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Taking the bus to the park? – a study of accessibility to green areas in Gothenburg through different modes of transport

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Abstract

Green areas in urban environments can have recreational, environmental and health benefits but for them to be utilized, high accessibility for inhabitants is necessary. In an expanding city like Gothenburg, maintaining geographic accessibility to green areas can be challenging. This study performs an accessibility analysis to assess whether Gothenburg has sufficient accessibility to green areas, and whether any spatial inequality occurs. It also aims to compare the accessibility by public transport to other modes of transport: walking, biking and driving car.

Earlier research of accessibility analysis to green areas have rarely included network analysis of public transport. For green areas in Gothenburg, no network analysis of any transport mode has previously been performed.

This study found that the accessibility is sufficient for most of the population of Gothenburg. Although the accessibility is not evenly distributed, no spatial inequality with regards to income was found. Compared to other transport modes public transport seems to be preferable primarily in relatively long-distance travels.

Keywords: Geography, Geographical information systems, GIS, Geographic accessibility, Public transport, Green areas, Location Quotient

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List of abbreviations

LQ – Location Quotient

Moran's I – Moran's Index of spatial autocorrelation

OSM – OpenStreetMap

GTFS – General Transit Feed Specification

SCB – Statistics Sweden (*Statisktiska centralbyrån* in swedish)

Ha – Hectares

GIS – Geographic Information System

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1. Introduction

Green areas are important components in the urban environment. They have several health benefits for the city inhabitants (Konijnendijk et al. 2013). In addition, they provide positive environmental impacts by increasing biodiversity, increasing carbon sequestration, improving air quality and cooling urban heat (Konarska et al. 2016; Konijnendijk et al. 2013).

For green areas to be used they need to have high geographic accessibility for the inhabitants of the city. The geographic accessibility notion concerns the ease with which people may reach desired sites (Gregory and Johnston 2009). According to Boverket Sverige (2007), a park needs to be within 300 meters access for a resident to use it regularly. In a study of the urban park *Slottskogen* in Gothenburg it was found that the accessibility was the most important factor for people to visit the park, followed by thermal environment (temperature) and park design (Thorsson et al. 2004). Hence, accessibility to green areas in cities is an important issue in urban planning.

Studies have shown that the accessibility to green areas can be insufficient (Nicholls 2001). Although most Swedish cities have recently tended to gain higher accessibility to forests in proximity to urban areas, the largest cities (which includes Gothenburg) tends to gain lower accessibility (Olsson 2013). Low accessibility to green areas in the urban environment might lead to health issues such as obesity, reduced physical activity and increased mortality (Konijnendijk et al. 2013; Coutts et al. 2010).

300 meters distance between resident and green area has been the standard in urban planning in Sweden the last decades (see section 2.3.2) (Boverket Sverige 2007; Grahn and Stigsdotter 2003). Malmö municipality is one of the governing bodies that have performed accessibility analysis on this basis (Malmö stad 2003). A similar analysis of green area deficiency was also performed in the municipality of Gothenburg (Göteborg stad 2014). The analysis found several zones with more than 300 meters from green areas. This analysis used the Euclidean distance, meaning straight-line distance, rather than distance along a street network. No network analyses of accessibility to green areas have been carried out in Gothenburg. However, the goals of Gothenburg municipality is not set in distance but rather in travel time (Göteborg stad 2014). The goals are: (1) parks should be accessible in 15 minutes by walking; and (2) natural experiences should be accessible in 30 minutes by public transport. Nevertheless, no analysis according to these goals have been carried out by Gothenburg municipality. Hence, this paper performs a geographic accessibility study according to these travel time goals, to determine

whether the accessibility is sufficient. This contributes to the knowledge of accessibility in Gothenburg.

Studies have also shown that accessibility to green areas can be unevenly distributed in the urban environment (Oh and Jeong 2007; Jonnerby 2014; Comber et al. 2008). Since there are many health benefits with high accessibility to green areas (Konijnendijk et al. 2013; Coutts et al. 2010) issues regarding spatial inequality of green area accessibility have recently been subject to debate in sustainable urban planning (La Rosa 2014; Paquet et al. 2013). These issues mainly include health inequalities and environmental justice. It is generally acknowledged that low-income residents benefit more from high access to green areas (La Rosa 2014; Gupta et al. 2016). Spatial inequality has been studied with regards to attributes like income, ethnicity and gender (Talen and Anselin 1998; Nicholls 2001; Comber et al. 2008) with varying results, but no studies have been carried out in a Swedish context. Hence, secondly, this study performs a spatial inequality analysis, both in general and in relation to income. This analysis may contribute to the development of methods for studying spatial inequalities of accessibility in Sweden.

A classical approach to geographic accessibility analyses to green areas have been to utilize Euclidean (straight-line) distances (Nicholls 2001; Göteborg stad 2014). However, several recent studies use network analysis methods instead, where distances are calculated along a walking network (Jonnerby 2014; Nicholls 2001; Oh and Jeong 2007; Zhou and Kim 2013). Network analysis provides more precise and more accurate results than Euclidean distance analysis (La Rosa 2014). Nonetheless, there are few studies that have used network analysis of other transport modes than walking e.g. public transport, biking or car driving. Consequently, few analyses have compared different transport modes regarding accessibility to green areas. Hence, lastly, this paper performs a comparison between different transport modes which may contribute to developing methods for accessibility analysis comparison.

1.1 Aim

The primary aim of this thesis is to study the relationship between place and accessibility to green areas in Gothenburg. A secondary aim is to explore the discrepancy between different modes of transport, to explore whether public transport is a viable choice compared to the other modes of transport: car-driving, biking and walking. The research questions of this project are as follows:

- Does Gothenburg have a sufficient geographic accessibility to green areas? The sufficiency will be determined according to the set time travel goals (Göteborg stad 2014)
- Is there spatial inequality, in general and in relation to income, in the geographic accessibility to green areas in Gothenburg?
- How time-efficient is public transport compared to other modes of transport when accessing green areas?

2. Background and previous research

2.1 Definitions of accessibility

To be able to study *geographic accessibility* a definition of the term needs to be established. It is a broad term with several definitions, and it is difficult to find an operational and theoretically sound one (Geurs and van Wee 2004). A well-known definition comes from Hansen (1959); "the potential of opportunities for interaction". Moreover, Burns (1980) use a different one: "the freedom of individuals to decide whether or not to participate in different activities" and Ben-Akiva and Lerman (1979) defines it as: "the benefits provided by a transportation/land-use system".

However, the one used in this study is as follows:

> "…the ease with which people can reach desired activity sites, such as those offering employment, shopping, medical care or recreation." (Gregory and Johnston 2009).

The concept of accessibility can be divided into four components, as this more elaborated definition pinpoints:

> "The extent to which the land-use transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s)." (Geurs and Ritsema van Eck 2001).

Within this definition, the four components can be identified and together they form the term geographic accessibility (Geurs and Ritsema van Eck 2001; Larsson et al. 2014b):

- Transport component – the ease of reaching a destination. Includes the limitations of the transport system.
- Land use component – the distribution of the opportunities in space, such as the localization of homes, jobs, culture and recreation. It is also important to consider the internal competition among those sites.
- Temporal component – the time that the activities are available may differ throughout the day, week or year, as well as the travel time and costs to reach the localization of the activity. Also, the time budget of the individual is a constraint to consider.
- Individual component – beyond the three components mentioned above, also individual values, opportunities and constraints affects a person's choices of how and what to access.

Another distinction that should be made here is the difference between access and accessibility (Geurs and van Wee 2004). Access regards the perspective of an individual; i.e. if a person may reach the desired activity. Accessibility regards the perspective of a location; e.g. how many people that can reach a particular site in a set time frame.

In summary, geographic accessibility is the ease with which people can reach desired activity sites, and it is affected by: (1) the transport system; (2) the availability of the destinations in space and time; and (3) the individual choices.

2.2 Measurements of accessibility

The definition "the ease with which people can reach desired activity sites"(Gregory and Johnston 2009) (see section 2.1) opens up for a discussion of how to measure the rather vague word "ease". Finding suitable measurements has been subject to much research and in the following paragraphs common accessibility measures are divided into four categories (Geurs and van Wee 2004):

- *Infrastructure-based measurements* are used to assess the performance of transport infrastructures. They are often used in transport planning. This includes e.g. measuring levels of congestion, average speed and limitations and barriers of the transport network. They focus on the transport infrastructure and may risk to give a limited picture of the connection between the transport network and the surrounding activities, such as housing, job opportunities and welfare services (Larsson et al. 2014b). The roads are seen as its own entities, rather than just being tools that are useful when trying to reach a site.
- *Location-based measurements* regards the accessibility at locations, meaning the spatially distributed activities that one wishes to access (Geurs and van Wee 2004). These measurements are typically used in urban planning and geography studies. One example of a location-based measurement is to calculate the travel time from one starting point to several destination points. Another example is the counting of the number of jobs within 30 minutes travel time from a specific origin (Larsson et al. 2014b). Other more complex measurements include, e.g. the use of distance decay, where the importance of a destination point is given a higher weight if it has a shorter distance from the origin point, and lower weight if it is further away. This can give a more realistic measurement of the accessibility. However, it loses simplicity and may be harder to present in an understandable manner, making it less used in planning. Other

complex measurements can include weights representing the importance of origin and destination points, e.g. including demographic properties.

- *Person-based measurements* looks at the accessible activities for an individual at certain times. Here, the time schedule of the individual is central (Geurs and van Wee 2004). These measurements have their foundation in the time-geography concept (Hägerstrand 1970). Time-geography refers to the idea that individuals have a time-budget which involves being at different activity locations at specific times of the day. For example, if an individual wants to take a walk in the park and has 40 minutes' opportunity during lunch break, maybe parks within 10 minutes' travel distance is the only ones that fit in the time-budget.
- *Utility-based measurements* is mainly used in economic studies and includes analyses of the economic benefits in the accessibility to different activities (Geurs and van Wee 2004; Larsson et al. 2014b). The strengths of these measurements are the strong connection to, which also requires a level of knowledge of, economic utility theory.

2.2.1 Network analysis in accessibility research

Calculating Euclidean distances is one approach in accessibility analysis, but calculating travel time along a network gives a better result, especially in peripheral parts of a city (Jordan et al. 2004; La Rosa 2014). For example, barriers can have large impacts on travel time but they are not accounted for in Euclidean distance analysis. Barriers are geographical hinders such as hills, rivers or coastlines, which may be impassable and therefore add largely to the travel time. Consequently, network analysis is widely used in recent accessibility analyses.

A network consists of: (1) network links, lines representing roads, power lines or rivers etc.; and (2) network nodes, points that connect links with each other (Heywood et al. 2011). A network also contains information of impedance, the cost for traversing a network link and for stopping at, turning at or visiting a node. Impedance might be e.g. travel time, distance or monetary cost. Network analysis can be used for several purposes. One typical is to analyze the shortest path between two points. It can also be used for location-allocation modelling, where an allocation of resources can be modelled from demand data.

To summarize section 2.2, there are several ways to measure accessibility and they can be categorized by whether they are based on: (1) the transport infrastructure; (2) the location of activities; (3) the time-budget of individuals; or (4) economic utility theory. In this study location-based measurements are used, looking at the number of residents that reaches green areas, in certain time spans. The more complex measurements using e.g. weights or distance decays, are not used. Network analysis is often used when measuring accessibility, which is the case in this paper. A network consists of links, nodes and impedance, and it can be used in a range of analyses. In this paper, an Origin-Destination cost analysis is performed, where each origin point finds the route of least impedance to one of the destination points.

2.3 The role of green areas in cities

The term accessibility has been considered in previous sections and now the focus moves over to green areas. First, studies of the importance of green areas in cities are discussed. Secondly, the different standards for green areas used in Swedish planning are presented.

2.3.1 Studies of green areas in the urban environment

Parks are important for the human health of urban dwellers (Chiesura 2004). For example, parks in urban areas may reduce stress and provide a sense of peacefulness and tranquility. Furthermore, urban parks increases peoples physical activity and reduces obesity (Konijnendijk et al. 2013).

Studies have also shown that parks contribute to noise reduction, air pollution removal, carbon sequestration and stormwater/run-off management (Konijnendijk et al. 2013). Moreover, urban parks are often hotspots for biodiversity, and are therefore suitable for education and tourism. Another consequence of parks is that they have positive effect on property values at the adjacent buildings. This effect languishes quickly with distance from parks though.

Parks also have local cooling effects (Konarska et al. 2016). The occurrence of raised temperatures in cities, called the Urban Heat Island, is reduced with urban vegetation, an occurrence called Parks Cooling Island. This has been observed in Gothenburg, along with several other places in the world (Konarska et al. 2016; Skoulika et al. 2014; Sugawara et al. 2006).

New urbanism is a movement that believes that closer access to amenities such as parks, will increase the pedestrian travels in that area (Lund 2003).This idea has been found to have some truth even though personal attitudes and other factors also influence the choice of travel mode and distance of travel.

2.3.2 Standards in green area accessibility

According to an official policy document for the municipality of Gothenburg, a document called “the strategy of green areas”, the goal is that natural experiences should be within 30 minutes travel time by public transport (Göteborg stad 2014). It also states that urban district parks, suitable for activities like child play, strolling and having picnic, should be within 15 minutes walking distance. Urban district parks, urban parks and larger natural areas has been digitized in this policy document. The latter two are providing natural experiences which, therefore, should be within 30 minutes' travel time with public transport. An analysis of accessibility insufficiency was produced in the policy document. In the analysis, Euclidean distance was used, instead of implementing the stated travel time standards. Areas with more than 300 meters to the closest park were marked as insufficient, and larger roads and great altitude differences were set as barriers.

The standard of 300 meters is set by the Swedish administrative authority for physical planning, *Boverket*, who claims that a green area need to be within this distance for a person to use it regularly (Boverket Sverige 2007). Accessibility to parks has seen several standards in Swedish physical planning over time. The standards are mainly set in distance rather than travel time (Lundgren Alm 2004). More elaborated standards from Boverket Sverige (1999) includes different types of parks:

- Within 500 meters, Urban district parks of minimum 10 ha.
- Within 200 meters, parks of minimum size 0.3 ha, with e.g. ball play as a possible activity.
- Within 50 meters, small parks where e.g. small children can play.

To summarize section 2.3, the role of green areas in the urban environment: many positive effects on human and natural health have been found in studies of green areas in cities. Hence, it is important to give guidelines in planning for green areas. These guidelines include the distance to, and size of, green areas. In this paper the standards set by Göteborg stad (2014) are used, since the study area in large parts overlaps the geographical extent of this policy document. Moreover, travel time is much more suitable than distance when studying public transport. Hence, travel time is the impedance used in this paper.

2.4 Spatial analysis of accessibility

There are many studies that use accessibility analysis within a GIS environment, with examples in all from studying accessibility to hospitals (Elldér et al. 2012; Loh et al. 2009; Eklund and Mårtensson 2012) to exploring the claims of better local access in the new urbanism movement (Lund 2003; Naess 2011). Some noteworthy studies, also including accessibility to green areas, are presented in the following paragraphs.

Hägerstrand (1970) presented ideas about time-geography that has relevance today when studying accessibility (mentioned in section 2.2). Time-geography upholds the notion that individuals care for a daily time-budget that affects the activity choices, and the accompanied travels. Some activities are relatively fixed, in space and/or in time, and acts as anchors in the daily schedule, which also moderate individual's opportunity to participate in activities and travels in space–time. This space–time fixity and flexibility of activities is a crucial part when studying accessibility, mobility, travel behavior and transportation issues (Kwan 1998; Hägerstrand 1970). In this paper, studying accessibility to green areas, location-based measurements are used rather than person-based measurements even though person-based measurements are more connected to time-geography (see section 2.2). Nevertheless, the public transport analysis was made during the hours when green areas in Gothenburg has the most visitors. Possibly these are the times that green area visits generally fit best with peoples' time-budget.

The access to green areas has received growing recognition as benefits for health and well-being (Higgs et al. 2012). Coutts et al. (2010) found that the amount of green areas within defined distances associates with mortality, both all-cause and cardiovascular (see also section 2.3.1).

Dony et al. (2015) found that inner-city areas have more access to parks while city outskirts have more access to natural areas. This is an issue in measuring accessibility to green areas. The analysis in this paper tries to address this (see section 3.3.5).

The manner in which data of green areas are represented also impact the accessibility analysis results. Research has investigated whether distance to parks should be measured to the central point of the park, to nearest park boundary, to park entrances or to other known access points (Nicholls 2001; Comber et al. 2008). Studies suggest that using multiple park entrances enables the park shape to be accounted for. This is the adapted approach in this paper.

In Sweden several projects of accessibility analysis has taken place, though rarely including green areas. Dahlgren (2008) used accessibility analysis to assist the Swedish National Rural Development Agency in the aim to develop national accessibility instruments. In the Västra Götaland region, containing Gothenburg, Larsson et al. (2014a) produced an accessibility instrument and an accessibility atlas including public transport and car travel.

An interesting result from accessibility studies is the so called accessibility paradox (Haugen 2012; Haugen and Vilhelmson 2013). With increased access to service amenities, shorter travel times should be needed. Nevertheless, travel times in service related trips have seen an increase in such cases, which is paradoxical. The authors showed that other factors and preferences are more important than proximity when choosing e.g. a school. This implies that promoting local access may be insufficient when planning for more sustainable travel behavior. This may also be applicable to green areas, as they may differ greatly in terms of appearance and suitable activities, among many other properties. Hence, short travel time may not be the sole most important factor when choosing which green area to visit.

In conclusion, many accessibility analysis studies have been performed in a GIS environment. Some ideas worth considering include the time-geography concept, and the paradox that better accessibility does not necessarily mean that people choose to travel less. Concerning accessibility to green areas, short distances have proven health benefits.

2.5 Studies of spatial inequality

In this section, spatial inequality and inequity in accessibility is presented.

Equality means that everyone should have equal access. Spatial equality refers to equal access for people grouped by geographical location. Equity is a related concept, normally referring to the fairness in the distribution of goods and services among groups of individuals (Geurs and Ritsema van Eck 2001). Two kinds of equity can be distinguished. Horizontal equity refers to the fairness when it comes to both costs and benefits, i.e. the people who pay most taxes should have the highest benefits. Vertical equity on the other hand, claims that costs and benefits should reflect people's needs and abilities; for example, disabled people should be provided special public transport services. The equity concept has several dimensions. First, spatial equity, in which the areas are divided geographically. Secondly, social and economic equity, where the grouping of individuals is done through aspects such as age, gender, ethnicity, household size or income.

A study of accessibility to Sahlgrenska Hospital, a major employer in Gothenburg, shows an uneven distribution of the residences of the workers (Elldér et al. 2012). Low-income female workers could save more travel time by choosing car instead of public transport, compared to their high-income male colleagues.

Nicholls (2001) studied the accessibility to public parks in Bryan, Texas. The recommendations at the time was that 10 acres (4.1 hectares) of open space should be available per 1000 residents. However, those standards left out the spatial distribution of the parks, a problem which the authors tried to overcome. The spatial distribution was studied using Euclidean distances, but that method had weaknesses, e.g. it did not follow actual travel routes and it excluded barriers. Another problem with the Euclidean distance analysis was the assumption that one may enter a park at all points of the park boundaries. In reality, one might need to travel further to reach an entry point. Hence, in addition to Euclidean distance analysis this study also used network analysis along a walking network. It also looked at equity, based on attributes of the population such as race, income and age, but found no inequity.

To summarize, spatial equity refers to the fairness in geographical distribution, and both studies of workplaces and parks have been performed in this manner. In this study equality is in focus since no breakdown into groups of different needs has been performed. The equality studied in this paper will be both in general and in relation to income.

2.6 Analysis for detecting spatial inequality

This section describes the Location Quotient and Moran's I for spatial autocorrelation, two methods for detecting spatial inequality in general.

Location Quotient is a mathematical measure that is useful in, among others branches, economic development research (Miller et al. 1991). It is a basic tool that measures the contribution of a smaller area to the whole area (Moineddin et al. 2003). E.g. the proportion of cancer patients Ohio state compared to the proportion of cancer patients in the whole of United States. The location quotient for the $_i$th area is defined as:

$$lq_i = \frac{\frac{x_i}{n_i}}{\frac{x}{n}} = \frac{r_i}{r}$$

Here x_i denotes the outcome in the $_i$th area, and n_i denotes the population size of the $_i$th area. Similarly, x and n are the outcome and population size of the total area, respectively. An lq below 1 means that the event is underrepresented; a number above 1 means that the event is overrepresented.

Measures of spatial autocorrelation, such as the Moran's I-formula, can be used to statistically determine if a pattern is clustered or random. It is widely used within geography and is for example useful when studying geographical differences in health issues (Getis and Ord 1992). With regard to transport and accessibility, Górniak (2016) measured the spatial autocorrelation of accessibility of motorways in selected parts of Europe. In Black and Thomas (1998), a network spatial auto-correlation method was applied in a study of accidents on motorways. A significant clustering was identified. Talen and Anselin (1998) looked at the equality in which public playgrounds were distributed in Tulsa, USA. Tulsa was divided into census tracts and the playground count of each tract was the basis for the Moran's I analysis. The results indicated a random distribution despite a seemingly clustered pattern on the map.

Spatial autocorrelation is based on both feature locations and feature values (ESRI 2017). In this context "feature" refers to a point, line or polygon. If neighboring feature values are similar and deviates from the mean, i.e. the values are spatially clustered, a positive value is returned. Whereas a negative value is returned if the neighboring feature values are dissimilar. Hence, a positive value means spatial clustering. A negative value means dispersion. Values close to zero indicate that the spatial distribution is random. Moreover, the analysis produces a p-value and z-value, which indicate the significance of the index. Moran's I is defined as

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2}$$

where N is the number of units indexed by i and j. X is the variable of interest. $\bar{X}$ is the mean of X. w_{ij} is an element of a matrix of spatial weights.

In summary, Location Quotient and Moran's Index spatial auto-correlation are two measures that can be used to evaluate the spatial equality. Both methods are used in this paper.

2.7 The use of public transport

Lastly, some notes about studies of public transport. Studies have found several aspects that affect the use of public transport. Larger cities generally have higher usage of public transport (Santos et al. 2013). Other aspects that tends to increase the use of public transport are: (1) a high number of students; (2) low numbers of elderly; (3) low numbers of families with children below 17; (4) many public transport vehicles; (5) low fares; and (6) few rainy days.

Individuals experience the time spent outside of vehicle, i.e. walking and waiting, as more burdensome than the time spent on-board a public transport vehicle (Small 2012).

3. Material and methods

In this section, the data gathered and used is presented, followed by the methodology. The methodology in this thesis consists of four main steps: (1) construct network datasets for common types of transportation modes; (2) perform analyses of accessibility to green areas using the network datasets; (3) spatially analyze the inequality in accessibility to green areas; and (4) compare the types of transportation modes with regards to geographic accessibility.

3.1 Data and study area

In this section, the datasets used in the paper is presented (table 1) along with a presentation of the study area. The data comes from several sources. The main data sources are OpenStreetMap, data of public transport, income and population data from Statistics Sweden, as well as green areas data from the municipality of Gothenburg. The study area is the city of Gothenburg together with conurbations in proximity to the central city.

3.1.1 Data

The OpenStreetMap (OSM) data is used to a large extent in this paper (see table 1). OSM is a free of charge worldwide map that is being built by volunteers. It is released with an open-content license (OpenStreetMap Wiki 2017). It contains a wide range of geographical information in both point, line and polygon formats, in all from walking paths to beekeepers and waterfalls (OpenStreetMap Wiki 2016a). Since it is an ongoing project much information is still missing and further investigation on the quality of the data is needed (Brinkhoff 2016; OpenStreetMap Wiki 2017). Will (2014) performed a study of OSM quality in Gothenburg in relation to data from Lantmäteriet (Swedish National Mapping Agency). OSM was found to be of sufficient data quality, with some reservations regarding the accuracy of attributes. It was also found that the completeness of the OSM data was higher in areas with a high number of attributes; i.e., the central parts of the city. This may introduce a systematic error when comparing central parts with peripheral parts of the city.

The OSM data does not include an attribute table with columns, such as the shapefile-format used by ArcGIS, but instead includes an unrestricted amount of tags for each feature (OpenStreetMap Wiki 2016b). This free tagging system always have a key tag and a value tag in the format “*key=value*”. E.g. the key tag *highway* includes all transportable routes, and value tags include *motorways, roads, paths, cycleways* etc.

General Transit Feed Specification (GTFS) is a common standard for public transport schedules and the associated geographical information (Google developers 2016). It is constructed through several text-files containing information about agencies, stops, routes, trips, stop times, calendar, calendar dates, and possibly a few more optional files. In this case an open GTFS dataset covering all of Sweden is used (table 1). The dataset is provided by the Trafiklab project of Samtrafiken, a collaboration of several public transport operators of Sweden. Swedish legislation compels public transport operators to provide time schedules to Samtrafiken (Smith 2015; Lund 2017).

The income data from the official Swedish statistics governing body "Statistics Sweden" (SCB) represents purchasing power of households per consuming unit (table 1). The purchasing power is divided according to the number of consuming units the household contains, according to a standard at Statistics Sweden that makes households comparable to each other (SCB 2016).

The data about green areas within Gothenburg municipality are provided by Göteborg stad (Finsberg 2017). It is data from the "green strategy" policy document (Göteborg stad 2014) and includes: (1) *urban parks*, larger multifunctional parks that attracts visitors from all over the city; (2) *urban district parks*, medium-sized parks that is visited by inhabitants of the district; and (3) *larger natural areas*, areas with many biological and recreational values.

Table 1: the data used

Description	Source	Type/ Geometry	Spatial resolution	Year	URL
Roads, streets, paths, cycleways etc.	OpenStreetMap – key tag: *highway*	Line		2007-2017	mapzen.com
Public transport data	Trafiklab - GTFS Sverige 2	GTFS		2017	trafiklab.se
Parks and natural areas (within Gothenburg municipality)	Göteborg stad – urban district parks, urban parks and larger natural areas	Polygon		2014	Provided by mail from Göteborg stad
Parks and natural areas (outside Gothenburg Municipality)	OpenStreetMap – tags: certain value tags under key tags: *natural*, *landuse* and *leisure*	Polygon		2007-2017	mapzen.com
Population data	© SCB - B1: Befolkning efter ålder	Raster	250 meters (urban)	2015	Maps.slu.se (available for students at Swedish universities)
Income data	© SCB - IH1: Hushåll (20+ år) efter köpkraft	Raster	250 meters (urban)	2014	Maps.slu.se (available for students at Swedish universities)
Car parking	OpenStreetMap – tags: *Amenity=parking*	Polygon		2007-2017	mapzen.com
Road barriers (traffic lights, stop signs etc.)	OpenStreetMap	point		2007-2017	mapzen.com
Municipality borders, labels (own revision)	© Lantmäteriet - GSD-Administrativ indelning 1:250 000	Polygon		2015	Maps.slu.se (available for students at Swedish universities)
Coastline, water bodies	OpenStreetMap – tags: *Natural=water*, *waterways*	Polygon, line			mapzen.com

3.1.2 Study area

The geographical extent of this study is the Swedish city of Gothenburg, the second largest city of the country (Encyclopædia Britannica 2015). It is the principal city on the southwest coast of Sweden and is situated at the mouth of the Göta River. It was founded in year 1603 and still carries historical remains with old forts, churches and moats that encircle the old parts. The city has a history of building automobiles and ships. Some of the larger parks, besides the *Liseberg* amusement park, are *Slottskogen*, *the Botanical gardens*, and *Trädgårdsföreningen*.

Table 2: population development of metropolitan Gothenburg (*Storgöteborg*) which is a larger area than the study area in this thesis (SCB 2017).

Year	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Population	734,956	747,417	777,432	815,504	844,802	879,298	928,629	982,360

Gothenburg is a growing city, which means there is an increase in space needed for homes and services for the growing population (Göteborg stad 2009, 2014). The policy documents for the physical planning in the municipality still stresses the importance of preserving natural heritage as well as providing access to greenery (Göteborg stad 2009). It is also claimed that losses of nature, cultural and recreational values in the growing city will be compensated for. To develop an attractive public transport service is also stated as an important part in creating sustainable development of the growing city.

In 2013 a congestion charge was introduced in Gothenburg with the objective to reduce traffic congestion, improve environment and raise funding for a new infrastructural project, the West Swedish Agreement (Borjesson and Kristoffersson 2015; Andersson and Nassen 2016). The implementation of the congestion charge was preceded by improvements to the public transport system through implementations of individual bus lanes, longer trains and platforms, higher frequencies etc. (Andersson and Nassen 2016). The congestion charge was conflicting in the public sphere and in a local referendum the public vote was opposed. However, the referendum was only advisory and the charge was not removed (Andersson and Nassen 2016). Although the public attitude was more positive after the implementation of the charge, (Borjesson et al. 2016) the total traffic amount was not reduced as much as in other cities where similar processes have taken place (Andersson and Nassen 2016). According to Andersson and Nassen (2016) higher accessibility to public transport could reduce the propensity to use private cars in Gothenburg during this time.

3.2 Methods

In the GIS analysis, travel time is used as a measure for the accessibility of green areas; thus, excluding other measures like the monetary cost or access for people with disability. The accessibility is measured through location-based measurements (Geurs and van Wee 2004), analyzing the travel time from inhabitants residences to the location of the closest green area entrance (see section 2.2).

3.3 Network creation

This section describes the construction of the network datasets using the OpenStreetMap (OSM) data about roads, streets, paths, cycleways etc. First, four different travel networks were produced, one for each travel mode: walking, public transport, biking and car travel (see figure 1). Thereafter, origin points were estimated from the population raster dataset. Entries into green areas were used as destination points (figure 2 and table 3).

The OSM data was downloaded as a rectangular shape including Gothenburg urban area and close conurbations, as well as a surrounding buffer zone. Hence, network and green area data for a larger area than the actual study area was used. Consequently, no transport routes in the larger urban area was cut off. In addition, including green areas outside the actual study area was important. For some residents inside the study area, the closest green area could still be outside.

3.3.1 Walking

To create the walking network the appropriate OSM line features (key tag: *highway*) were chosen. Some of the features were deemed non-traversable for walking (value tags: *abandoned, construction, motorway, motorway link, trunk* and *trunk link*). The travel time for each feature was calculated with the walking speed of 1.4 m/s which is a regularly preferred walking speed (Browning et al. 2006). With these properties, a walking network was built. The network included; no restrictions, U-turns was allowed, and the same walking speed was used in all line features (see example in figure 1).

The network had many segments that were not connected to the rest of the network, which resulted in a problem when adding network locations (origins and destinations, see section 3.3.5 and 3.3.6). Origin and destination points needs to be snapped to the closest line segment of the network for the analysis. A problem occurred when the points were snapped to unconnected street segments. These points could not reach any location on the rest of the network, the analysis would not work. To remove the unconnected segments a service area analysis was carried out on the network, from one origin point, with line features as output and a very high number (900 minutes) as maximum distance. This resulted in a network that excluded unconnected parts, and the network was rebuilt.

3.3.2 Public transport

The public transport network is a multimodal network. It uses the walking network from previous step as a foundation, and connects the public transport (GTFS) data to it. Hence, to get from an origin to a destination with the public transport network one: (1) walks from the origin point to a public transport stop; (2) travels by a specific transit trip; (3) possibly transfers to another trip at another stop; and (4) walks from the final stop to the destination point (see figure 1) It does not necessarily mean that the route chooses the public transport stop that is closest to the origin/destination. Instead, the analysis determines the quickest route combining the walking time and the public transport time. If the quickest route is to not use public transport at all, but only use walking, the analysis will choose that option.

The downloadable ArcGIS toolbox, "add GTFS to a network dataset" was used to produce this public transport network (Morang 2017).

- The first step (after preprocessing the GTFS data) was to run the tool that generated transit lines and stops from the GTFS data. The tool also created a database of the time schedules.
- The second step was the creation of connector lines that connected the transit stops and the walking network. A point layer was created representing where the stops were snapped to the walking network streets. A new walking network street layer was created that included vertices at these points, since line features only connect to each other at vertices in the analysis.
- The third step was to create a new network dataset.
    - Here the connectivity settings were important. The transit lines were connected to the connector lines (at transit stops). The connector lines were in turn connected to the walking network streets (at "stops snapped to streets"). This ensured that the only place to switch from walking to public transport was at transit stops. A public transport vehicle cannot be exited in between two stops.
    - Speed parameters were set. A speed of 1.4 m/s was specified for each walking street, same as in the walking network. The connectors were given a constant of 15 seconds, representing a delay when entering or exiting a vehicle, as presented in the user's guide (Morang 2017). This is not a representation of the time waiting for the transit

vehicle, but rather a representation of the time it takes to board/exit the vehicle. For the transit lines, the speed was set according to other rules, namely referring to a software extension that made a request from the public transport schedule database every time an analysis was performed. This particular GTFS dataset (see table 1) was set up using data about every single date, instead of data about generic weekdays. Hence, appropriate settings for such occasion needed to be made.

- The fourth step was to finalize the network by providing the public transport schedule database with ID numbers connecting it to the newly built network.
- When adding origin and destination points (section 3.3.5 and 3.3.6) they were set to only snap to the streets of the walking network and not to the transit lines, since one cannot start the travel on a public transport vehicle between two transit stops. The settings were also set to use specific dates.

To acquire a fair travel time, an analysis was made starting every minute during an hour. For some of the highly-visited green areas of Gothenburg (*the Botanical Gardens, Slottskogen* and *Trädgårdsföreningen*) the most common visiting times is weekdays between 12:00-13:00 and weekends between 13:00-14:00 (Google maps 2017a, b, c) Therefore, a batch analysis is made for every minute between 12:00-13:00 on a Wednesday and between 13:00-14:00 on a Sunday. The mean value of these 120 analyses is calculated with the aid of Microsoft Excel. Salonen and Toivonen (2013) added half a headway time to the total travel time in one of their public transport networks, as representative of the time spent waiting for a transit vehicle. That is not done in this analysis in this thesis because the time spent waiting is inherently incorporated in the analysis. Because one analysis starts at each minute the time spent waiting for a vehicle is subject to the time between when one reaches the transit stop, and when the next vehicle departs.

3.3.3 Biking

In the GIS environment, a toolbox (*OpenStreetMap toolbox*) was used, since it had prepared settings for creating a biking network. It created a built network dataset from a complete OSM-file, without requiring a selection of what categories of data that should be encompassed. An included configuration process determined the properties of the network. The properties that was given through the configuration are stated in the appendix. In general terms, all roads traversable by bike were included and a general biking speed of 16 km/h was implemented. However, the speed was slower if the surface quality of the road was worse. A time penalty was added at barriers such as traffic lights and stops.

3.3.4 Car travel

As with the other networks, OSM is used for creating the network for car travel. Same as with the biking network, prepared setting from the *OpenStreetMap toolbox* was used to create the car travel network. The properties given through the configuration is presented in the appendix. In general terms, all roads traversable by car was included. Speed was set as the speed limit of the road, if such information was included in the data. Otherwise, a speed was added according to the road category (see appendix). However, the speed was slower if the surface quality of the road was worse. A time penalty was added at barriers such as traffic lights and stops.

The problem with using speed limits as an approach in calculating travel time is that it excludes several factors that add to the total travel time, namely walking times to and from parking space, time spent to find a parking space and traffic congestion (Yiannakoulias et al. 2013; Salonen and Toivonen 2013). Salonen and Toivonen (2013) studied differences between car travel networks with different sophistication levels in Helsinki, a city of similar size to Gothenburg (SCB 2017; Salonen and Toivonen 2013), and the above-mentioned factors were taken into account. In the analyses in this thesis, the same factors are introduced.

- When adding congestion data to the analysis, the travel times were 1.76 times longer than if the speed limits were used. Hence, the drive times in the analysis are multiplied with 1.76.
- A general time of 0.73 minutes was added for finding a parking space (Kalenoja and Häyrynen 2003).
- The distance walking to and from parking space (from origin point and to destination point, respectively) were 180 meters in central parts of the city and 135 meters outside the central parts (Kurri and Laakso 2002). However, in this analysis the destination point were parking spaces within 100 meters of green area entrance (see section 3.3.5. Therefore, the middle value of 50 meters for walking from parking space to destination point were used.

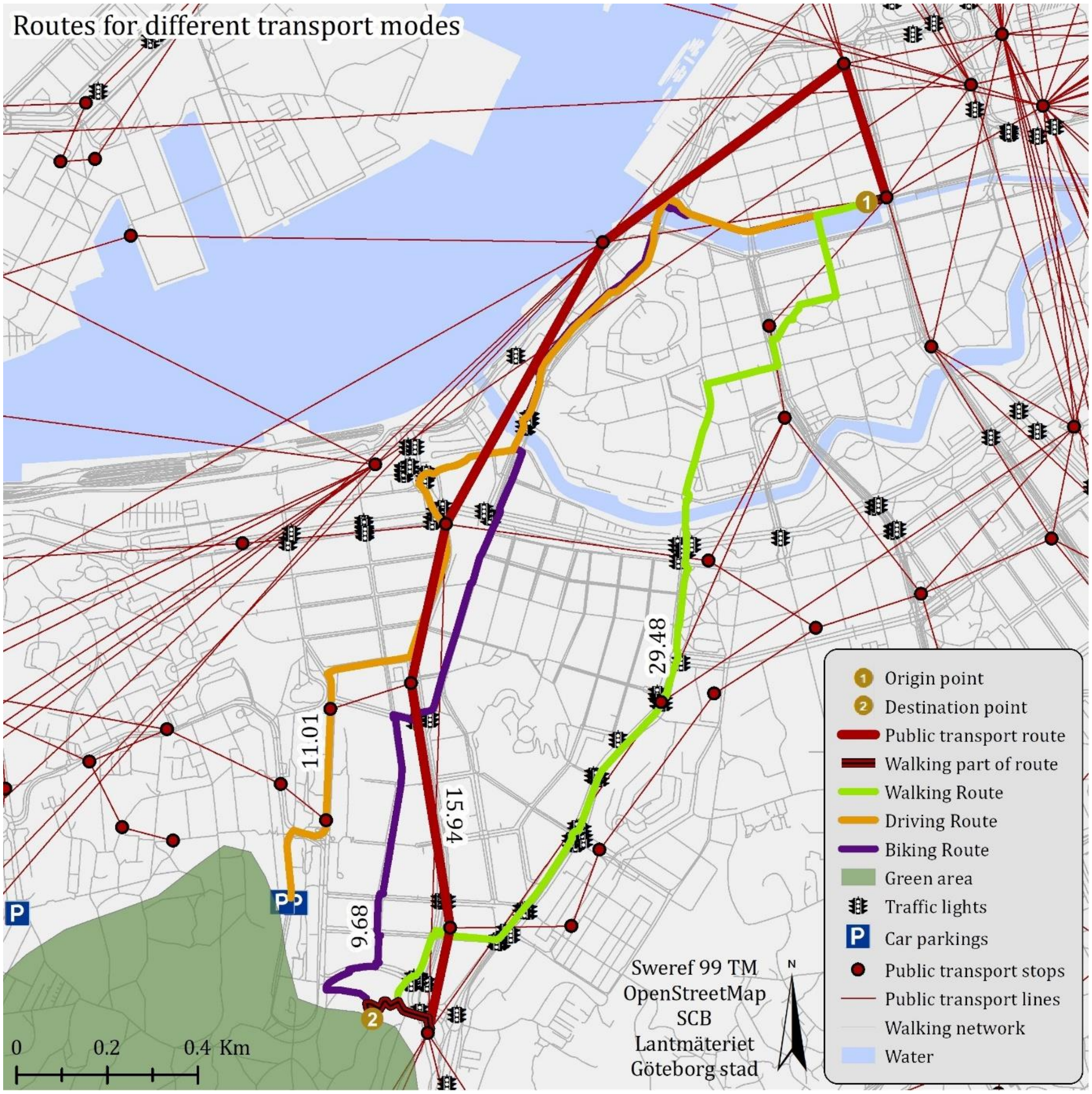

Figure 1: a close-up on central Gothenburg presenting results of a route analyses for all four transport modes. The route is the quickest between a chosen origin point and a chosen arbitrary destination point (not necessarily the closest destination point in the following analysis). The parts of the public transport route that uses walking are marked with black stripes in the line. The routes are labelled with the travel time in minutes. For the driving route, the destination is set at the parking space closest to the destination in this example. The public transport lines are represented with straight lines between stops rather than by the actual route taken by the vehicle, since the GTFS data does not include actual route information.

3.3.5 Destination points (green areas)

The creation of the destination points consisted of two main steps: (1) selection of green areas; and (2) creation of destination points that represent green area entrances.

First, for destination points in the network, two different selections of green areas were made: *Parks and nature* and *Nature*. The selections are described in table 3 and visualized in figure 2. *Parks and nature* consists of a higher number of green areas than *Nature*. All green areas included in *Nature* is also included in *Parks and nature*. The data originated from two sources: within Gothenburg municipality the data came from *Göteborg stad*, and from the other municipalities OSM data are utilized. The selections were based on the policy goals of Gothenburg municipality (Göteborg stad 2014): urban district parks should be within 15 minutes walking distance, whereas natural areas and urban parks should be within 30 minutes travel time with public transport.

There is a reason that there is no selection of only parks that excludes natural areas. The selections are made to make central and peripheral parts of the city comparable. The majority of the urban district parks were located in the densely populated central areas of Gothenburg; thus, an analysis of only urban district parks would indicate poor accessibility in the less densely populated areas in the outskirts of the city. However, these peripheral areas are generally closer to natural areas, which can also supply opportunities to perform the desired activities of urban district parks.

For the *Parks and nature* selection within the borders of Gothenburg municipality, data about urban district parks, urban parks and larger natural areas were used. This data had been digitized along with the creation of the policy document " the green strategy" (Göteborg stad 2014). It was digitized with a low accuracy, and few details, since the intended use of the data was for overview maps of Gothenburg (Finsberg 2017). For one urban district, Örgryte-Härlanda, a specific policy document has been produced by the municipality, along with a layer with more detailed park polygons. Some urban district parks in this district has been removed and some new is added. Hence, for the analysis in this paper the old park polygons in the district were replaced by the new ones. For the *Parks and nature* selection all green areas from this source was included.

Secondly, outside the Gothenburg municipality borders, such official data was not provided. Instead data about green areas were obtained from OpenStreetMap. The *Parks and nature* selection here was based on classification and area size (see table 3). Park polygons were selected if they were larger than 1 ha (tag classification: *Leisure=garden, park, recreation* *ground* or *playground*). Nature polygons larger than 100 ha were also selected (tag classification; *Natural=grassland, meadow, marsh, scrub, wood, wetland, scree, bare rock* or *rock*; *Landuse=village green, recreation ground, meadow, greenfield, grass, forest* or *flowerbed*)

For the *Nature* selection, the urban parks and larger natural areas from Göteborg stad was very abundant. This meant that for most of the population, *Nature* would be well within 30 minutes' travel time with public transport. Although this result would be interesting, it would render the public transport analysis unused. This is because most of the analysis results would be the same for the walking network and the public transport network, meaning it would almost always be quicker to walk than to use the public transport. Therefore, the available technique of analyzing the public transport would be of no value. In the light of this, a size requirement was introduced (table 3). The *Nature* selection included: urban parks over 100 ha, and larger natural areas over 300 ha. However, if the area was situated along the coastline, a size over 100 ha was deemed to be sufficient, since the ocean in itself could be considered to enrich a nature experience. The Gothenburg municipality was the only one in the study area that had any coastline; hence, no consideration was needed to whether natural areas outside Gothenburg was seaside and needed special treatment.

For the *Nature* selection outside Gothenburg municipality the same tag classification was used as with the *Parks and nature* selection, with the difference being a stricter size requirement: >100 ha for parks; and >300 ha for nature.

Table 3: characteristics of the green area selections: *Parks and nature* and *Nature*. The data used differed whether it was inside or outside the Gothenburg municipality borders

Geographical extent	**Source**	**Green area type**	**Name**	***Parks and nature* - Size**	***Nature* - Size**
Inside Gothenburg	Göteborg Stad	Park	Urban district parks	All	None
			Urban parks	All	> 100 ha
		Nature	Larger natural areas	All	> 300 ha, or if seaside > 100 ha
Outside Gothenburg	OpenStreetMap polygons	Park	Key tag “Leisure”	> 1 ha	> 100 ha
		Nature	Key tags “Natural” and “Land use”	> 100 ha	> 300 ha

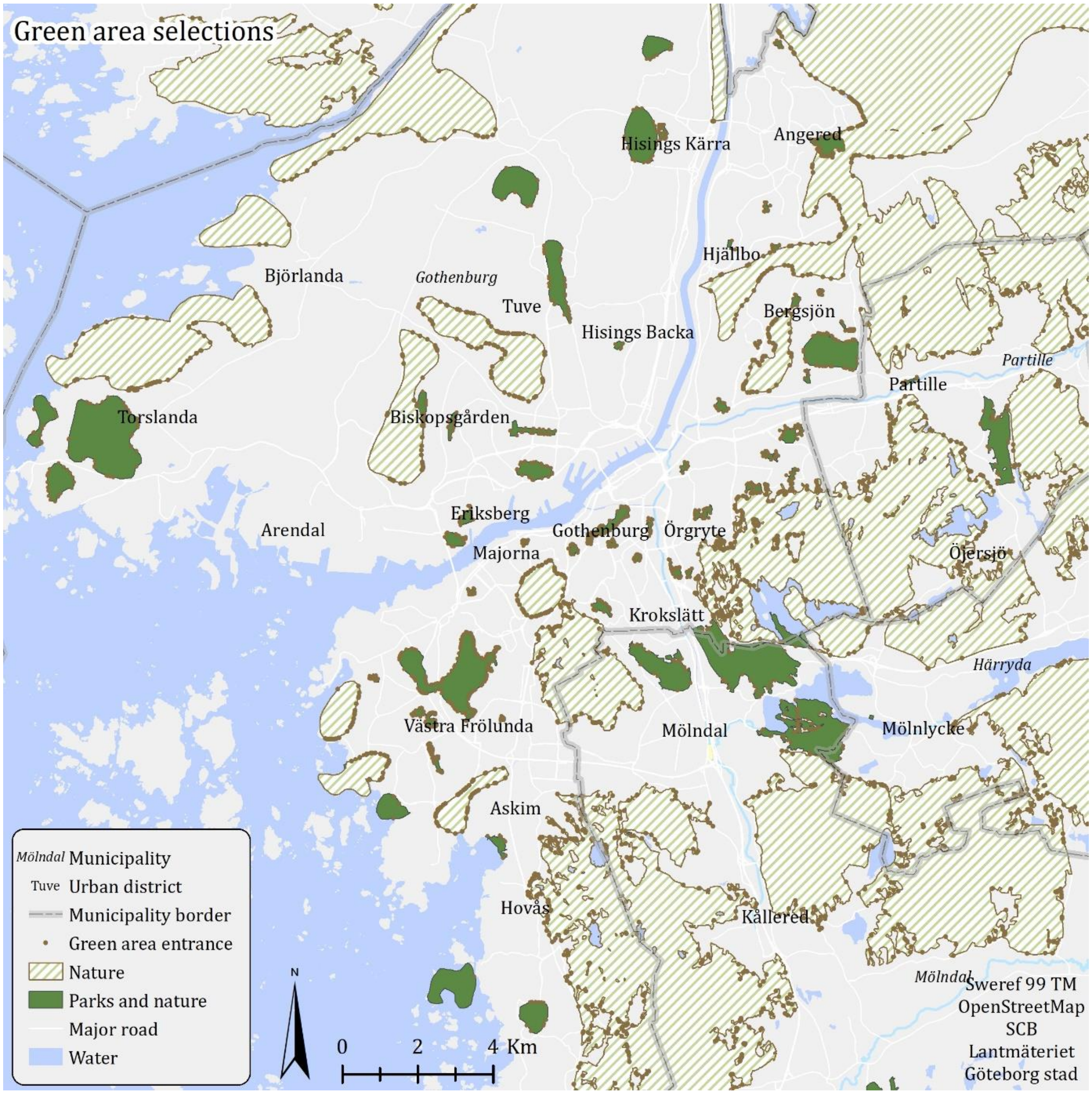

Figure 2: the two green area selections and the entrances to them in the walking and the public transport network. All areas in *Nature* are also included in *Parks and nature.*

In the second step, a point layer was created that represented entries into these green area selections. The points were positioned at the intersections of the walking network lines and the edge of the green area polygons. The public transport network used the same points as the walking network, but for the biking network a new green area entrance layer was made since the networks differs slightly.

For the car travel network, the method of creating green area entries needed to be different compared to the other travel modes because cars need parking spaces. Here, amenities classified as parking in the OSM data was used. With the help of the QGIS program, all tags in the OSM data for the parking polygons were extracted and inspected. Some parking spaces were removed, namely those categorized as private, no access, and commuter parking. Those spaces with a max-stay of three hours or less were also excluded in the analysis. However, most of the parking spaces did not include any of the above-mentioned information. Therefore, the analysis included a large number of parking spaces. In reality, many of these parking spaces were probably private or unsuitable in another way, but the lack of information in the dataset prevented a correct selection of them. The polygons were thereafter converted into a point layer. The points within 100 meters' distance from the *Nature* entrances in the walking network, were selected. The resulting *Nature* adjacent car parking spaces were set as destination points in the car travel network.

3.3.6 Origin points (Population)

The population dataset obtained from SCB (see table 1) was used to create origin points, which represented the starting locations of the travels. In the population dataset, each pixel value represents the total population in that area. The pixel size was 250 meters in urban areas, and 1000 meters in rural areas. However, since this thesis primarily focuses on urban areas, the rural pixels were excluded. The central point of each pixel was used as origin points.

3.4 Spatial analysis

Presented in this section is the analysis carried out investigating the accessibility, spatial inequality and comparison between transport modes.

3.4.1 Accessibility in Gothenburg

The methods for assessing the accessibility in Gothenburg was based on the standards in the policy document "the Green strategy" (Göteborg stad 2014). That is, urban district parks should be within 15 minutes walking distance, and nature experience should be accessible by public transport within 30 minutes travel time.

Two analyses are performed in this section. One walking analysis and one public transport analysis. First, for the walking analysis the *Parks and nature* selection of green areas was used. An analysis tool called *Origin-destination cost matrix* was used. The tool found the closest destination for each origin. Each origin point received a number representing travel time in minutes to closest destination. These numbers were connected to the population grid for visualization. The travel times of the points were also categorized for further statistical visualization.

The public transport analysis was performed in a similar way as the walking analysis. The difference being that the walking network was replaced by the public transport network, and the destination points were replaced by the entrances to the *Nature* selection. Moreover, the analysis was carried out for each minute for two hours, one on a weekday and one on a weekend (see section 3.3.2). Mean values were found for each origin point.

3.4.2 Spatial Inequality

For this section, methods for detecting spatial inequality were implemented. Both linear regression in relation to income, and general spatial inequality measures of Location Quotient and Moran's I, were calculated.

The linear regression analysis explored whether there was a relationship between income levels and travel time (to *Nature* by public transport). The income data, purchasing power of households per consuming units, were provided in the same geographical extent and resolution as the population data, a grid with pixel size 250 meters within urban areas. Hence, it was joined with the results from the travel time analysis (section 3.4.1). The income data included both the mean value in Swedish crowns (SEK) and four income categories showing number of households with low, medium-low, medium-high and high income levels. The relation between the mean income and travel time was calculated with linear regression. The four income categories were also reflected upon in relation to the travel time spectrum.

Location Quotient (LQ) calculations required a mean value for the total study area for each of the four transport modes. For each pixel (origin point) the inhabitant count was multiplied by the travel time. The sum of the resulting numbers was divided by the total population. This gave a mean travel time for the total study area. The travel times of the pixels were divided by these mean values to give an LQ value (see section 2.6).

Moran´s I Spatial Autocorrelation was calculated in the GIS with an appropriate tool (see section 2.6). A zone of indifference of 2500 meters, corresponding the length of 10 pixels, was used in the analysis. I.e. all pixels within 2500 meters gained equal weight in the analysis and pixels further away were given descending weights with increased Euclidean distance. This was done since the resolution of the pixels was high in comparison to the abundance of green areas. A Moran's I analysis with only the neighboring pixels would give an unrepresentative value since it is rather expected that neighboring values have similar values.

3.4.3 Comparison between transport modes

Here, a comparison is made in travel time between the four transport modes. Calculations were also made of the distribution among different travel time categories, as well as the mean travel time, for all transport modes. Lastly, Location Quotient-comparisons were produced by subtracting the LQ values of car and bike travel respectively, from the LQ values of public transport travel. This indicates what areas of the study area that has a well-developed public transport network relative to the networks of car and bike travel.

4. Results

The results of this thesis are divided into three main sections: (1) accessibility in Gothenburg by public transport and walking; (2) spatial inequality in accessibility; and (3) transport mode comparison.

4.1 Accessibility in Gothenburg

This section assesses to what extent the accessibility to green areas in Gothenburg is sufficient. It is divided into two parts: (1) *Parks and nature* should be within 15 minutes walking distance; and (2) *Nature* should be accessible by public transport within 30 minutes. These standards are based on the policy goals set by the Gothenburg municipality (Göteborg stad 2014).

4.1.1 Walking time – Parks and nature

Figure 3 shows that most areas in Gothenburg are within 15 minutes' walk to the closest *Park or nature*. The sparsely populated Arendal has the longest distance with two pixels having values over 45 minutes. Parts of Hisings Backa, Torslanda, Björlanda and Angered have also relatively long walking times. Most of these areas are relatively peripheral to the city, except the area in southern Hisings Backa. Figure 4 shows that about 93 % of the inhabitants in the study area have less than 15 minutes' walk to the closest *Park or nature*. Therefore, the goal set by the municipality of Gothenburg is fulfilled for 93 % of the population.

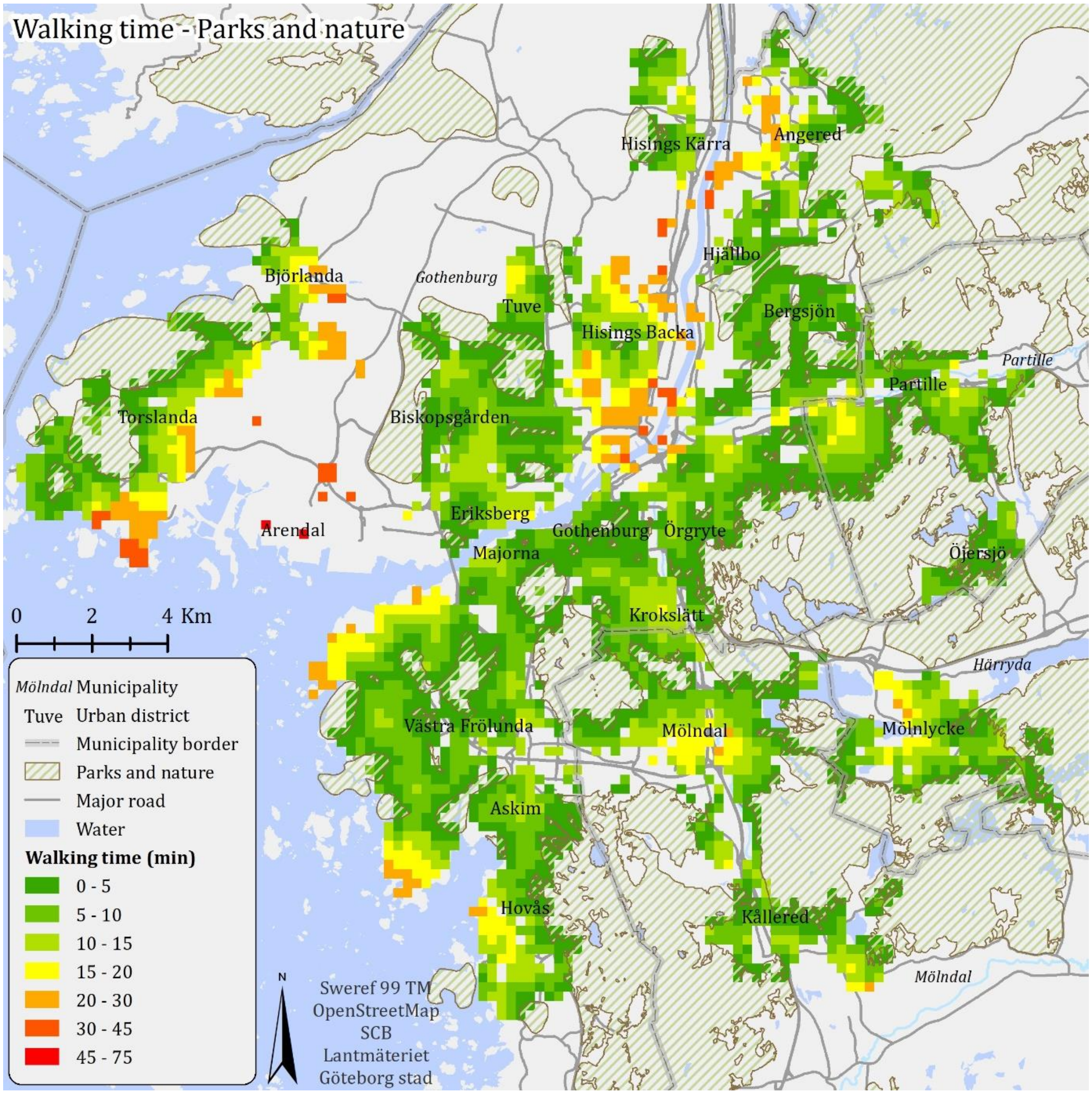

Figure 3: walking time to the closest *Park or nature* in Gothenburg city. The pixels represent resident areas and the color of the pixels represents the walking time in minutes.

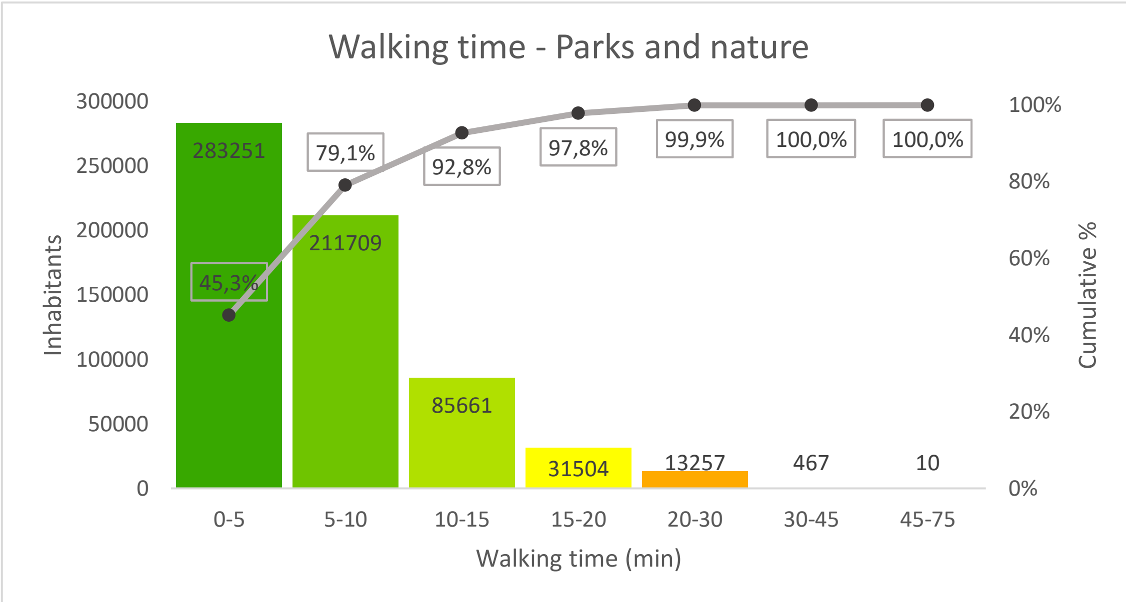

Figure 4: the diagram shows the number of inhabitants within each walking time category on the left axis (and labelled by the staples) and the cumulative percentage on the right axis.

4.1.2 Travel time by public transport – Nature

Most areas are within 30 minutes' travel time by public transport to the closest *Nature* (figure 5). However, some areas in Torslanda, Hisings Backa and Hisings Kärra comprise longer travel times. Some similarities with the previous map (walking to *Parks and nature*) can be seen (figure 3). E.g. some of the areas in Hisings Backa and Torslanda have low accessibility in both cases. Both analyses fulfill the accessibility goals with over 90 % of the population, figure 6 shows that about 98 % of the population have less than 30 minutes' travel time to the closest *Nature*, which is even higher than in the previous analysis (walking to *Parks and nature*).

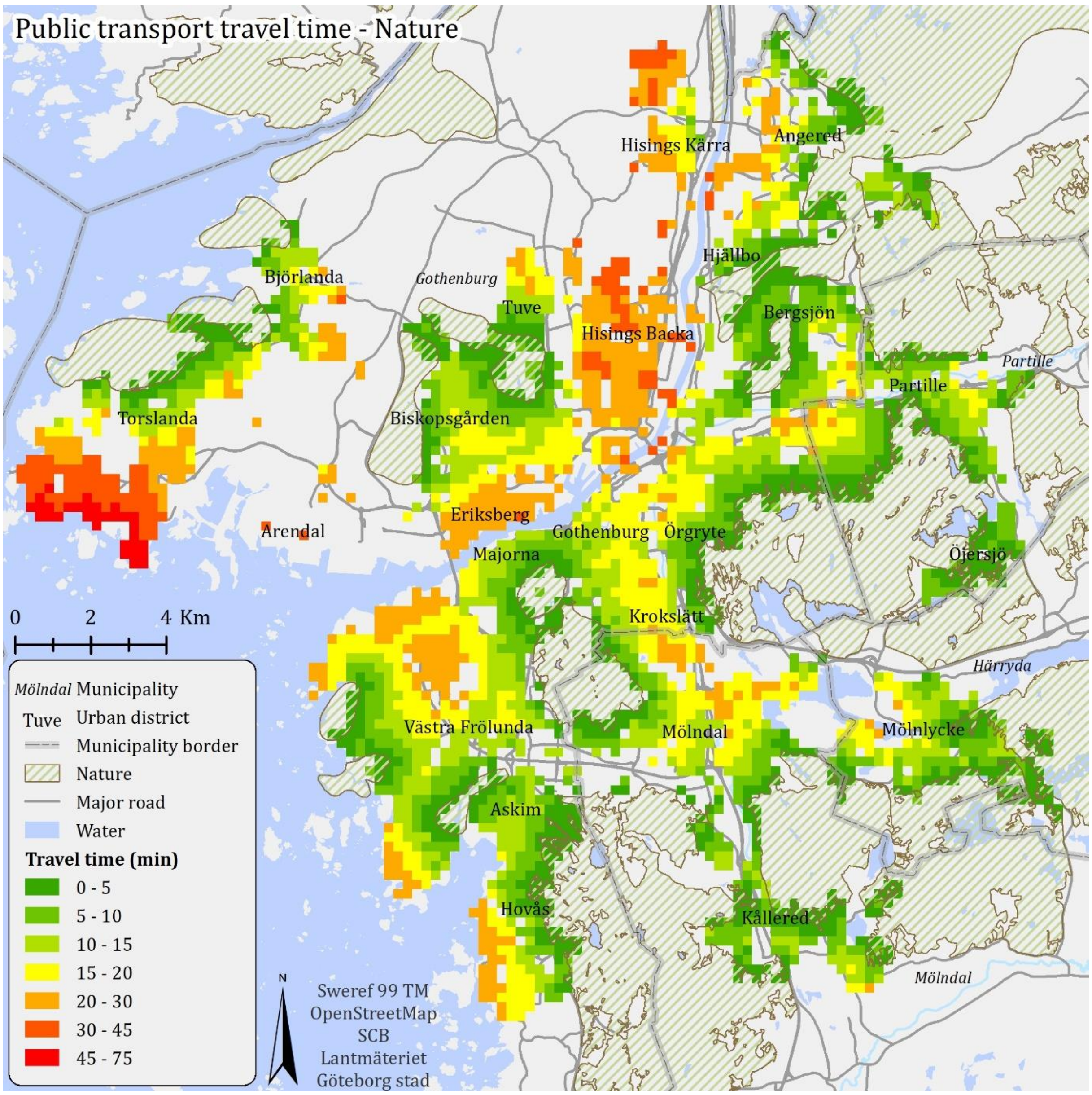

Figure 5: travel time by public transport to closest *Nature* in Gothenburg city. The pixels represent residents and the color of the pixels represents the travel time in minutes.

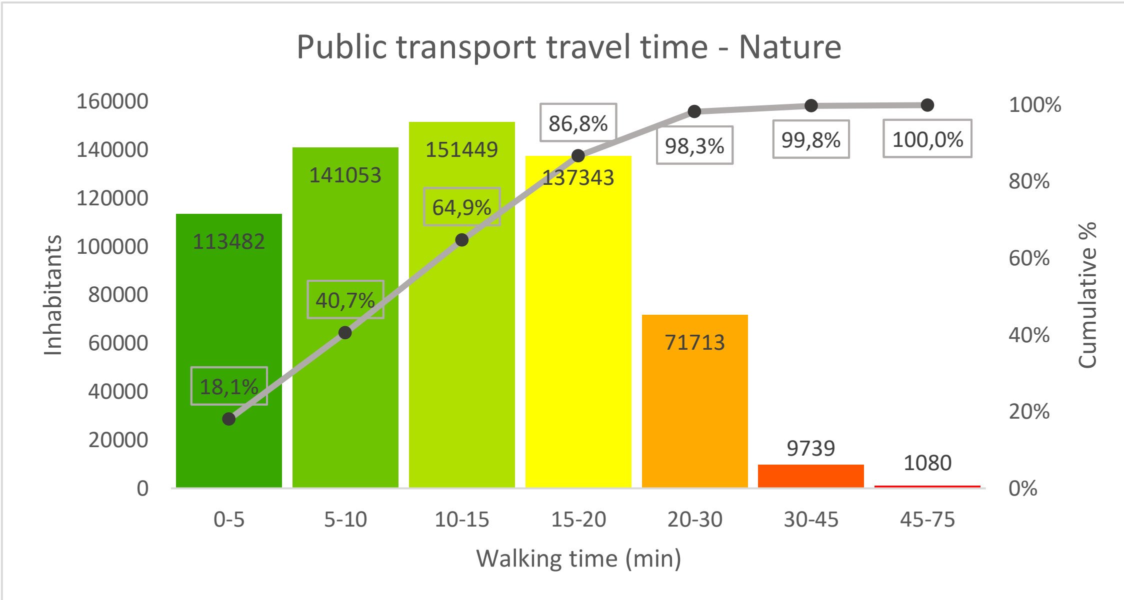

Figure 6: the number of inhabitants within each travel time category on the left axis (labelled by the staples) and the cumulative percentage on the right axis (labelled by the points).

4.2 Spatial inequality

This section presents the results of the spatial analyses with regards to inequality in accessibility. First, an analysis of the relationship between income and travel time is presented. Thereafter, a Location Quotient comparison map is presented with the result of the Moran´s I spatial auto-correlation.

Figure 7 shows the correlation between income levels and accessibility to green areas by public transport. The result show that there is no significant correlation. The regression function (figure 7) gives a relatively low negative x-value, meaning that higher income correlates with further distance from green areas. However, since the R-square is close to zero that model explains little of the variability in the income data. Figure 8 displays a similar pattern as figure 7. In up to 30 minutes' travel time the distribution is relatively even among the income categories. However, at above 30 minutes, a pattern appears where further distance seemingly correlates with higher income.

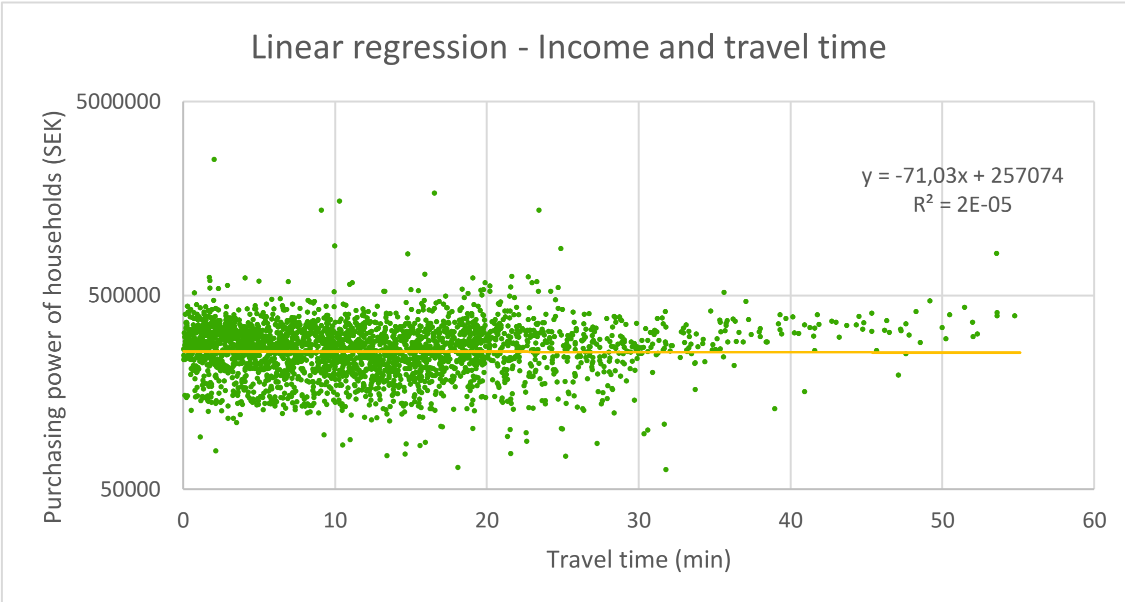

Figure 7: a scatter plot with travel time by public transport in minutes on the horizontal axis. Purchasing power of households per consuming unit, is on the vertical axis. The least square regression line is presented together with the function and R-square value.

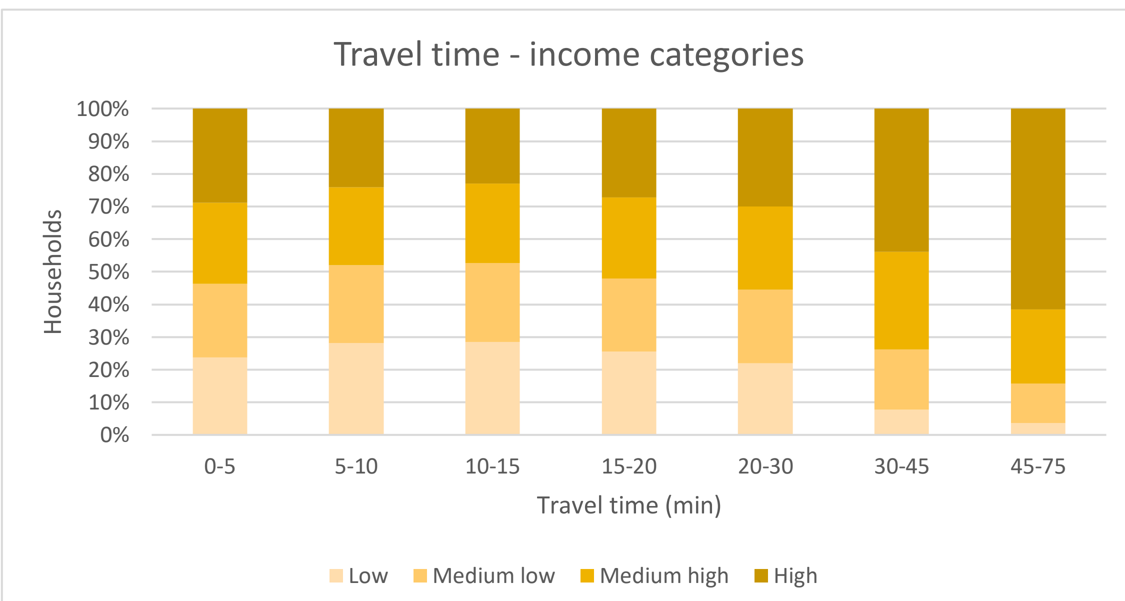

Figure 8: the distribution of categories of income levels (purchasing power of households per consuming unit) per travel time category. On the x-axis is the travel time by public transport to closest *Nature*. On the y-axis is the percentage of households in each income category.

Figure 9 shows the LQ values (the travel time of each pixel as a quota of the mean travel time of the whole area) of the two analyses. Note that the walking map was analyzed with *Parks and* *nature* (a higher number of green areas) and the public transport analyses used *Nature* (the more restrictive selection). Hence, it is not a comparison between transport modes, rather a comparison of the two goals of green area accessibility.

The maps have both similarities and differences. In general, central parts seem to have slightly higher accessibility in the walking to *Parks or nature* analysis, than in public transport to *Nature.* In both cases, large portions of Hisings Backa have higher LQ, meaning longer travel time than the global average. Moreover, in both cases parts of Torslanda have high values, even though the areas are not completely overlapping. For the public transport map, it seems as the majority of the southeastern parts, Partille, Öjersjö, Mölnlycke and Kållered, have generally low LQ. A difference in the maps is found in the northern parts of the map, in Hisings Kärra on the west side of the river. Here, the LQ is high in the walking map but low in the public transport map. The opposite is true on the other side of the stream, in western Angered.

In figure 9 the Moran's I measures of spatial autocorrelation are also presented. The Moran's I was 0.40 and 0.17 for the travel times of public transport and walking, respectively. The z-scores are very high, and the p-values are very close to zero, in both cases. Both z-scores and p-values are associated with the standard normal distribution. A z-score above 2.58 corresponds to a p-value of 0.01, meaning there is a confidence level of 99 % to reject the null hypothesis that there is complete spatial randomness in accessibility. Hence, no randomness in accessibility is observed in the results. Because the index in both cases also are positive we can also determine that a spatial clustering occurs in both cases. The spatial clustering is stronger in the public transport map. Remember that the walking analysis includes a higher number of green areas.

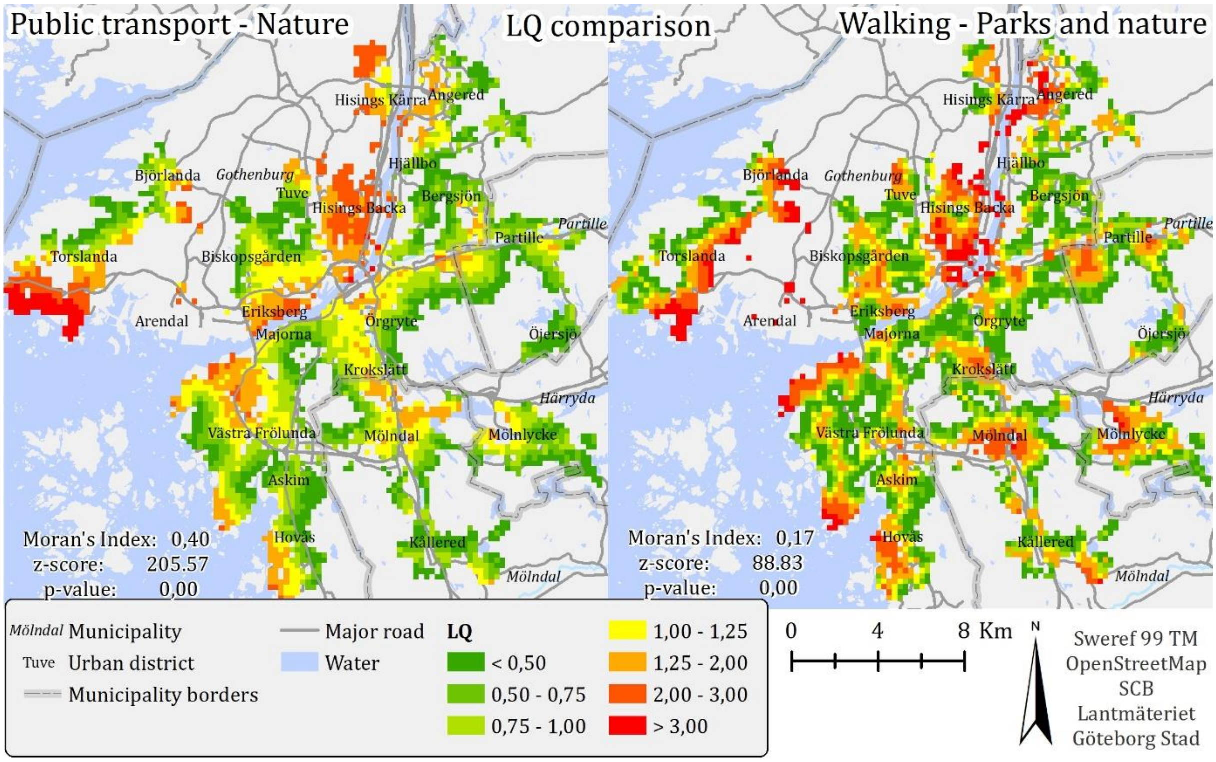

Figure 9: a comparison of the Location Quotient values for the Public transport analysis (travel time to *Nature*) and the walking analysis (travel time to *Parks and nature*). The Moran's I analysis results are also presented.

4.3 Comparison between transport modes

This section presents the comparison between the four transport modes (walking, public transport, biking and car). Note that in this section all transport modes are analyzed by the travel time to *Nature*.

Figures 10 and 11 shows that the accessibility is higher for biking and driving compared to public transport and walking. Note that biking has a much shorter travel time compared to public transport.

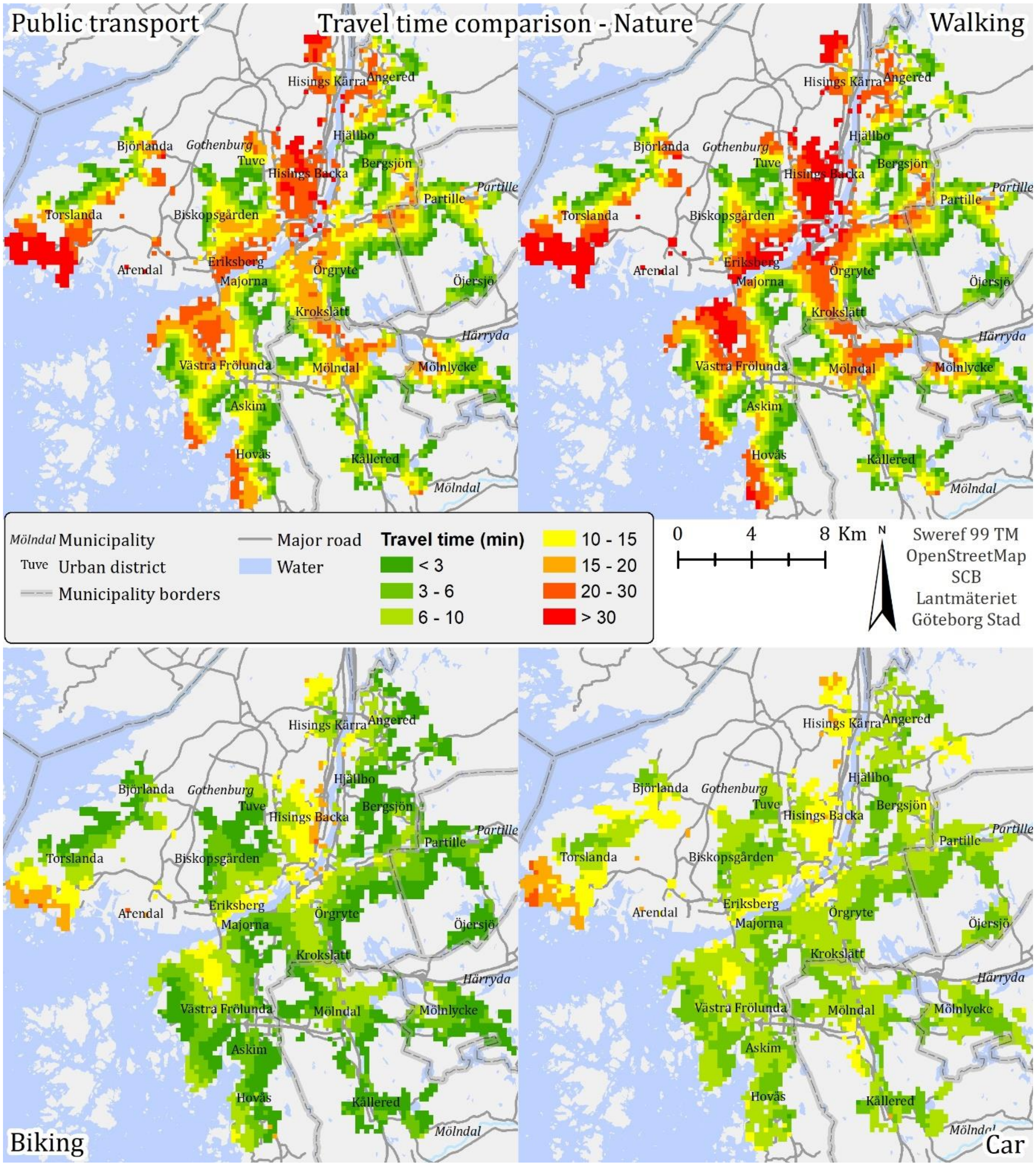

Figure 10: Comparison between the transport modes travel time to closest *Nature*.

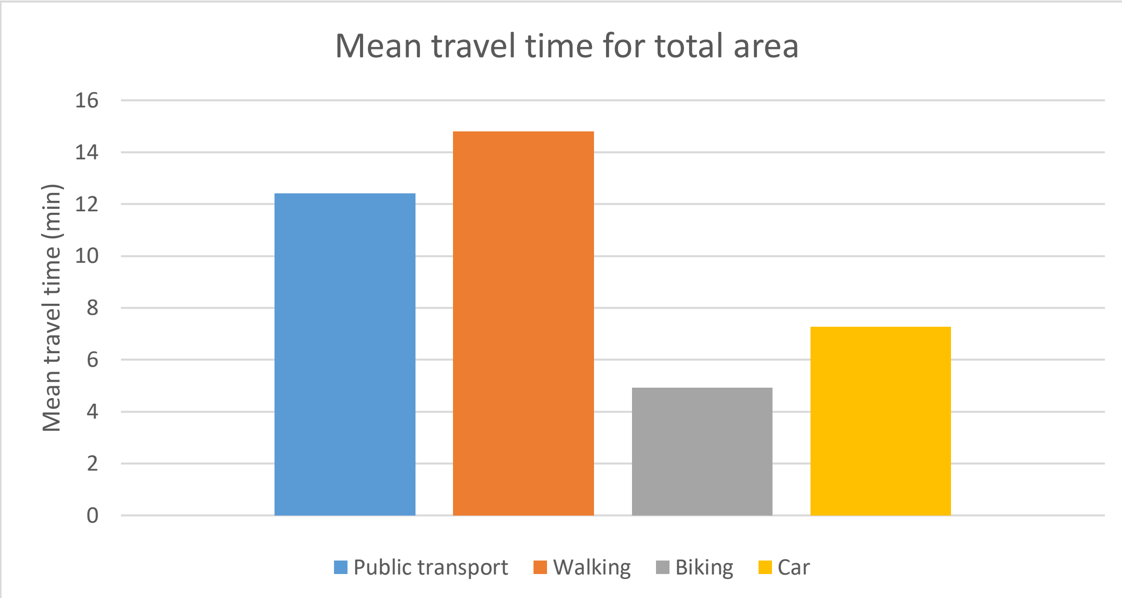

Figure 11: the mean travel time (to *Nature*) of the study area for each transport mode.

Figure 12 shows a comparison of the distribution of residents in each time category and for every transport mode. Biking is faster than the other travel modes, with almost 60 % within the 0-5 minute's category. Car travel is also relatively quick, with most of the inhabitants residing within the 5-10 minutes category. In short distance travels, up to 10 minutes, public transport is rather similar to walking. In time categories above 10 minutes there is a difference in favor of public transport, compared to walking.

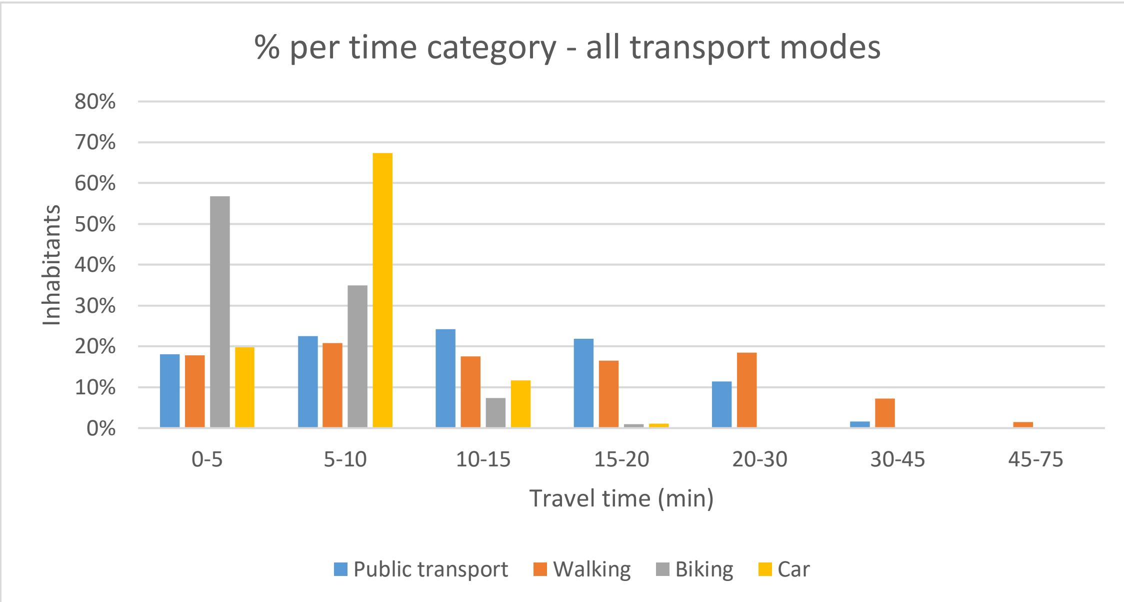

Figure 12: a comparison in travel time (to *Nature*) of all four transport modes. The figure shows the percentage of people that resides in each travel time category.

Figure 13 and 14 compares the location quotient values between different transport modes. Public transport LQ has been compared with car travel (figure 13) and biking (figure 14), respectively.

Pixels having values below zero (green colors) represent areas where the accessibility by public transport has a lower LQ than the accessibility by car or bike. Pixels with values above zero (red colors) are areas where car or bike travel has lower LQ than public transport (figure 13 and 14). This is not a representation of which transport mode that has the shortest travel time, but rather an indication of where the public transport infrastructure is better developed in relation to the infrastructure for cars and bikes, respectively.

The LQ comparison between car and public transport (figure 13) shows that when there are short distances to *Nature*, the LQ values are lower for the public transport. However, in these areas travelling by public transport (which is a multimodal network with both public transport and walking) are almost only done through walking. Travelling by car seems very favorable at longer distances compared to travelling with public transport.

The comparison of the public transport and biking networks indicates where the public transport network is well-developed; for example, the central parts of Gothenburg, and the eastern parts of Hisings Backa. At the same time, the western parts of Hisings Backa have a relatively less developed public transport. Southern Torslanda has also substantial variations on a relatively small scale, within the district. The western part has considerably better accessibility than the eastern part.

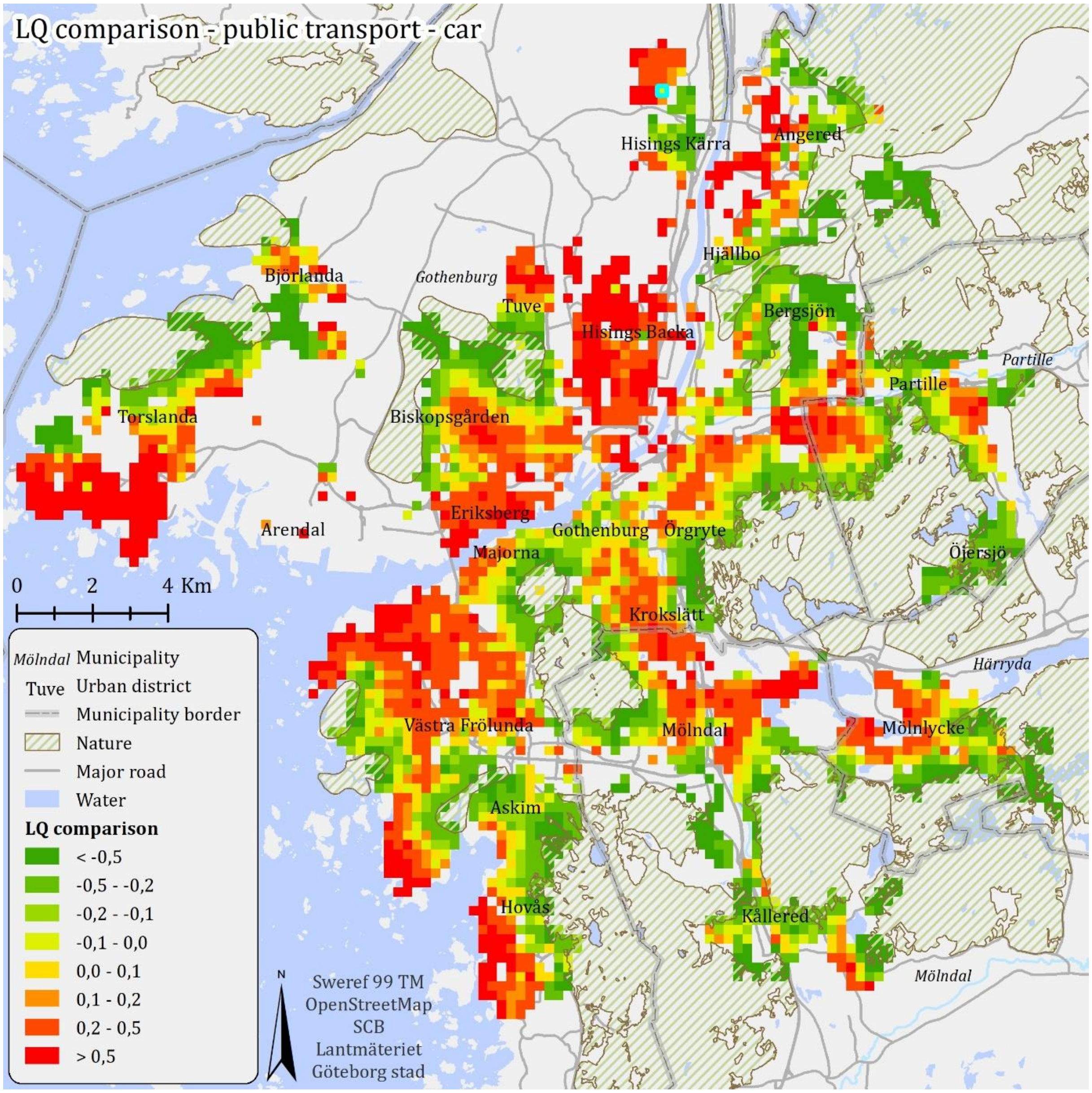

Figure 13: a comparison between the location quotient values of public transport and car. A value below 0 represents areas where public transport has a lower LQ than car, and vice versa.

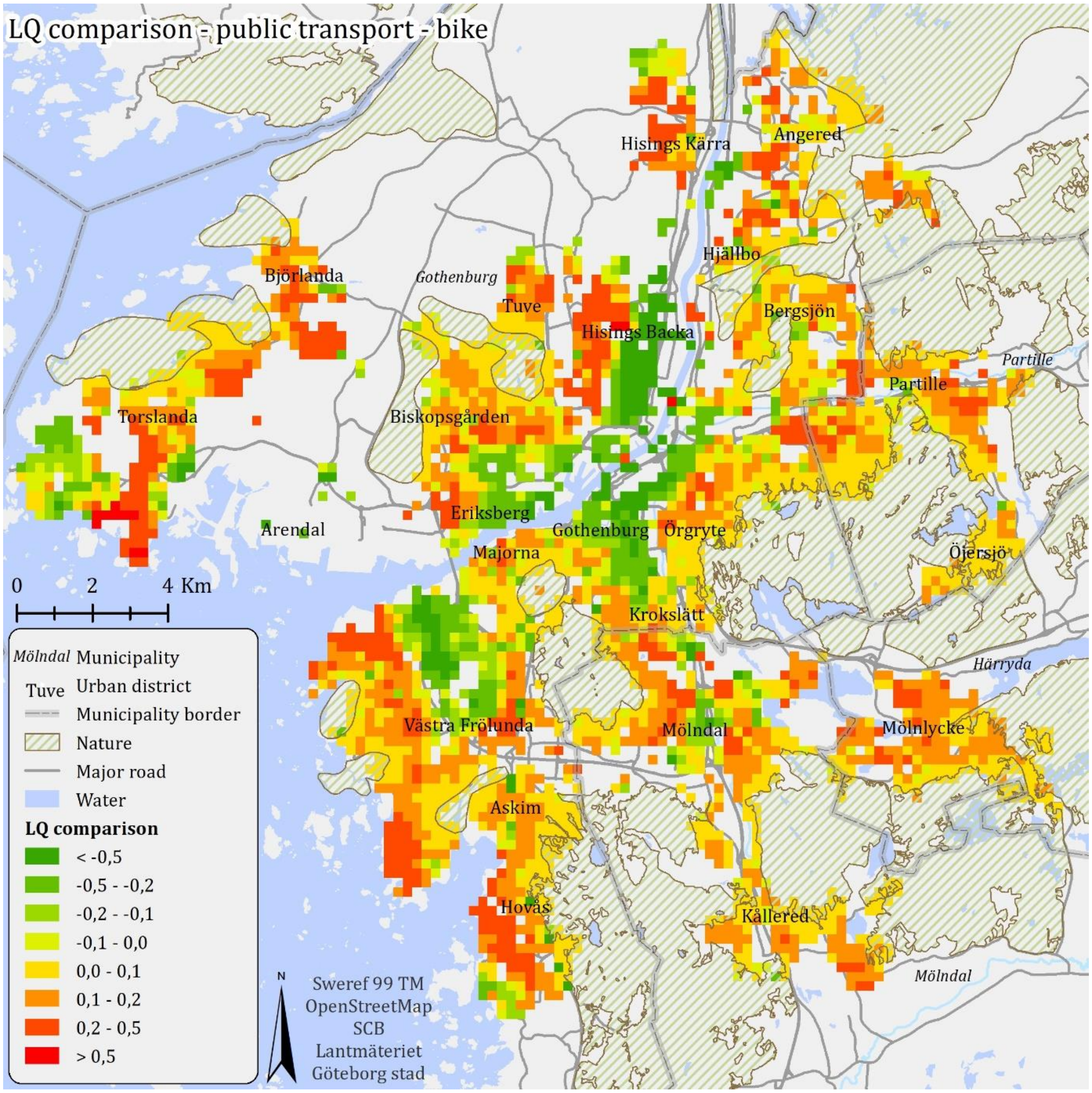

Figure 14: a comparison between the location quotient values of public transport and bike. A value below 0 represents areas where public transport has a lower LQ than bike, and vice versa.

5. Discussion

The discussion consists of five sections. The first three sections discuss the results, whereas the latter two discuss the methods and possible future studies.

5.1 The geographic accessibility in Gothenburg

The results from the accessibility analysis shows that 93 % of the population in the study area resides within 15 minutes walking time to closest *Park or nature*. Hence, the accessibility to green areas in Gothenburg is generally sufficient according to the goals set by Gothenburg municipality (Göteborg stad 2014). However, some areas do have a deficiency in this aspect. Possibly, the most noteworthy finding is southern Hisings Backa, which is a relatively central part of the city. In this area the Frihamnen district is located (Dahl 2017). Frihamnen is experiencing redevelopment from an old harbor into a new urban district. In this context, a new urban park is planned, called the Jubileepark. The harbor environment and user participation is incorporated in the long-term park development process. Other than this area, mainly smaller peripheral parts of the city are outside 15 minutes' walk to green areas, e.g. parts of Torslanda, Angered and Västra Frölunda. Several of these areas are located seaside. Maybe the sea is considered a natural experience even without green areas adjacent to it. This may be taken into consideration in the physical planning process. During the analysis process of this paper it was found that the OSM data within Gothenburg municipality, that eventually was not used, included no parks or nature along the coastline of Västra Frölunda. An accessibility analysis with this data would have resulted in very low accessibility in this area. In conclusion, the accessibility to *Parks and nature* by walking is sufficient for most areas and the areas of deficiency are compensated by being seaside or having a new park planned.

Furthermore, the accessibility to *Nature* by public transport fulfill the requirements to a higher degree than in previous case (walking to *Parks and nature*). Results show that 98 % are within 30 minutes to closest *Nature* by public transport travel. Remember that the selection of *Nature* is even more restrictive than the selection of urban parks and larger natural areas that Gothenburg municipality (Göteborg stad 2014) produced. Thus, the number of people reaching urban parks or larger natural areas within 30 minutes, which is the actual goal set by the municipality, is even higher than 98 %.

5.2 Spatial inequality

Even though the accessibility is clustered no spatial inequality of accessibility in relation to income was found in the study. However, no thorough analysis of income and accessibility to green areas has been carried out in this paper. Other variables potentially affecting the accessibility should have been controlled as well. Hence, no complete conclusion can be drawn, but some notable outcomes can be discussed. The linear regression analysis shows no relation between income and distance to *Nature* by public transport. In contrast, a study of accessibility to a major workplace in Gothenburg showed inequality regarding income (Elldér et al. 2012). Their study does not involve green areas, but still it indicates spatial inequality in accessibility by public transport in Gothenburg. Even though no relation is found in the linear regression in this paper, the result also show that very long travel times tends to have an overrepresentation of high income residents. Dempsey et al. (2012) points out that low density villa suburbs are often in high demand even though they may have relatively poor access to urban services. High income residents might have long travel times since they reside in low-density districts with poorer access to urban services. Note that the low-density districts are not rural areas since they are excluded in this analysis. Moreover, relatively few people reside in these areas. Less than 2 % of the total population of Gothenburg have more than 30 minutes' travel time from *Nature*. These areas are mainly found in the peripheral parts of the city, the southern parts of Torslanda and northern parts of Hisings Kärra. For most of the population there still seems to be little relation between income and travel time.

The income distribution of residents in close proximity to green areas show a small overrepresentation of high income people. This may suggest that green areas increase adjacent property values, which has been found in other studies (Konijnendijk et al. 2013). The reviewed studies in Konijnendijk et al. (2013) have also observed that the increase in property values disappear rapidly with distance from green areas, which seem to support the result in this paper. Hence, living very close to a park or natural area seem to be desirable.

The Moran's I results showed that the values of accessibility to green areas are clustered. A significant spatial autocorrelation for the LQ values of both public transport and walking occurred. The spatial clustering was highest for the public transport accessibility. There is a relatively low count of green areas compared to the large number of origin points, consequently, it is rather expected that origin points adjacent to each other share similar values. The *Nature* selection of green areas is more restrictive than the *Parks and nature*, thus including fewer green areas. Hence, the results of the public transport analysis show even higher levels of clustering.

5.3 Comparison between transport modes

Comparing public transport to the other travel modes resulted in some notable differences and similarities. There are substantial differences in travel times between public transport and car/bike. For both car and bike travel about 90 % can reach *Nature* within 10 minutes; for public transport about 40 % can reach nature within 10 minutes. The travel times by public transport are considerably higher than car and bike. Compared to walking the difference is smaller. Close to green areas there is no difference in travel times between walking and public transport. This is expected since the public transport network is a combination of walking and public transport, and may exclude public transport travel if it is quicker to walk between origin and destination. In short distances walking typically is quicker. In longer distance travels the differences between walking and public transport becomes more apparent. For example, in the central parts of the city, northern Västra Frölunda and Hisings Backa, the travel times are shorter by public transport. These areas appear to have well developed public transport. However, a smaller difference between walking and public transport is found in southern Torslanda, despite the long distance. This area seems to have a less developed public transport infrastructure, which may be because it is a peripheral district with rather low population density. In this analysis, no consideration has been taken to comfort. Travelling by bike or walking for extended periods of time may not be desirable. Therefore, public transport may be preferred, regardless of longer travel times, but this study does not acknowledge that. Conclusively, travelling with public transport is preferable primarily in long distance travels, in comparison with walking and biking.

The LQ comparisons goes beyond just focusing on the differences in travel times between the different transport modes. Instead it measures the geographic distribution of accessibility by one travel mode, and compare it with the geographic distribution of another. It may assess the quality of the networks, indicating areas with poor/well developed public transport. However, the comparison between car and public transport is unsuccessful in indicating the level of development of the public transport. The added time of the car travel in the start and the end of the travel has a large impact in short distances. Thus, in short distances, walking (in the public transport network) is generally almost as quick or maybe even quicker than car travel. In long distance travels the difference is much more distinct in favor of driving. Therefore, the LQ comparison only show lower LQ for public transport close to nature, and lower LQ for car driving at long distances. On the contrary, the LQ comparison between biking and public transport gives more information on the spatial distribution of how well developed the public transport network is. These two transport modes have higher comparability since the biking travel time does not include a general added time penalty such as the car travel network. The central parts of Gothenburg seem to have well developed public transport infrastructure. In Hisings Backa the public transport seems to mainly traverse in the eastern part of the district and in north-south direction. It is also possible to distinguish some hotspots for the public transport, e.g. central Mölndal, parts of Eriksberg, Torslanda and northern Västra Frölunda. This is possibly public transport hubs that acts as transit stops for many routes. In summary, the LQ comparison between bike and public transport can be used to assess the quality of the geographic accessibility by public transport.

5.4 Methods discussion

The measurements used in this paper connects green area entrances (destination points) and inhabitant's homes (origin points) to networks. Hence, the measurements are location-based, using localizations of activities around the travel networks rather than only focusing on the networks. Thereafter, travel times between origin points and destination points were calculated and used as the impedance in these measurements, instead of e.g. distance or monetary cost. This is further discussed in section 5.5.

One major challenge of the study was to select which parks and natural areas to include in the analysis. There is a difference in how green areas are distributed in the centrum and the periphery of the city. Generally, in the central parts of a city there is a high abundance of parks but few natural areas. In the outskirts, the opposite is true. This has been shown in Dony et al. (2015). It is a challenge to find a way to counterbalance these differences to make centrum and periphery comparable. The selections of green areas in this paper are made in appreciation of this. Even though general rules of e.g. size, classification and localization of the green areas are set, the selections are still arbitrary, since the rules are arbitrary. With different rules, the results would have been vastly different. Another issue is that the selection is made of data from two different sources that are produced for diverse purposes and on various levels of detail. To combine them in the analysis here is somewhat inherently problematic. For example, the lower level of detail in one of the datasets might mean that green areas intersect with the network at places where the roads in reality do not enter the green area, thus producing a false entrance. Meanwhile, the higher level of detail in the other dataset excludes this problem. To summarize, data of green areas are fundamental for the study but it is difficult to make an unbiased selection of them.

A wide range of properties may determine the sophistication of the networks. The car travel network is rather generalized in this paper. In reality, car travel differs according to several parameters, e.g. congestion, individual driving speed, number of turns etc. The added time penalties for congestion, walking to and from parking space and finding parking space, are based on studies of a similar city, Helsinki. Still, these numbers are relatively generalized and could have been better estimated, e.g. by introducing congestion data at different times of the day, considering the distance from car parking to green area entrance and examining whether the parking spaces have fees.

For the walking and biking networks, the speeds are generalized in this paper, but in reality they can be affected by slope, weather, individuality etc. Another issue in the walking/biking networks is that several walkable areas are not representable as line segments; e.g., squares, parking spaces and some grass areas. In reality, these areas are often traversable in many different directions, which cannot be represented as line segments. Instead they are represented as polygons in the OSM data and are thus excluded from the walking network. The public transport network has several issues as well. First, the transit stops were given as a single point in the GTFS data when, in actuality, a stop might have several platforms/localizations in proximity to each other. At several occasions in this analysis, stops were in reality dually located on walking paths or platforms on each side of the road. However, in the data they were represented as only one point in between. Therefore, the stop was snapped to the road in between. Hence, the walking route needed to reach the stop would be longer or shorter than if the stop would have been correctly located on the paths or platforms. Another issue might be that there is no time penalty when switching public transport vehicle at stops. Moreover, the public transport network cannot handle priorities of transport modes. Even if walking is quicker, one might prefer travelling long distances by public transport instead, but this is not considered in the analysis. In closing, the networks are flawed models of the reality and can have various levels of sophistication. Without rejecting the methods of this paper, several issues still need acknowledgement.

However, it might not matter how sophisticated the method is, if the data quality is inadequate. The quality of the OSM data is seen as adequate, but since the data is open source and a work in progress, it is partly unfinished, especially in peripheral parts of Gothenburg (OpenStreetMap Wiki 2017; Will 2014). Some data quality issues needed handling during the work: (1) some of the roads were unclassified and therefore included in both walking, biking and driving networks (with a generalized speed); (2) most of car parking places did not include the information of whether it had private or public access; thus, all parking places that did not have this information were considered accessible in the analysis. Also, some roads were included in the networks that probably should not be. For the biking network all roads that might be usable for biking is included. In reality, cyclist may prefer to avoid some larger roads. Another issue is that some origin points were snapped to large roads, even though inhabitants rarely start their travel in the middle of a large road. At occasions, this led to long re-routes. In closing, the OSM data include high levels of detail but the quality has some issues.

Some finishing notes on the statistical analysis. First, the linear regression could use weighted population points according to number of inhabitants, instead of each point having the same weight. Secondly, maybe another approach to using Moran's I could be used. For example, dividing the study area in larger districts, counting the number of green areas within each district and calculate Moran's I from that. However, parks and natural areas are of very different sizes and qualities and may need some ranking system in that case. Also, the accessibility along networks will not be accounted for in such an analysis.

5.5 Future studies/Outlook

In future studies, other location-based measures could be used to develop the results. In the results of this paper most residents reached *Nature* in less than 30 minutes despite a more restrictive selection of green areas than in the analysis of Gothenburg municipality (Göteborg stad 2014). An alternative approach could be to instead calculate the number of green areas reached within 30 minutes' travel time of each origin point. Distance decay could also be introduced, where green areas could be given weights depending on how close they are. Furthermore, the green areas could be given weights based on certain properties; e.g., whether they are classified as urban district park, urban park or natural area. Different green areas have dissimilar properties that may influence the choice of which one to visit. Hence, a larger number of green areas within reach increases the chance of one of them being preferable. Maybe the measurement could indicate how many different types of green areas that are reached within 30 minutes. Another way to analyze the accessibility could be to assess if more classical standards are met, where a certain size of green areas per inhabitant should be available (see section 2.5 and Nicholls 2001). Other than amending the measurements, some details in the method could be improved. If congestion data is introduced, the car network could be analyzed at the same hours as the analysis of public transport, i.e. the hours the green areas are most visited. More correct data of public car parking amenities would also increase the accuracy of the car network. Furthermore, the statistical analysis of spatial inequality could be elaborated and include other socioeconomic parameters. To conclude, some details could be amended to improve the method in the future. However, the most interesting outlook would probably be to develop other location-based measures.

6. Conclusions

The aim of this paper is to study the geographic accessibility to green areas in Gothenburg. The purpose is to determine whether the accessibility: (1) is sufficient according to set goals (Göteborg stad 2014); (2) has spatial inequality; and (3) varies in different transport modes.

The methods utilized travel time in location-based measurements to evaluate the accessibility. Network analysis in a GIS environment was performed on four travel modes: public transport, walking, biking and driving car. Residents were set as origin points. The destination was the closest entrance into a green area.

Few studies of accessibility to green areas have included public transport travel in the analysis. In Gothenburg, no studies of accessibility to green areas have used network analysis of any transport mode. The results of this paper showed that the accessibility was sufficient according to the Gothenburg municipality goals, for most of the urban population. Although a few areas experienced a deficiency, the results showed no indications of spatial inequality with regards to income and accessibility. However, no complete analysis of the relationship between income and accessibility was carried out in this thesis. That is, all possible variables that may influence the relationship between income and accessibility were not analyzed. Therefore, further studies on this topic are needed. Accessibility by public transport was rather unfavorable compared to both biking and driving, at both short and long distances. Compared to walking it is mainly favorable in long-distance travels. The comparison to other transport modes also shows that public transport network is well developed in central parts of the city and in a rather well distributed sense in the whole study area. However, the differences can be substantial on a smaller scale, within districts.

To conclude the discussion about the methods: the results in this paper are greatly affected by the inevitably subjective selection of green areas. Since a city contains a wide range of green areas with great differences in properties, it is a challenge to perform an unbiased selection. Furthermore, the networks contain several points of improvement potential, e.g. the use of live congestion data for the car network. Methods could also include other location-based measurements.

7. References

Andersson, D., and J. Nassen. 2016. The Gothenburg congestion charge scheme: A pre-post analysis of commuting behavior and travel satisfaction. *Journal of Transport Geography,* 52**:** 82-89. DOI: 10.1016/j.jtrangeo.2016.02.014

Ben-Akiva, M., and S. R. Lerman. 1979. Disaggregate travel and mobility choice models and measures of accessibility. *Behavioural travel modelling***:** 654-679.

Black, W. R., and I. Thomas. 1998. Accidents on Belgium's motorways: A network autocorrelation analysis. *Journal of Transport Geography,* 6**:** 23-31.

Borjesson, M., J. Eliasson, and C. Hamilton. 2016. Why experience changes attitudes to congestion pricing: The case of Gothenburg. *Transportation Research Part A: Policy and Practice,* 85**:** 1-16. DOI: 10.1016/j.tra.2015.12.002

Borjesson, M., and I. Kristoffersson. 2015. The gothenburg congestion charge. Effects, design and politics. *Transportation Research Part A: Policy and Practice,* 75**:** 134-146. DOI: 10.1016/j.tra.2015.03.011

Boverket Sverige. 1999. *Gröna områden i planeringen*. Boverkets publikationsservice.

Boverket Sverige. 2007. *Bostadsnära natur : inspiration & vägledning*. Karlskrona : Boverket, 2007, 1. uppl.

Brinkhoff, T. 2016. Open Street Map Data as Source for Built-Up and Urban Areas on Global Scale. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences***:** 557-564.

Browning, R. C., E. A. Baker, J. A. Herron, and R. Kram. 2006. Effects of obesity and sex on the energetic cost and preferred speed of walking. *Journal Of Applied Physiology (Bethesda, Md.: 1985),* 100**:** 390-398.

Burns, L. D. 1980. Transportation, temporal, and spatial components of accessibility.

Chiesura, A. 2004. The role of urban parks for the sustainable city. *Landscape and urban planning,* 68**:** 129-138.

Comber, A., C. Brunsdon, and E. Green. 2008. Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. *Landscape and Urban Planning,* 86**:** 103-114.

Coutts, C., M. Horner, and T. Chapin. 2010. Using geographical information system to model the effects of green space accessibility on mortality in Florida. *Geocarto International,* 25**:** 471-484.

Dahl, C. 2017. Gothenborg's Jublieumsparken 0.5 and Frihamnen: explorations into the aesthetic of DIY. *SPOOL,* 3**:** 73-96.

Dahlgren, A. 2008. Geographic Accessibility Analysis - Methods and Application. Licentiate thesis. Real Estate Science, Department of Technology and Society: Lund University.

Dempsey, N., C. Brown, and G. Bramley. 2012. The key to sustainable urban development in UK cities? The influence of density on social sustainability. *Progress in Planning,* 77**:** 89-141. DOI: 10.1016/j.progress.2012.01.001

Dony, C. C., E. M. Delmelle, and E. C. Delmelle. 2015. Re-conceptualizing accessibility to parks in multi-modal cities: A Variable-width Floating Catchment Area (VFCA) method. *Landscape and Urban Planning,* 143**:** 90-99.

Eklund, L., and U. Mårtensson. 2012. Using geographical information systems to analyse accessibility to health services in the West Bank, Occupied Palestinian Territory. *Eastern Mediterranean Health Journal,* 18**:** 796-802.

Elldér, E., A. Gil Sola, and A. Larsson. 2012. Featured graphic: Spatial inequality and workplace accessibility: the case of a major hospital in Göteborg, Sweden. *Environment and Planning A*.

Encyclopædia Britannica. 2015. Gothenburg. Retrieved 2017-02-06, from. https://global.britannica.com/place/Gothenburg-Sweden

ESRI. 2017. How Spatial Autocorrelation (Global Moran's I) works. Retrieved 2017-05-10, from. http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/h-how-spatial-autocorrelation-moran-s-i-spatial-st.htm#GUID-74FCFBA4-158D-4D0A-9C3A-D7F46107F580

Finsberg, M. 2017. Parker mm i Göteborg [E-mail].

Getis, A., and J. K. Ord. 1992. The analysis of spatial association by use of distance statistics. *Geographical analysis,* 24**:** 189-206.

Geurs, K., and J. Ritsema van Eck. 2001. Accessibility measures: review and applications. Evaluation of accessibility impacts of land-use transportation scenarios, and related social and economic impact. In *Bereikbaarheidsmaten: review en case studies. Beoordeling van bereikbaarheidseffecten van ruimtelijk-infrastructurele scenario's, en gerelateerde sociale en economische effecten*. Rijksinstituut voor Volksgezondheid en Milieu RIVM.

Geurs, K. T., and B. van Wee. 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography,* 12**:** 127-140. DOI: 10.1016/j.jtrangeo.2003.10.005

Google developers. 2016. GTFS Static Overview. Retrieved 2017-06-13 2017, from. https://developers.google.com/transit/gtfs/

Google maps. 2017a. Göteborgs Botaniska Trädgård. Retrieved 2017-03-04, from. https://www.google.se/search?q=botaniska+tr%C3%A4dg%C3%A5rden+g%C3%B6teborg&oq=botaniska&aqs=chrome.1.69i57j0l5.4483j0j7&sourceid=chrome&ie=UTF-8

Google maps. 2017b. Slottskogen. Retrieved 2017-03-04, from. https://www.google.se/search?q=botaniska+tr%C3%A4dg%C3%A5rden+g%C3%B6teborg&oq=botaniska&aqs=chrome.1.69i57j0l5.4483j0j7&sourceid=chrome&ie=UTF-8#q=slottsskogen+g%C3%B6teborg

Google maps. 2017c. Trädgårdsföreningen, Göteborg. Retrieved 2017-03-04, from. https://www.google.se/search?q=botaniska+tr%C3%A4dg%C3%A5rden+g%C3%B6teborg&oq=botaniska&aqs=chrome.1.69i57j0l5.4483j0j7&sourceid=chrome&ie=UTF-8#q=tr%C3%A4dg%C3%A5rdsf%C3%B6reningen

Górniak, J. 2016. The Spatial Autocorrelation Analysis For Transport Accessibility In Selected Regions Of The European Union. *AUTOKORELACJA PRZESTRZENNA DOSTĘPNOŚCI TRANSPORTOWEJ W REGIONACH WYBRANYCH KRAJÓW UNII EUROPEJSKIEJ.,* 19**:** 25-42. DOI: 10.1515/cer-2016-0036

Grahn, P., and U. A. Stigsdotter. 2003. Landscape planning and stress. *Urban Forestry & Urban Greening,* 2**:** 1-18. DOI: 10.1078/1618-8667-00019

Gregory, D., and R. J. Johnston. 2009. *The dictionary of human geography*. Malden, MA : Wiley-Blackwell, 2009, 5th ed.
Gupta, K., A. Roy, K. Luthra, S. Maithani, and Mahavir. 2016. GIS based analysis for assessing the accessibility at hierarchical levels of urban green spaces. *Urban Forestry & Urban Greening,* 18**:** 198-211. DOI: http://dx.doi.org/10.1016/j.ufug.2016.06.005
Göteborg stad. 2009. Comprehensive plan for Göteborg, summary. Retrieved 2017-02-03, from. http://goteborg.se/wps/wcm/connect/ef7f3608-57e7-4020-afcf-ccf657e2e16e/OPA_Sammanfattning_OP_eng.pdf?MOD=AJPERES
Göteborg stad. 2014. Grönstrategi för en tät och grön stad. ed. Park och Natur. https://goteborg.se/wps/wcm/connect/0bbf9fb8-a6a9-43bf-9548-34e7697d8f0e/Gr%C3%B6nstrategi_20140324.pdf?MOD=AJPERES.
Hansen, W. G. 1959. How Accessibility Shapes Land Use. *Journal of the American Institute of Planners,* 25**:** 73-76. DOI: 10.1080/01944365908978307
Haugen, K. 2012. The accessibility paradox: Everyday geographies of proximity, distance and mobility. PhD Thesis Umeå universitet
Haugen, K., and B. Vilhelmson. 2013. The divergent role of spatial access: The changing supply and location of service amenities and service travel distance in Sweden. *Transportation Research Part A,* 49**:** 10-20. DOI: 10.1016/j.tra.2013.01.001
Heywood, D. I., S. Cornelius, and S. Carver. 2011. *An introduction to geographical information systems*. Harlow : Prentice Hall, 2011, 4. ed.
Higgs, G., R. Fry, and M. Langford. 2012. Investigating the implications of using alternative GIS-based techniques to measure accessibility to green space. *Environment and Planning B: Planning and Design,* 39**:** 326-343.
Hägerstrand, T. 1970. What about people in regional science? *Papers in Regional Science,* 24**:** 7.
Jonnerby, L. 2014. GIS-analys av tillgängligheten till parker i Umeå tätort.
Jordan, H., P. Roderick, D. Martin, and S. Barnett. 2004. Distance, rurality and the need for care: access to health services in South West England. *International journal of health geographics,* 3**:** 21.
Kalenoja, H., and J.-P. Häyrynen. 2003. Keskustan pysäköinti osana liikennejärjestelmää, Tampereen keskustan pysäköintitutkimus. *Tampereen teknillinen yliopisto, Liikenne-ja kuljetustekniikka Tutkimusraportti*.
Konarska, J., B. Holmer, F. Lindberg, and S. Thorsson. 2016. Influence of vegetation and building geometry on the spatial variations of air temperature and cooling rates in a high-latitude city. *International Journal of Climatology,* 36**:** 2379.
Konijnendijk, C. C., M. Annerstedt, A. B. Nielsen, and S. Maruthaveeran, 2013. Benefits of urban parks: a systematic review. A report for IPFRA. IFPRA Report. [in Swedish, English summary]
Kurri, J., and J. Laakso. 2002. Parking policy measures and their effects in the Helsinki metropolitan area. *The Helsinki Metropolitan Area Publication Series C,* 18.
Kwan, M.-P. 1998. Space-time and integral measures of individual accessibility: A comparative analysis using a point-based framework. *Geographical Analysis,* 30:3**:** 191-216.
La Rosa, D. 2014. Accessibility to greenspaces: GIS based indicators for sustainable planning in a dense urban context. *Ecological Indicators,* 42**:** 122-134. DOI: http://dx.doi.org/10.1016/j.ecolind.2013.11.011

Larsson, A., E. Elldér, and B. Vilhelmson. 2014a. Accessibility Atlas to analyse regional acessibility to labour in the food sector. *COST Action TU1002–Assessing Usability of Accessibility Instruments, edited by Brömmelstroet, M., Silva, C., and Bertolini, L***:** 115-121.

Larsson, A., E. Elldér, and B. Vilhelmson, 2014b. Geografisk tillgänglighet. Institutionen för ekonomi och samhälle, Kulturgeografi Report, University of Gothenburg. [in Swedish, English summary]

Loh, C.-P. A., S. C. Cobb, and C. K. Johnson. 2009. Potential and Actual Accessibility to Hospital and Hospital Services in Northeast Florida. *Southeastern Geographer***:** 171.

Lund, A., 2017. Kraftsamling Öppna Trafikdata - en målbild för Sverige. Report Vinnova: 2016-03467. [in Swedish, English summary]

Lund, H. 2003. Testing the Claims of New Urbanism. *Journal of the American Planning Association,* 69**:** 414.

Lundgren Alm, E. 2004. *Grönstrukturens synliggörande : en förutsättning för integration av kunskaper om grönstrukturen i stadsplaneringen*. Göteborg : Chalmers tekniska högskola, 2004.

Malmö stad, 2003. Grönplan för Malmö 2003. Report. [in Swedish, English summary]

Miller, M. M., L. J. Gibson, and N. G. Wright. 1991. Location quotient: A basic tool for economic development analysis. *Economic Development Review,* 9**:** 65.

Moineddin, R., J. Beyene, and E. Boyle. 2003. On the location quotient confidence interval. *Geographical Analysis,* 35**:** 249-256.

Morang, M. 2017. Add GTFS to a Network Dataset User's Guide. Retrieved 2017-02-20, from. http://transit.melindamorang.com/UsersGuides/AddGTFStoaNetworkDataset/AddGTFStoND_UsersGuide.html

Naess, P. 2011. 'New urbanism'or metropolitan-level centralization? A comparison of the influences of metropolitan-level and neighborhood-level urban form characteristics on travel behavior. *Journal of Transport and Land Use,* 4**:** 25-44.

Nicholls, S. 2001. Measuring the accessibility and equity of public parks: a case study using GIS. *Managing Leisure,* 6**:** 201-219. DOI: 10.1080/13606710110084651

Oh, K., and S. Jeong. 2007. Assessing the spatial distribution of urban parks using GIS. *Landscape and urban planning,* 82**:** 25-32.

Olsson, O. 2013. Changed availability of urban fringe forests in Sweden in 2000-2010. *Scandinavian Journal of Forest Research***:** 386. DOI: 10.1080/02827581.2012.749942

OpenStreetMap Wiki. 2016a. Map Features.

OpenStreetMap Wiki. 2016b. Tags. Retrieved 2017-04-24, from. https://wiki.openstreetmap.org/wiki/Tags

OpenStreetMap Wiki. 2017. About OpenStreetMap. Retrieved 2017-05-22, from. https://wiki.openstreetmap.org/wiki/About_OpenStreetMap

Paquet, C., T. P. Orschulok, N. T. Coffee, N. J. Howard, G. Hugo, A. W. Taylor, R. J. Adams, and M. Daniel. 2013. Are accessibility and characteristics of public open spaces associated with a better cardiometabolic health? *Landscape and Urban Planning,* 118**:** 70-78. DOI: http://dx.doi.org/10.1016/j.landurbplan.2012.11.011

Salonen, M., and T. Toivonen. 2013. Modelling travel time in urban networks: comparable measures for private car and public transport. *Journal of Transport Geography,* 31**:** 143-153. DOI: 10.1016/j.jtrangeo.2013.06.011

Santos, G., H. Maoh, D. Potoglou, and T. von Brunn. 2013. Factors influencing modal split of commuting journeys in medium-size European cities. *Journal of Transport Geography,* 30**:** 127-137. DOI: 10.1016/j.jtrangeo.2013.04.005

SCB, 2016. Produktkatalog 2016 - SCB:s Marknadsprofiler. Report, Statistiska centralbyrån. [in Swedish, English summary]

SCB. 2017. Folkmängden efter region, civilstånd, ålder och kön. År 1968 - 2015. Statistiska centralbyrån.

Skoulika, F., M. Santamouris, D. Kolokotsa, and N. Boemi. 2014. On the thermal characteristics and the mitigation potential of a medium size urban park in Athens, Greece. *Landscape and Urban Planning,* 123**:** 73-86.

Small, K. A. 2012. Valuation of travel time. *Economics of Transportation,* 1**:** 2.

Smith, G. 2015. Marknadsplatser för öppna data: En fallstudie kring användare, användning och upplevt värde. In *Wednesday, December 9, 2015*.

Sugawara, H., K. Narita, T. Mikami, T. Honjo, and K. Ishii. 2006. Cool island intensity in a large urban green: Seasonal variation and relationship to atmospheric condition. *Tenki,* 53**:** 3-14.

Talen, E., and L. Anselin. 1998. Assessing spatial equity: An evaluation of measures of accessibility to public playgrounds. *Environment and Planning A,* 30**:** 595-613.

Thorsson, S., M. Lindqvist, and S. Lindqvist. 2004. Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden. *International Journal of Biometeorology,* 48**:** 149-156. DOI: 10.1007/s00484-003-0189-8

Will, J. 2014. Development of an automated matching algorithm to assess the quality of the OpenStreetMap road network: a case study in Göteborg, Sweden. *Student thesis series INES*.

Yiannakoulias, N., W. Bland, and L. W. Svenson. 2013. Estimating the effect of turn penalties and traffic congestion on measuring spatial accessibility to primary health care. *Applied Geography,* 39**:** 172-182. DOI: 10.1016/j.apgeog.2012.12.003

Zhou, X., and J. Kim. 2013. Social disparities in tree canopy and park accessibility: A case study of six cities in Illinois using GIS and remote sensing. *Urban forestry & urban greening,* 12**:** 88-97.

Appendix

Detailed methods for creating bike and car networks are presented here, including what tags, parameters and values that were used.

Biking network details

- Including a number of line segment categories, namely those with the tags *Highway= primary, primary_link, secondary, secondary_link, tertiary, tertiary_link, unclassified, residential, living_street, service, track, cycleway, footway, bridleway, pedestrian, path* (Excluding some not suitable for biking, e.g. *Highway= steps, abandoned, construction, motorway, motorway_link, trunk* and *trunk_link*). However, if the segment had the tag *bicycle=no* it was restricted.
- Applied a general biking speed of 16 km/h (or 4.44 m/s) that was divided by a certain number if the features had the following tags (table 4):

Table 4: speed penalty for biking and driving car.

Key tag	Value tag	Speed divided by
Surface	*Compacted*	1.25
	Metal	1.5
	Unpaved, gravel, fine_gravel, pebblestone, sand, dirt, grass	2
Smoothness	*Intermediate*	1.25
	Bad	1.5
	Very_bad	1.75
	Horrible	2
	Very_horrible	3
	Impassable	5

- At barriers, such as stops and traffic signals, 0.1 minutes were added to the cycle time.

Car travel network details

- Including motorcar navigable roads, namely those with tags *Highway=motorway, motorway_link, trunk, trunk_link, primary, primary_link, secondary, secondary_link, tertiary, tertiary_link, living_street, residential, unclassified* or *road* (excluding e.g. *service, cycleway, footway, bridleway, pedestrian, path*)

- Using the speed limitations that is given in tags. Although, many segments do not include that tag, in which case table 5 shows the given speed per tag.

Table 5: the speed given to segments that do not include a tag with max speed.

Key tag	**Value tag**	**Speed kph**
Highway	*Motorway*	110
	Motorway_link, Trunk	90
	Trunk_link, Primary	70
	Primary_link, secondary	60
	Secondary_link, tertiary	55
	Unclassified	50
	Tertiary_link	45
	Residential	40
	Living_street	10

- Multiplied driving speed with 1.76
- Adding time for walking to and from parking space, and finding parking space.
  - 3.47 minutes inside city center (all origin points inside a radius of 2500 meters from city center point).
  - 2.94 minutes outside city center.
- Adding a speed penalty in the same manner as with biking (table 4)
- Access was restricted if these tags were present *Access=no, destination, delivery, agricultural, forestry* or *private* (tags *Access=yes, designated, official* or *permissive* is not restricted)
- One-way streets were restricted in the wrong direction.
- Barriers, like *stops, traffic_signals* and *toll_booths*, gave 0.1 extra minutes.
- Barriers, like *block, bollard, chain, debris, jersey_barrier, lift_gate, log, spikes* and *swing_gate* were restricted.

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