test centers using different modes of transport (cars vs. pedestrians)(Tao et al., 2020). Despite the scientific effort to measure accessibility to healthcare facilities during the pandemic around the world, none considered accessibility by bicycles to vaccination centers, a common mode of transportation in the Netherlands.

1.2 Cycling in the Netherlands

About 85% of the Netherlands population owns private bikes and has 22,000 km of bicycle lanes (Heinen et al., 2013; Rietveld, 2000). More than a quarter (28%) of all trips are made by bike (De Haas and Hamersma, 2020). Bicycles are mostly used for leisure, shopping, and work (De Haas and Hamersma, 2020). During the pandemic, the average distance for cycling increased from 3.4 km to 4.4 km in 2020(De Haas et al., 2020), and 37% of the population used bicycles as an alternative to public transportation (except for trains) (De Haas et al., 2020). Therefore, this study examines accessibility to COVID-19 vaccination centers using bicycles as the transport mode.

This study aimed to evaluate physical accessibility levels to COVID-19 vaccination centers by bicycle and how this changed over time as vaccination centers closed.

2 Materials and method

2.1 Data

Population data for the Netherlands with a spatial resolution of 100 x 100 meters was obtained for 2018(CBS, 2018). Data included the number of residents and age categories. The age groups were categorized as follows: 0 to 14 years, 15 to 24 years, 25 to 44 years, 45 to 64 years, and older than 64 years.

COVID-19 vaccination center locations in the Netherlands were collected manually from GGD websites at two different moments in time (June 2021 and August 2021)(Rijksoverheid, 2021). The addresses of 193 vaccination centers locations were geocoded using the ArcGIS Pro 2.7 address geocoder. Each center included an address, status (open or closed), municipality, and GGD region in which the center was located. For the purpose of this study, centers were classified as open and closed. Closed centers were those closed by August 31st, while open centers were locations that remained open and operational after August 31st.

Travel behavior in the Netherlands was obtained for the year of 2019(CBS, 2019) and used to determine travel speed and travel time isochrones. Based on trip distances and trip times, the average travel speed by bicycle was determined to be 11 km/h. Since 75% of bike trips made for "service and personal care" are completed within a 20-minute travel time, we used this as the boundary limit within which individuals would be willing to travel to a vaccination center.

Roads and bicycles network was obtained from OpenStreetMap (May 30, 2021)(OSM, 2021). All roads that cyclists can use were included. The following roads were excluded: bridleway, busway, motorway, motorway links, and stairs steps(Ramm, 2022). A total of 2,096,255 features representing cyclable network was used, including 229,487 features designated as a cycleway. Travel time by bicycle was computed for each road network segment using the average bicycle travel speed described earlier. All analyses were conducted in ArcGIS Pro 2.7.

Boundaries – Administrative boundaries for the health regions (GGD) (N= 25) and municipalities (N = 352) were obtained for the Netherlands(CBS, 2021, 2020).

2.2 Analysis

Travel time by bicycle to each vaccination center: For each covid vaccination center, service areas were determined. Essentially the time traveled from each vaccination center was accumulated as described in(Blanford et al., 2012; Weiss et al., 2020). By accumulating the cycling travel time for each network segment, isochrones were calculated for each vaccination center, starting with 0 minutes and ending at cut-off values of 10 minutes, 15 minutes, and 20 minutes.

Population with access to vaccination centers by bicycle: Populations within 20 minutes of a vaccination center were considered to be accessible to vaccination centers, and those greater than 20 minutes away were considered to be inaccessible. To evaluate the variation in travel time by bicycle for individuals with access to vaccination centers, 10, 15, and 20-minute time intervals were selected as benchmarks in the calculations. Accessibility was summarized by municipality.

Change in accessibility: Change in accessibility was determined by comparing the population with access to open vaccination centers before and after August 31st.

3 Results

3.1 Distribution of vaccination centers

Vaccination centers were highly concentrated in the country's western areas (Figure 1). The GGD regions with the highest number of vaccination centers included Utrecht (N=32), Amsterdam (N=13), and Rotterdam-Rijnmond (N=20); the remaining GGD regions had less than ten vaccination centers.

The number of vaccination centers decreased from 193 centers to 99 centers (Figure 1) in August, with many closures occurring in the western regions. The greatest number of closures occurred in Rotterdam-Rijnmond.

3.2 Change in accessibility levels

In June, 45% of the whole Dutch population was within a 20-minute bicycle ride of a vaccination center (Figure 2a) and considered to be accessible. Accessibility was highest in the western and central GGD regions (Utrecht (1), Amsterdam (2), Rotterdam-Rijnmond (3), Haaglanden (9), and Flevoland (12)). Other GGD regions had considerably lower accessibility levels with larger differences among their municipalities compared to the western regions. The northern and eastern regions had better accessibility levels compared to the southern regions.

After August 31st, the population with accessibility decreased from 45% to 28%. Only Utrecht (1) maintained high accessibility levels.

3.3 The effect on age groups and travel time

More than 7 million people had access to a vaccination center in June (Table 1). The majority are aged between 25 to 64 years old. The closures affected around 2.7 million people, accounting for 38% of the population who had access before the closure. The elderly (> 65 years) were the most affected; their proportion decreased by 41%, followed by the 45 to 64 years age group with a 40% decrease. The age group (25 to 44 years) was the least affected, with a 34% decrease.

Age group	Before the closure (N)	After the closure (N)	difference (%)
00 to 14	1,106	679	-39
15 to 24	866	567	-35
25 to 44	1,949	1,279	-34
45 to 64	1,921	1,159	-40
Older than 65	1,228	730	-41
Total	7,070	4,414	-38

Table 1. The number (in thousands) and the difference of population with accessibility to COVID-19 vaccination centers according to their age using regular bikes before and after the closure.

Forty-five percent of the population were able to reach a vaccination center in less than 20 minutes before the closures (Table 2), with nearly 18% of the population within a 10-minute bike ride and 27% between 10 to 20 minutes. The closures reduced accessibility, with only 10.8% of the population able to reach vaccination centers in less than 10 minutes and under 20% of the population within a 10-to-20-minute bike trip.

Travel time	Before the closure (%)	After the closure (%)
<10 Min	17.8	10.6
10 – 15 Min	15	9.3
15 – 20 Min	12.2	8
>20 Min	55	72.1

Table 2. Percentage of the population with access by bicycle according to travel time to the nearest vaccination center

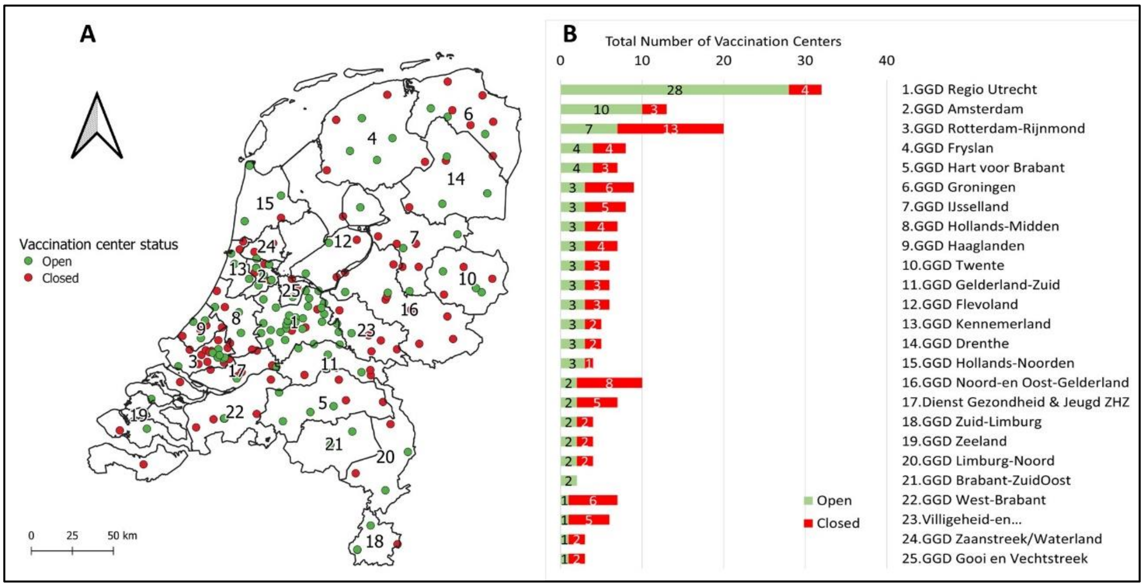

Figure 1. (A) Location of Covid-19 vaccination centers in the Netherlands and (B) the total number of open and closed centers in each GGD region. Closed: Vaccination centers that were be closed by August 31st. Open: Vaccination centers that remained open after August 31st.

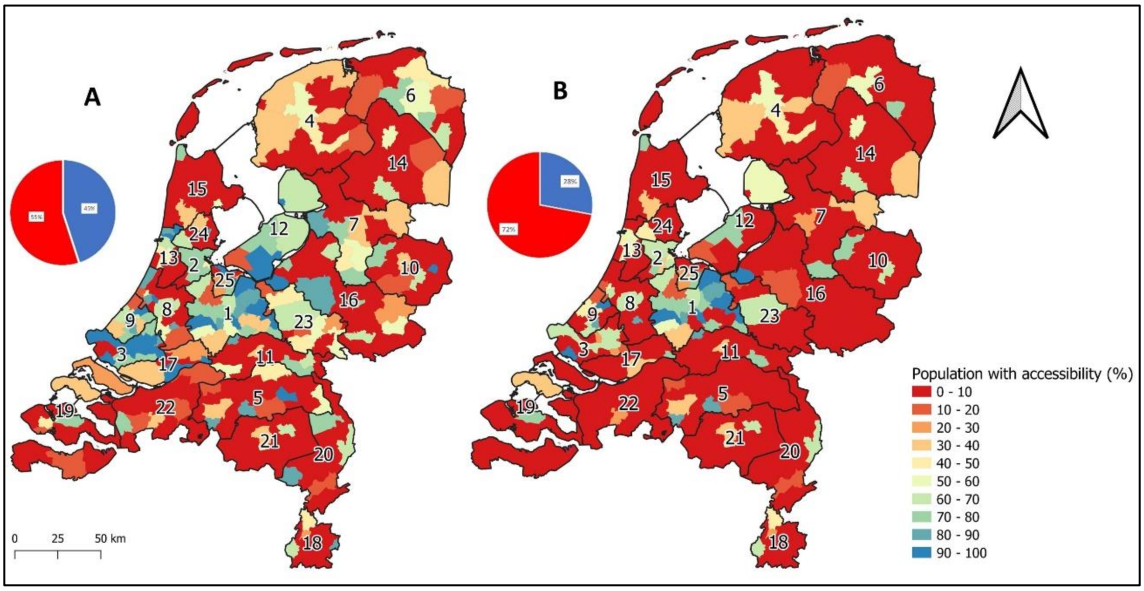

Figure 2. Share of population with accessibility to vaccination centers by bikes (A) before the closure, (B) after the closure

4 Conclusion

Our work contributes to the scientific efforts to understand the challenges caused by the COVID-19 pandemic in the healthcare sector. Our study differs from previous research in that it focuses solely on bicycle transportation as the primary mode of transportation and takes into account the impact of vaccination center closures on accessibility levels. Furthermore, we used high-resolution population data to determine the proportion of the population with access and which age groups may be most affected. The outcomes of this study can help decision-makers: assess the impact location of health facilities has on accessibility levels and develop localized solutions that examine the effects of location-based strategy changes on the ease of reaching vital health services.

The results show that the number of vaccination centers decreased from 193 to 99 centers due to the closure of 94 centers in a short time, resulting in a sharp decrease in accessibility levels from 45% to 28% for the whole country. The vaccination centers were highly concentrated in the western regions, showing a negative impact of the uneven distribution of vaccination centers, with less than 50% of the population having accessibility before and after the closure. Around 2.7 million people, which accounted for 38% of the population who had access to vaccination centers before the closure, were affected. All age groups were impacted, with the elderly population (older than 65 years) being the most affected. Policymakers may benefit from understanding the negative impact that the swift closure of vaccination centers can have on accessibility, especially during a time when booster shots may still be necessary.

Although the study provides an overview of accessibility levels, there are several limitations. Population estimates may not be entirely accurate since we used data from 2018. Furthermore, we only focused on measuring accessibility levels for regular bicycles. Future research should also consider e-bikes and other affordable transportation modes, including scooters. Our study focused on the accessibility of the nearest vaccination center. However, it is important to note that some people may not be able to reach these centers by bike, as electronic reservation unavailability could make it necessary to travel further to other centers. Further research on exploring the effects of these limitations on biking accessibility to more distant vaccination centers is needed.

Based on our results, we recommend that policymakers take advantage of strategic mathematical models, such as location-allocation models, to explore the distribution of vaccination centers. This will help ensure that vaccination centers are located in areas with the greatest need, particularly in areas with low accessibility, and are targeting the appropriate population groups. Additionally, we suggest that policymakers provide subsidies to enhance the biking experience for people, such as subsidizing purchasing e-bikes, as they can serve as an efficient and environmentally friendly mode of transportation to access vaccination centers.

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