OPENSTREETMAP BASED ACCESSIBILITY ANALYSIS OF URBAN GREEN AND RECREATIONAL SPACES BY WALKING AND CYCLING FOR TEN CITIES IN GERMANY

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ABSTRACT:

"Urban Green and Recreational Spaces" (UGRS) provide numerous benefits to the surrounding area, residents, and the entire urban community. While the quality of UGRS is important, so is their city-wide coverage for easy and quick access. This is especially true for big cities where UGRS are often the only spaces for local outdoor recreational activities in and with nature. The study at hand introduces a newly developed tool to quantitatively analyze and rank the ten most populous German cities by their capability to provide UGRS to their citizens. For this, different isochrone ranges by travel time are calculated for walking and cycling transport modes starting from four point feature categories comprising respective OSM tags. The study produced satisfying results with relatively high population percentages reaching UGRS in five minutes by walking or cycling, e.g. *Green Areas* are reached by 38-68% and 88-99%, respectively. This indicates that the cities are overall well provided with UGRS, keeping in mind that no preceding qualitative evaluations of the individual UGRS took place. Overall, this study showed the extensive ability of the developed tool by analyzing four different categories, two modes of transportation, and a sophisticated accessibility calculation via isochrones. Nonetheless, it can be argued that such quantitative results should be supported by considering preceding qualitative ratings in order to obtain more meaningful results for practical utilisation. This incorporation of qualitative features could be the topic of future research.

1. INTRODUCTION

The enormous importance of urban space with currently 55% of the world population living in cities is still projected to rise (United Nations et al., 2019). This is even more pronounced with an urban population of over 75% in Germany (United Nations et al., 2019; Rösel, F. and Weishaupt, T., 2020). Consequentially, these patterns of urbanization put high pressure on urban space in general and "Urban Green and Recreational Spaces" (UGRSs), namely *Green Areas*, *Water bodies*, *Cultural/Historic* and *Recreation/Tourism* sites, specifically (Caspersen et al., 2006; Hunter et al., 2017; Sugiyama et al., 2008). While commercial or industrial uses are likely to be more economically attractive to landowners, UGRSs provide numerous benefits to the surrounding residents, the district and the entire community (Gaston, 2010; Hunter et al., 2017; Kruize et al., 2019; Maas et al., 2006). Especially benefits of "Urban Green Spaces" (UGSs) can vary widely in their characteristics and differ from UGRSs that they do don't include *Water bodies*, *Cultural/Historic* and *Recreation/Tourism* sites. UGSs can balance the natural urban environment by lowering air and noise pollution, providing cooling effects and thus reducing "Urban Heat Island" effects and serving as buffer areas during heavy precipitation events (Jaafari et al., 2020; Krug and Mücke, 2018; Nowak and Heisler, 2010; US EPA, 2014).
Besides these primarily physical benefits, UGRSs also visually diversify the city, provide space for connection, recreation and enhances perceived safety and increases the property values in the surrounding area (Dole, 1989; Harris et al., 2018; Kruize et al., 2019; Maas et al., 2006; Sugiyama et al., 2008).
Especially the non-monetary attributes of UGRS such as recreational and stress relieving characteristics became even more relevant as the immediate urban environment has gained more and more importance due to the Corona Crisis (Venter et al., 2020). Accessibility to urban recreation areas such as parks or water bodies, e.g. by bicycle or by foot, has become more important for urban development due to Corona, as there were fewer opportunities to use other urban recreational facilities due to the restrictions (Ugolini et al., 2020). In cities, green spaces are therefore often the only option for outdoor recreation during Corona restrictions. This highlights the importance of locally accessible UGRSs by city dwellers (Ugolini et al., 2020).
Following the Sustainable Development Goal 11.7 "Provide Access To Safe And Inclusive Green And Public Spaces" and preceding research, this work is investigating the distribution and accessibility of UGRSs by exploiting a new approach of combining OpenStreetMap and demographic data with a selected isochrone provider in German cities (Gupta et al., 2012; Kabisch et al., 2016; Lang et al., 2008; United Nations, n.d.).
To achieve this, the presented work is contextualized in the current state of the art, then the underlying data sets are described as well as the routing provider introduced. Based on this, our own methodology and workflow is described, and the developed tool presented in detail, followed by the illustration of our results. The central research questions of this work and the extent to which they could be answered are subsequently discussed. The central research question is:

How does the distribution and accessibility of recreational spaces compare for the 10 most populous cities in Germany in relation to their population size and area by exploring different modes of transportation and travel times?

1.1 State of the Art

The diversity of methods to survey different aspects of UGRSs is numerous. Besides the methodologies about physical accessibility of UGRSs, several other perspectives on distribution, quantity and quality, relevance to resilient city planning, and social as well as individual well-being are investigated. Simple quantification of UGRSs in an urban area is often done by classifying remote sensing images to calculate the percentage of green in that area to develop an indicator of greenness to facilitate monitoring or further decision-making (Gupta et al., 2012; Lang et al., 2008).
A more accessibility-based methodology was applied by Kabisch et al. 2016 to investigate the availability and distribution of UGRSs across several European cities. They applied 300 m and 500 m buffer *as the crow flies* using a grid based land-cover data set from the European Urban Atlas (Copernicus Land Monitoring Service - Urban Atlas — European Environment Agency, n.d.).
The calculation of simple buffers around UGRSs is, besides Network Analysis Approaches, the most common method for analysing the accessibility of UGRSs. Here, most often circle geometries with one radius between 300 m and 700 m (Gupta et al., 2016; Kabisch et al., 2016; Vîlcea and Șoșea, 2020; Wilson et al., 2007; Wolch et al., 2013) for all featured UGRSs are calculated usually centred on the centroids of the given UGRSs.
Gupta et al. 2016 applied a more sophisticated analysis by adjusting the radius based on the hierarchy levels of the UGRS. By directly comparing the euclidean buffer method with the network analysis approach Gupta et al. 2016 discovered that the network analysis method estimates a substantially smaller area serviced by the UGRS than the euclidean buffer approach (around 40% less). The network analysis can generally answer questions about linear relations by modelling reality by centres, arcs and nodes. This can be used to calculate distances along arcs and between nodes also in larger navigation networks (Comber et al., 2008). This method therefore takes better account of the real accessibility radius by considering the actual road network.
The creation of isochrone accessibility zones are another but less exploited way to investigate the reachability of UGRS (Biazzo et al., 2019; Kolcsár and Szilassi, 2018). Isochrones can be understood as isolines for travel time or distance on the given road network, representing an area that can be reached in a given time or distance by a certain kind of locomotion, e.g. 5 minutes or 300 meters of walking. According to Gupta et al. 2016 the acceptable travel time to the next UGRS depends not only on the mode of travel but also on the facilities and features of the UGRS. Walking times range between 0-5 minutes for the lowest level, around 10 minutes are preferred for a neighbouring park and up to 15 minutes are acceptable for a higher hierarchical level such as a community park. When motorized driving distances are considered, travel times of up to one hour for community parks are found to be acceptable (Biazzo et al., 2019; Kolcsár and Szilassi, 2018).
The databases for most of the presented UGRSs accessibility studies are of official or proprietary nature (Comber et al., 2008; Gupta et al., 2016; Maas et al., 2006; Wolch et al., 2013). Open volunteered geographical data such as OpenStreetMap data is only rarely considered. For the calculation of the isochrones, this work incorporates one routing provider based on OpenStreetMap.
The classification of UGRSs in terms of quality and recreational value can include a variety of factors. Gupta et al. 2016 base their hierarchical classification on the area and served population of a park. Other features like walking/cycling routes, sport fields, water features, playgrounds, and drinking fountains were found to enhance the attractiveness of UGRSs for physical activity by Akpinar (2016), Cohen et al. (2006) and Schipperijn et al. (2013). Overall, higher attractiveness of UGRSs was found to relate to its vegetation maintenance, cleanliness, scenery, and overall facility quality (Akpinar, 2016; McCormack et al., 2010). While the before mentioned findings are mostly based on literature reviews, surveys, and interviews (Akpinar, 2016; McCormack et al., 2010), this work uses tags in the OpenStreetMap data to choose, categorize, and analyse UGRSs.
"OpenStreetMap" (OSM) is possibly the most prominent open-data licensed mapping project build and maintained by volunteers worldwide (OpenStreetMap, 2021a). Due to the normally untrained contributors, the data quality of OSM is frequently questioned (Heipke, 2010; Ludwig et al., 2021). While the road and bicycle lane network in Germany is assumed to be well mapped (Zielstra and Zipf, 2010; Hochmair et al., 2013), the land use classification and especially the identification of publicly accessible UGRS can be challenging (Dorn et al., 2015; Jokar Arsanjani et al., 2015; Schultz et al., 2017).
Nonetheless, a survey by Ludwig and Zipf 2019 concluded in a high degree of completeness for public green spaces in the city of Dresden. It can be assumed that this result is transferable to other large cities in Germany, as Dorn et al. 2015 worked out that a high population density seems to indicate a higher quality of land use mapping. Furthermore, Ludwig and Zipf (2019) have compiled a catalogue of tags representing land uses with a high percentage of greenness which are likely to represent UGSs. These outcomes support the adoption of OSM as a data source for the analysis of UGRS accessibility.
Additionally, since there are many more places with recreational value than just vegetated areas that can be found in cities and their surroundings, this work will focus on a variety of recreational areas and "Points of interest" (POIs). This includes e.g. historic places such as castles, or viewpoints. Furthermore, places where recreational activities such as swimming or picnics can take place are included as well. This is based on the assumption that all these places offer the opportunity for outdoor recreational activities, which is especially important regarding the need to place social activities outside due to the Corona restrictions. Hence, the definition of UGRSs for this work is not limited to vegetated areas, but includes all kinds of places where outdoor activities can take place.
This work will therefore combine different, so far little used approaches to use the OSM road network in combination with OSM tags in a new context. The current approach is considered to allow a detailed assessment of the accessibility of urban leisure destinations and to be compared across several major cities in Germany for walking and cycling modes using a travel time-based isochrone provider. The use of a time-based isochrone analysis as the basis for calculating the accessibility of UGRSs is also a method that is not so frequently used.

2. DATA & METHODS

Chapter 2.1 describes what data was used and from what sources it was taken. Chapter 2.3 describes the detailed technical implementation of how the data was acquired, preprocessed and finally brought together and analysed.

2.1 Data

In the following section, the data used in this study is presented. This includes the selection of tags from OSM in chapter 2.1.1 representing different categories, population raster data from the European Commission in chapter 2.1.2, and isochrones calculated with the routing engine "openrouteservice" (ORS) in chapter 2.1.3, which is based on the OSM street network as well.

2.1.1 Recreational Spaces in OSM

Based on the definition of UGRSs provided in Chapter 1, suitable OSM key-value pairs were identified in the OSM tag wiki (OpenStreetMap, 2021b). This includes tags which are used to describe vegetated public areas, such as *leisure=park*, but also other cultural and touristic POIs, for example *historic=castle*, which can serve as recreational spaces. Furthermore, a criterion for the selection of suitable tags was the availability of these tags within urban areas. This excludes tags such as *leisure=nature_reserve*, although they are places with recreational value.
Additionally, the study by (Ludwig and Zipf, 2019) investigating tags that have a high probability of representing vegetated areas was used to find relevant tags representing UGRSs. According to their research, tags such as *landuse=meadow*, *leisure=park*, and *landuse=grass* have a high probability for vegetation presence in Germany. Other tags mentioned in the study with a high likelihood of being vegetated, such as *landuse=allotments*, were not considered in the following analysis, since the objective of this work is to analyse places which are available to the public and can be used for recreational activities.
As the definition of places with recreational value for this study is not limited to simply vegetated areas, tags describing points of interest which can be visited for recreational and touristic activities, such as *tourism=viewpoint* or *tourism=picnic_site*, were included as well. The tags were grouped into four categories: *green spaces*, which include vegetated areas relevant for inner city life, *water* POIs that resembles common places of recreation connected with water, *cultural/historic* POIs, including places with historic or cultural value, and *recreation/tourism*, which comprises tags associated with general recreation and places of touristic interest. The resulting list of tags and their categories can be seen in Table 1.

Table 1. Tag key-value pair selection overview. Source: Own creation.

Tag	Key-value pairs
Green Areas	leisure=park landuse=grass landuse=recreation_ground landuse=meadow
Water	leisure=swimming_area natural=beach leisure=beach_resort water=lake water=reservoir water=pond
Cultural/Historic	historic=monument historic=ruins historic=castle historic=fort historic=memorial
Recreation/Tourism	tourism=viewpoint tourism=attraction natural=peak tourism=picnic_site leisure=firepit amenity=bbq amenity=biergarten tourism=camp_site tourism=camp_pitch tourism=caravan_site

2.1.2 Population Data

In order to measure, rank, and compare the accessibility of UGRSs for different cities, a population raster dataset was used to count the population within each isochronal polygon, i.e. to calculate how many people have access to a UGRS for a specified travel time and mode of transportation. The GHS-POP population data was obtained from the "Global Human Settlement Layer" (GHSL) program by the European Commission (European Commission, 2021), which offers freely available datasets containing population numbers worldwide. The dataset used for this analysis contains the most recently available raster from 2019, which has a spatial resolution of 250x250 m and estimates the total number of people per pixel for the year of 2015. The GHSL is an open data dataset that is collected from Census and Housing data from around the globe by the "Socioeconomic Data and Applications Center" (SEDAC) institute (Socioeconomic Data and Applications Center, 2021).

2.1.3 Openrouteservice - Isochrone Calculation

The calculation of isochrones is based on a pathfinding algorithm to define the extent of the area that is reachable within the given parameters. Typically, a pathfinding algorithm requires a starting and end point to find the e.g. shortest, fastest or easiest path on a graph. A mathematical graph represents the given network as nodes (points) connected by edges (lines). The shortest path between two points can now be calculated by finding the path with the minimum possible sum of all weights of the required edges.
In the case of isochrones, this is done in all directions from the given starting point. The end of each path is reached when the sum of the weights is higher than the given threshold, e.g. 5 min walking. The end points of each path are then connected to form an area. This polygon then represents the area that can be reached in the given time or distance from the starting point. When the graph is based on a road network, the association of a weight to an edge can for example be based on its length, the kind of road or the maximum speed limit. How the weighting is included in the calculation of the route is also influenced by the mode of transport. Here, not only the speed of the mode of travel is decisive, but also determines which edges on the graph can be used. For example, a car is not allowed to drive through the pedestrian zone and a pedestrian is not allowed to walk on the motorway.
In order to find the shortest path on a given graph, path finding algorithms have been developed. The possibly best known path finding algorithm "Dijkstra" is briefly explained in the following. First, the starting node is assigned with the cost of 0 and all other nodes with the cost of infinity. From the starting node all its neighbouring nodes are visited and assigned travel costs, if these costs are lower than the already assigned ones. These costs are derived from the weights of all edges used. From here on, this process is repeated until the shortest path to the end node is found. This is achieved through an iterative process that takes the node with the lowest assigned costs, which was not already used as point of departure, as starting

point and repeats the calculation for its neighbouring nodes. When the target node is reached, the steps are retraced by following the previous nodes and the most cost-efficient path is found (Joshi, 2017).
Since this algorithm not only reveals the shortest path to the target node, but to every single reachable node on the graph, it is not the most efficient solution to find the single shortest path form one to another node. The A* algorithm was developed as generalisation and extension to Dijkstra algorithm in order to improve efficiency by applying an estimation function. This heuristic approach allows for a better focus of the search and thus enables better performance (Waldschmidt, 2008).
Another kind of approach, so-called hierarchical approaches "try to exploit the hierarchical structure of the given network. In a preprocessing step, a hierarchy is extracted, which can be used to accelerate all subsequent queries" (Bauer et al., 2008). In a road network, this hierarchy is based on the exploitation of properties of the different types of roads, such as motorways, main or residential roads. This rating is then used to create *transit-nodes* of higher ranked junctions (nodes) to skip lower level roads (edges) in between to save time during the final path computation (Bauer et al., 2008).
The ORS is initiated and maintained by the Heidelberg Institute for Geoinformation Technology (HeiGIT). The foundation for the routing graphs of ORS is the OSM road network (OpenRouteService, 2021). As unofficially communicated by an ORS employee, the ORS bases its routing calculations on the before mentioned contraction hierarchy or A* routing algorithms as presented in Bauer et al. 2008 (ask.OpenRouteService.org, 2021). The ORS "Application programming interface" (API) for isochronal calculations can be partially customized by various parameters. Adjustable parameters are, for example, the driving mode, the maximum distance or time value and the number and size of the intervals to be calculated.
For this study, the travel time for calculating the isochrones was set to 150, 300, and 450 seconds. According to Gupta et al. 2016, preferred travel times to residential green areas, neighbourhood parks, and community parks range from 0-15 minutes. The travel times for this study were chosen accordingly to cover a variety of recreational areas at different scales. The maximum travel time was set to 450 and not e.g. 900, as the study by Gupta et al. 2016 would suggest, since there were no qualitative features included in this study to measure or rank urban spaces suitable for recreation. Assuming that small recreational areas are more frequent than large ones, using a smaller value for the travel time is likely to accept a slight underestimation of accessibility, rather than to overestimate how many people can easily reach a recreational space.

2.2 Conceptual Approach

The goal is to have a coherent yet flexible approach that allows end users to calculate meaningful statistics on the distribution and accessibility of POIs in a comparable analysis across an arbitrary selection of cities. The conceptual approach can be seen in Figure 1. For technical details see chapter 2.3.

2.2.1 Data Pre-Processing

The used input data sets can be summed up to the population raster data described in chapter 2.1.2 and OSM data from the chapters 2.1.1 and 2.1.3.
The population data is already pre-transformed into the WGS84 coordinate system with "European Petroleum Survey Group Geodesy" (EPSG) code 4326. For the import of the population data set into the raster enabled PostgreSQL database the same EPSG is used. When imported, an index is automatically generated to be able to access the data faster.
The OSM data in form of tags as described in chapter 2.1.1 is acquired by using the ohsome API with already pre-processed OSM data. Ohsome stores OSM in the so called "OpenStreetMap History Data Analysis" (OSHDB) in a lossless gridded partition format (Raifer et al., 2019, p. 6).
The data transmitted via the API calls can be seen as original since the pre-processing in the OSHDB has solely structural reasons to be able to store and deliver the data more efficiently. ORS on the other hand heavily pre-processes the original OSM data by generating a routing graph from the respective nodes and edges. For more details see chapter 2.1.3. As a data input the OSM data extract from Germany is used. It serves as the base for calculating the required Isochrones with ORS.

2.3 Technical Approach

The following chapter describes the technical approach with each processing step which can be seen in the conceptual processing Workflow in Figure 1.
The systematic combination from Figure 1 is a combination of multiple individual applications that all contribute in their own way to the whole system. Each application runs in an isolated environment and only interacts with the other applications via pre-defined interfaces.

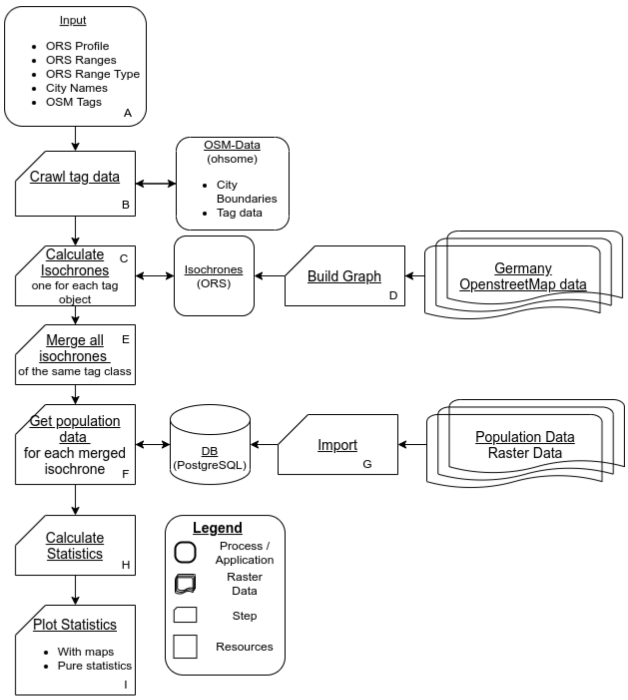

Figure 1. Conceptual processing Workflow. Source: Own creation.

The individual processing steps can be seen from A to I in the processing flow from Figure 1. At first the user of the processing tool is required to set the input parameters such as the used ORS profile, ORS ranges, range type, city names and tags (Figure 1, A). The "ORS profile" defines the profile that is used to calculate the isochrones. Implemented ORS profiles are pedestrian and bicycle. The "ORS ranges" define the value

in seconds or meters the isochrones are calculated for. ”ORS range type” defines the type of the ORS ranges in travel distance or travel time. ”City names” defines a list of city names the tool will run the analysis for. ”OSM Tags” defines a list of OSM tags for which the tool will acquire data from the ohsome API. Tags can be ordered in relatable categories.
In step B (Figure 1, B) the corresponding OSM data is downloaded. As the first step, the tool downloads the city boundaries from the ohsome endpoint ”/elements/geometry” with the filter query ”boundary=administrative and name={city_name}” ({city_name} reflect the iterative city name input). Then the POIs are downloaded from the endpoint ”/elements/centroid” for each city boundary and are categorized into their respective category. The used filter query consists of a simple ”or” chain constructed by the tags per category.
The output of step B is given as an input to step C (Figure 1, B & C) to calculate the isochrones with ORS. One isochrone is calculated for each POI and afterwards dissolved with all the other isochrones from the same tag of the same category of the same city (s. Figure 1, E). The dissolved isochrones are enriched with population information (s. Figure 1, F) from the population raster data stored in the PostgreSQL database. Additionally, the total population per city boundary is gathered.
As step H (s. Figure 1, H) the raw data is analysed and prepared to be able to plot informative and decisive information. Key information are the ”total population per POI” and the ”reached population per category” in percentage compared to the whole population of the corresponding city. The first value describes how many people share one POI of a specific category together. The second indicator shows how much percent of the total population of a city has access to a specific category within the selected range.
As a last step, the calculated statistics from step H are plotted into charts and maps automatically.

2.3.1 Processing Backend

The processing backend was written in Python 3, and it structures the processing workflow from Figure 1 into a coherent working system. Each component, ORS, ohsome, PostgreSQL are run locally and executed in isolated Docker environments. The isolated environments only communicate via the implemented interfaces and data is only stored for the time of the execution. Results are written directly to disk as plots and spatial data in form of PNG and GeoJSON files. The code is structured and build in a way it can be easily executed on a wide range of different range, tag and profile variations across different routing providers. The source code can be found freely available on GitHub (s. Psotta et al. (2021)).

3. RESULTS

In total, 28.689 isochrones were calculated with a total combined area of around 3416 km², comprising four tag categories and three travel times. It is crucial to mention that calculating that many isochrones requires a software set up specifically for this purpose. Using a public API, requests for isochrones are restricted to e.g. 500 per day in case of ORS (OpenRouteService.org, 2021). This limit can be raised to 2500 per day, which does not ease the need either. Proprietary routing providers impose even tighter API usage policies which made a cross-provider comparison unfeasible or at least tied to a financial budget this research could not provide.
Furthermore, it is important to note that the number of used tags is not necessarily reflected in the number of features compiled by one category as each tag can comprise a very different amount of features. This can clearly be noticed in the direct comparison between the amount of features in the categories *Green Areas* and *Recreation/Tourism* e.g. for the city of Berlin (see Figure 8). While the category *Green Areas* only comprises four tags (see table 1) it has considerably more features than the *Recreation/Tourism* category encompassing features identified by ten tags.
In the following, the results will focus on the travel range of 300 seconds according to the preferred travel times to recreational spaces by Gupta et al. 2016. Another constraint that limits the size of isochrones to at least 300 seconds is the rather large 250x250 m resolution of the population raster data. Too small isochrones could easily yield overestimates. Furthermore, the presented tag categories will be limited to *Green Areas*, *Historic POIs*, and *Touristic POIs*. *Water Areas* present the most problematic category for the calculation of isochrones, since it is not possible to easily generate a starting point for the routing engine due to their often irregular and not walkable shapes. They are therefore omitted in the following presentation of the results.
In Figure 2 the ten most populous German cities are listed and ranked by their total population. This is calculated based on the population data and city boundaries. Berlin has by far the most population, followed by Hamburg, Munich and Cologne all having a population over one Million People. The remaining six cities have between 700 and 500 thousand inhabitants. The total numbers serve as reference values in the following section, which will mainly focus on the percentage with access to POIs and the ratio population/POI.

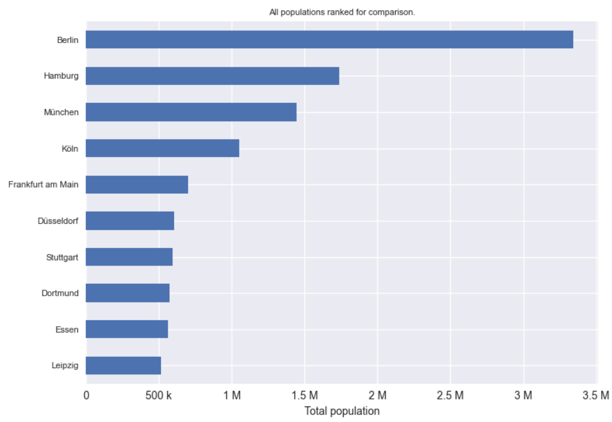

Figure 2. The ten most populous cities in Germany. Ranked by total population.

In Figures 3 and 4, the percentage of the reached population and the ratio population per POI is displayed for each tag category and a travel time of 300 seconds. The diagrams for 450 seconds can be found in the Appendix in chapter 6 for bicycle (s. Figure 10) and walking (s. Figure 9). Overall, it is apparent that more people are reached in the cycling scenario. This is for example visible for *Green Areas* (s. 4, 3) which are reached by 38-69% of the population by foot, and 88-99% by bike in 300 seconds.
In both scenarios, Munich ranks highest, as it supplies the most people with POIs in four of the six possible variations (*Green Areas* and *Touristic POIs* walking and cycling.
On the other hand Hamburg has potentially the least population per POI in five of the six possibilities (*Green Area* and *Historic*

walking and cycling and *Tourism* walking. Furthermore, the ranking of relative population within the tag categories of each city is not coherent with the absolute numbers. For example, even though the population of Munich ranks third and is less than half of the population of Berlin, *Green Areas* are reached by the highest total number of people in Munich in the walking scenario (see 3) and also shows the second-highest values for the percentage of people who have access to *Green Areas*. However, this only accounts for the ranking of the categories within each city. Comparing the percentage of the population with POI access across all cities, it becomes apparent that the supply of population with POIs goes in the opposite direction of population size. For example, in Stuttgart, 37.6% of the population have access to *Historic POIs* in the walking scenario, which is the highest percentage for this category. However, in total numbers, Stuttgart is only 7th in the ranking for *Historic POIs*.

The differences between cities become even more apparent analysing the ratio population/POI. For *Historic POIs*, Munich ranks first with 897 people/POI in the walking scenario and 3245 people/POI in the cycling scenario. Considering the percentage of the population with access to *Historic POIs*, Munich is 6th in the cycling scenario (83.5%) and ranks second last in the walking scenario (23.1%).

Overall, Munich has the highest ranking in the walking scenario for *Green Areas* and *Touristic POIs*. Stuttgart ranks first for walking *Historic POIs* but is slightly defeated by Essen which provides most of its population access to *Historic POIs*. Regarding the cycling scenario, Munich ranks highest for *Green Areas* and *Touristic POIs* as well, whereas Essen has the highest percentage of people who have access to *Historic POIs*.

The isochrones for the highest rankings of the walking scenario are displayed in Figures 5 - 7. The maps also include the isochrones for cycling to facilitate comparison. For the category *Green Areas*, Figure 5 shows that Munich has green spaces distributed throughout the entire city, whose isochronal polygons of the walking scenario are interconnected. The polygons of the cycling scenario cover almost the entire area of the city. However, the walking scenario already covers almost 70 % of the population, so there is a moderate change compared to the cycling scenario that covers 99.3 %.

The results for *Historic POIs* in Stuttgart have a different dynamic: Figure 6 shows that most *Historic POIs* are located in the central parts of Stuttgart, creating a continuous large polygon for the walking scenario in the centre, which extends to the northern part with some unconnected smaller polygons. In the south, there are only few historic places and the isochrones only cover a small area. Similar to green areas in Munich, the isochrones in the cycling scenario form a large polygon covering almost the entire city. However, for *Historic POIs* the cycling scenario increases the ratio of people with access to the POIs more than for green areas, namely from 37.6% to 97.8%.

Regarding *Touristic POIs* in Munich, it can be observed that there are considerably less POIs than for green areas. There is a cluster of POIs in the centre which forms a connected polygon. However, due to the low number of POIs, the isochronal polygons are overall less connected and mostly separate from each other. While there are many gaps between the isochronal polygons for the walking scenario, the cycling scenario covers almost the entire area. In the walking scenario, 14.4% of the population has access to *Touristic POIs* within 5 minutes, which increases to 83.5% in the cycling scenario.

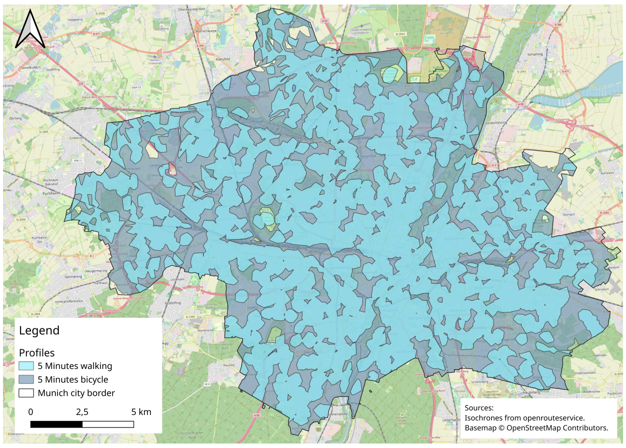

Figure 5. Munich - Green Areas 5 Minutes walking and cycling.

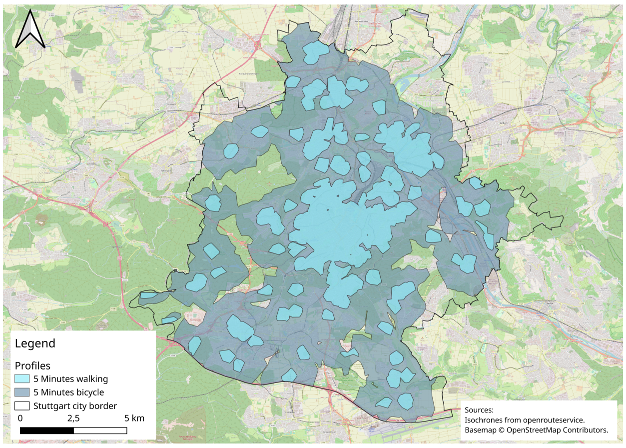

Figure 6. Stuttgart - Historic POIs 5 Minutes walking and cycling.

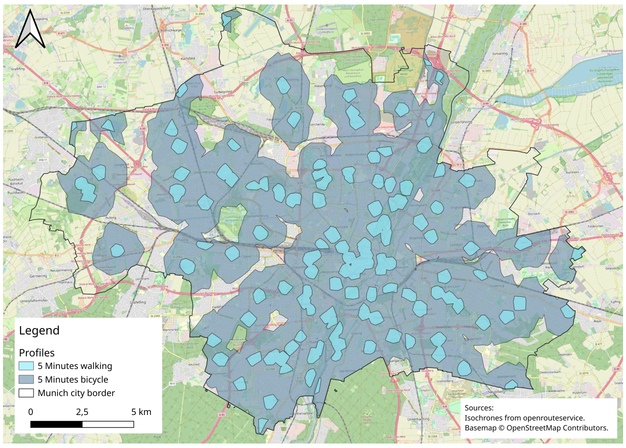

Figure 7. Munich - Touristic POIs 5 Minutes walking and cycling.

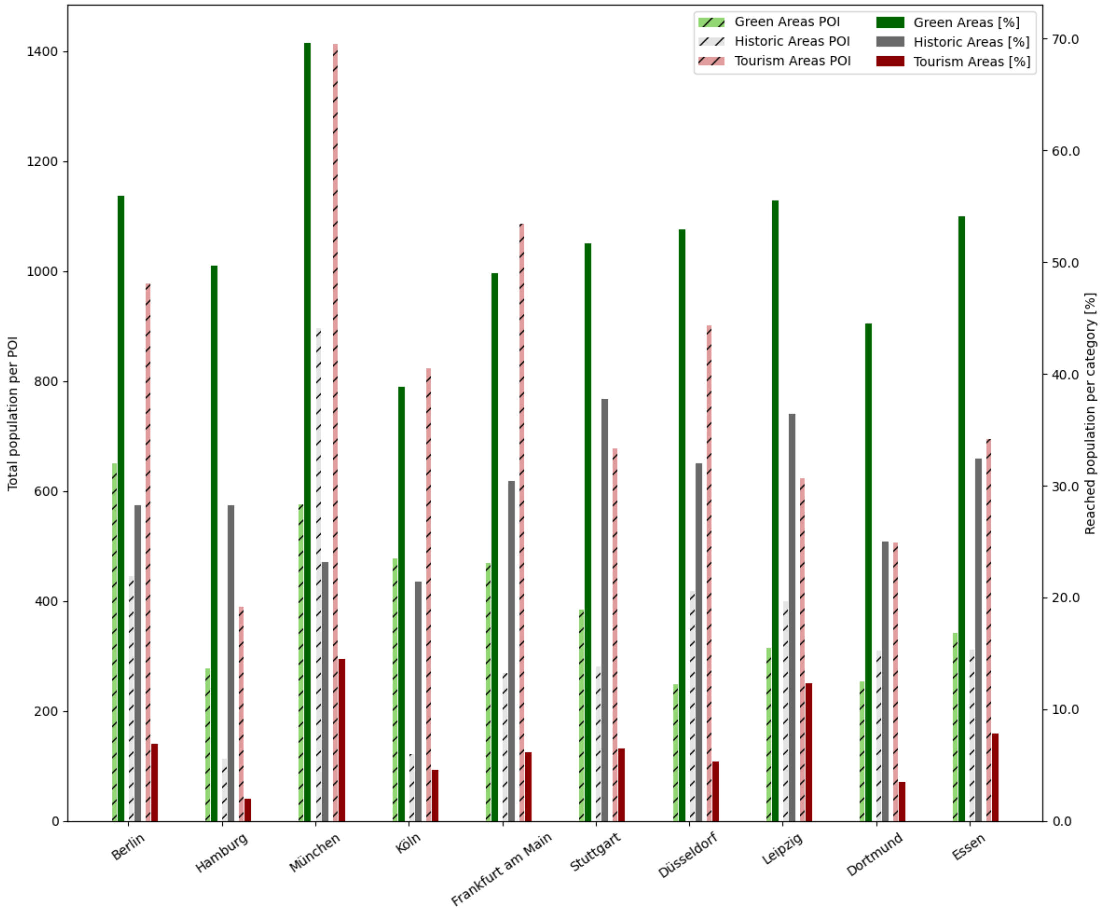

Figure 3. Reached Population 5 minutes walking.

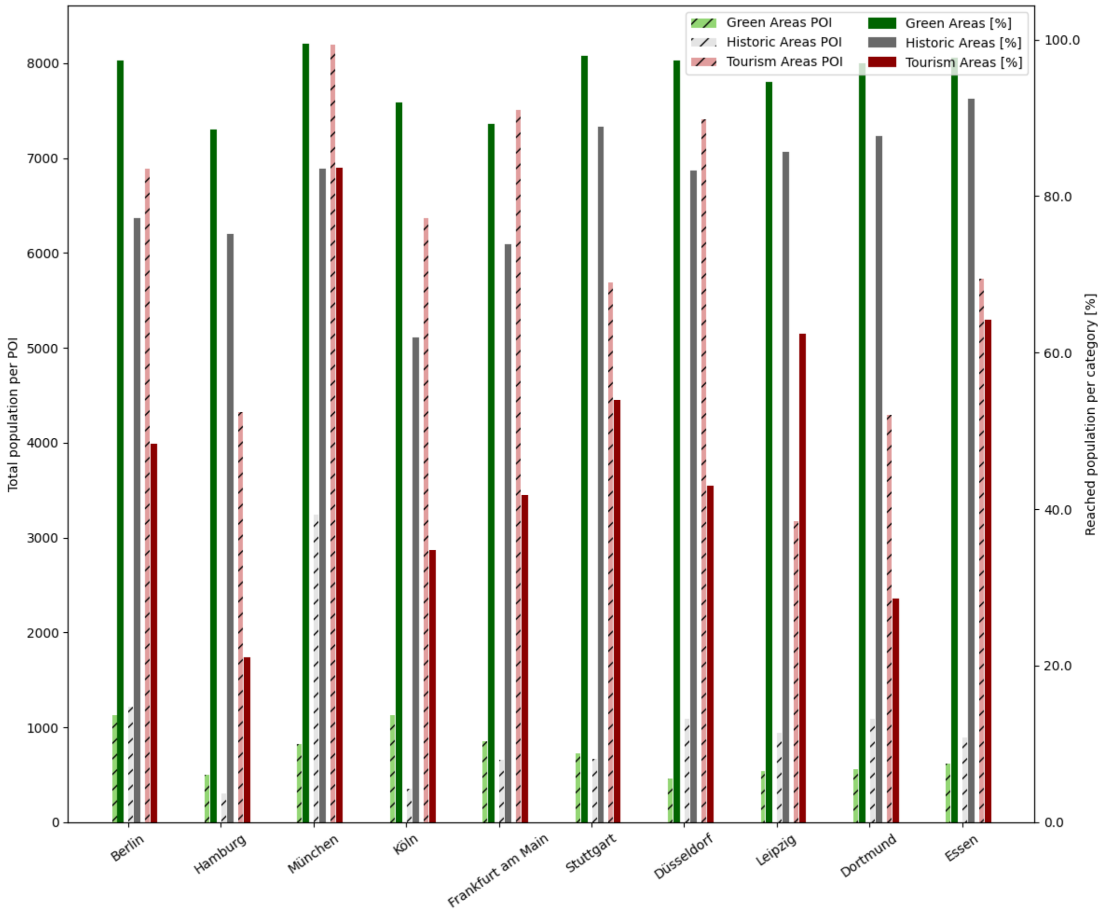

Figure 4. Reached Population 5 minutes cycling.

4. DISCUSSION

Naturally, ranking the total number of people with access to recreational POIs reflects the number of inhabitants in each city, which is why Berlin has the highest number of people with access to recreational areas. However, the relative numbers show that many cities with a lower number of inhabitants, such as Leipzig or Stuttgart, have a similar or higher percentage of people with access to recreational POIs. In the Walking scenario, Leipzig even exceeds the two biggest cities in terms of inhabitants, Berlin and Hamburg, for all tag categories, although it has the third-lowest number of POIs in total (s. Figure 12) and in terms of total POIs per category ranks among the cities with the lowest counts in all categories (s. Figure 11). This phenomenon can likely be explained by population density or area of the cities as well as the spatial distribution of POIs. Cities covering a smaller area also possibly have less distance between POIs, which is why even with a low number of POIs, a high percentage of the population is reached. On the other hand, Hamburg has the highest number of POIs, but only an average percentage of people with access to them. Since the isochrones are dissolved during processing, a cluster with many POIs within a small radius can result in a similar number of reached people as very few POIs within the same area. This underlines the use of a relative comparable metric as people per POI and reached population in percent per category (s. Figures 3 and 4).

One limitation of the presented method is the spatial confinement to administrative city borders, as it presents a bias towards the calculation of population with access to recreational spaces. For example, if there is a POI within a city limit but close to the border, the population right outside city limits is not considered in this approach. However, in reality, people living beyond city limits most likely have access to this POI as well. Furthermore, there could also be POIs right outside a border, which can theoretically be accessed by people living within the city, but are not included. Considering this, the results probably underestimate the total and relative number of people who have access to recreational places.

Furthermore, the focus of this work solely lies on the quantification of access to recreational spaces. This presents different issues: First, there is no information on the actual quality each POI presents. There might be places which can be reached by many people, but are e.g. poorly maintained which does not make them attractive for recreational activities or the general sojourn. However, this is a limitation of OSM data as this kind of information is normally not included in OSM tags. One metric that can give first insights about the quality of a POI is the ratio population per POI, as this gives information about the amount of people that might be expected there. Assuming that people prefer less crowded places for recreation, a low ranking would be favourable, like in the case of historic places in Hamburg (e.g. s. Figure 4). Secondly, the tags are not weighted or further categorized other than by land cover or theme. For example, it could be assumed that a community park presents a higher pull factor than a small patch of grass. Considering this, tags could be, for example, further categorized by size and physical accessibility and weighted accordingly in the results in order to generate a more insightful rating.

Additionally, the results depend on the underlying data and its quality as well as the algorithms of ORS, which have some bias. The use of OSM tags to describe real-world objects is not always consistent. For example, as described by Ludwig and Zipf (2019), specific tags can be an indicator for greenness, but they do not automatically translate to vegetated areas, which is a possible source of uncertainty for the results.

Another source of uncertainty stems from the usage of a rather complex software to calculate the time based isochrones (s. chapter 2.1.3). On the one hand ORS calculates the results in form of isochrones showing detailed information on how far a person can reach in a pre-defined time frame. On the other hand it is using often abstract assumptions to represent the real world that can only be considered an approximation to the former and can only be as exact as the data given as a base. In that sense difficulties rose mostly from incomplete OSM data in e.g. coastal areas and on islands.

As stated prior, the population raster yielded population results for the city boundaries that are close to the official values (s. figure 2) but due to the generalized resolution of just 250x250m too small isochrones could not be reliably dissolved into the correct population amounts. As a result of this and the reasons stated in chapter 1 the minimal isochrones range was set to 300 seconds.

Overall, the results show that the ten largest cities in Germany are well supplied with green areas. In six cities, more than 50% of the population can reach a green space in 300 seconds by foot. In the cycling scenario, all cities provide access to green areas for $> 80\%$ of the population, in 8 cities even for $> 90\%$. The POIs in the other tag categories can be reached by less people, which is possibly due to the unbalanced number of POIs in each class. Considering that such high percentages are already reached with a travel time of 300 seconds, a higher value of e.g. 900 seconds as mentioned in chapter 2.1.3 would possibly not change much in the results and just increase the proportion of people with access to 100%. Again, this emphasizes the need for a qualitative analysis, which e.g. pre-selects POIs according to their quality in order to get a more realistic list of POIs as starting points for the isochrones, which only include places that are actually used for recreational activities. In this regard, it could be argued that the approach of this work overestimates the number of relevant POIs and could be fine-tuned in a more detailed resulting research.

5. CONCLUSION

The result of this work is twofold. On the one hand, a full fetched accessibility analysis tool was developed. The accessibility tool is written in Python 3 and is freely accessible on GitHub (Psotta et al., 2021). With only a handful of input parameters such as the isochrone provider parametrization, the search area, and a list of OSM tags one can easily acquire the amount of people reached by the given time, mode of transport and places. Thus, the tool can be applied to a vast amount of research questions ranging different topics from natural to social sciences and from smaller to larger scale.

On the other hand, an overview study on the accessibility of various Urban Green and Recreational Spaces by foot and by bicycle was conducted for four categories in the 10 most populous cities in Germany. These categories were *Green Areas*, *Water bodies*, *Cultural/Historic* and *Recreation/Tourism* sites encompassing features represented by a total of 25 OSM tags. By applying the newly developed tool to the research question, the cities could be easily compared by their distribution and accessibility of UGRS. The overall results indicate that a relatively high proportion of the population can reach a UGRS in five minutes or less. For example, *Green Areas* can be reached by 38-68% by foot and 88-99% by cycling within the given five minutes. While these results do not fully reflect current research indicating more heterogeneous patterns and distributions of UGRS access (Gupta et al., 2016; Vîlcea and Șoșea, 2020; Kolcsár and Szilassi, 2018), this study presents a new combination of contemporary approaches. Incorporating walking and cycling means of transport as well as analyzing and comparing four different UGRS categories by encompassing respective OSM tags has proven to be a valuable way of determining accessibility of UGRSs. The quality of this study's results could be further improved in future research through the incorporation of qualitative factors such as the size or condition of the given points of interest.

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LIST OF FIGURES

ACRONYMS

SEDAC "Socioeconomic Data and Applications Center"

GHSL "Global Human Settlement Layer"

EPSG "European Petroleum Survey Group Geodesy"

OSHDB "OpenStreetMap History Data Analysis"

API "Application programming interface"

UGS "Urban Green Space"

UGRS "Urban Green and Recreational Space"

ORS "openrouteservice"

POI "Point of Interest"

GIF "Graphics Interchange Format"

HTML "Hypertext Markup Language"

JS "JavaScript"

OSM "OpenStreetMap"

URL "Uniform Resource Locator"

6. APPENDIX

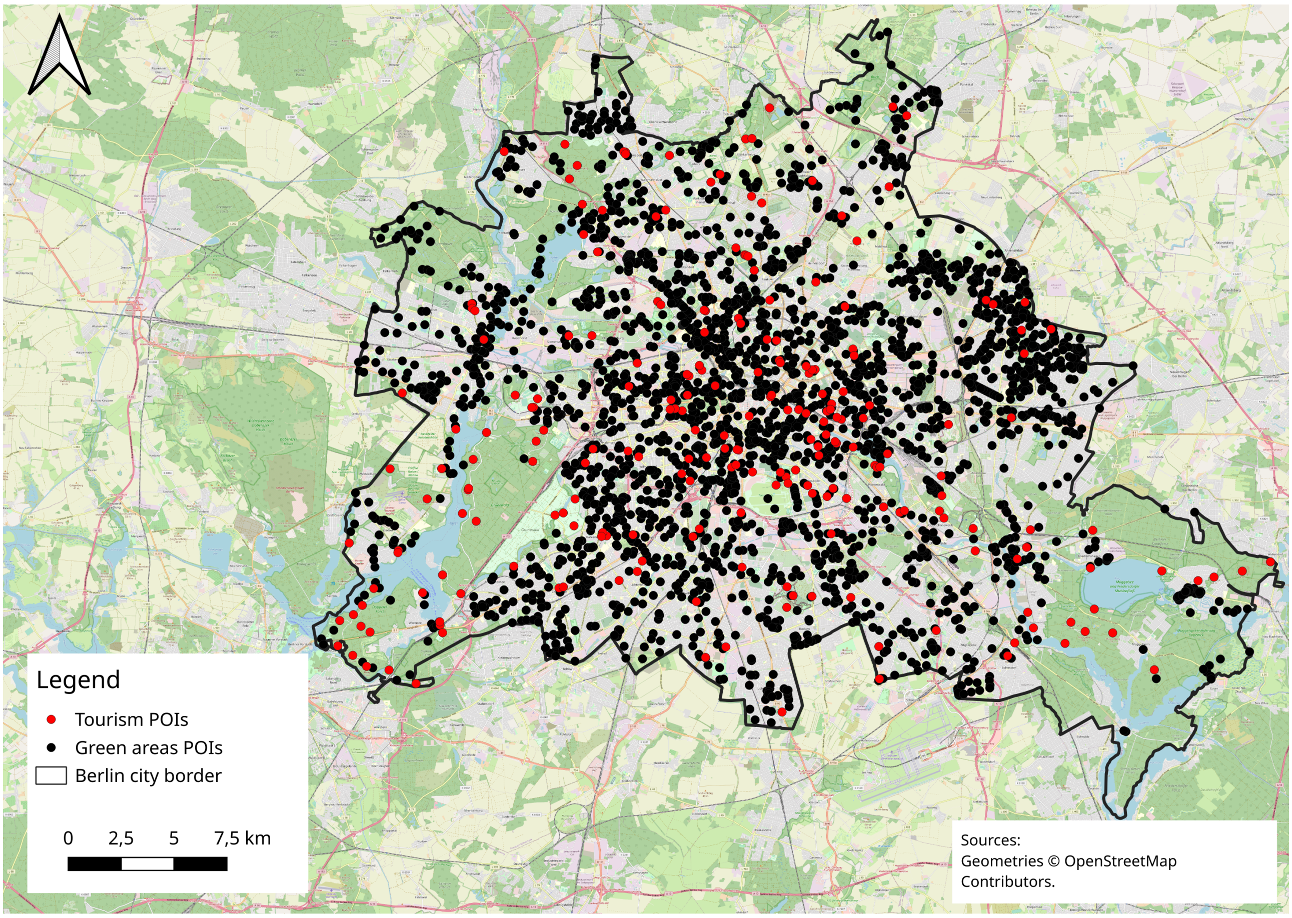

Figure 8. Comparison POIs for tourism and green areas in the city of Berlin. Source: own creation.

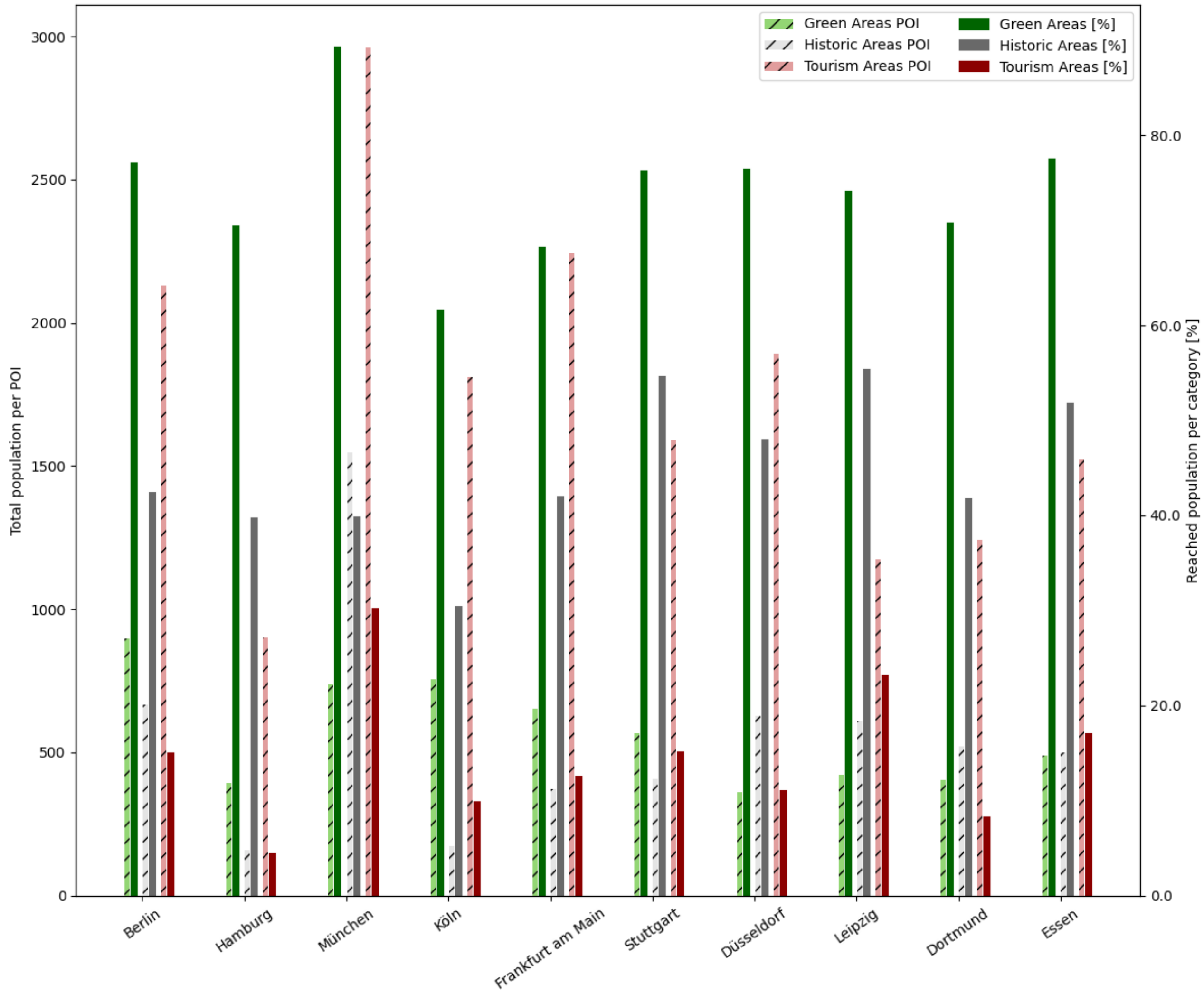

Figure 9. Reached Population 7.5 minutes walking.

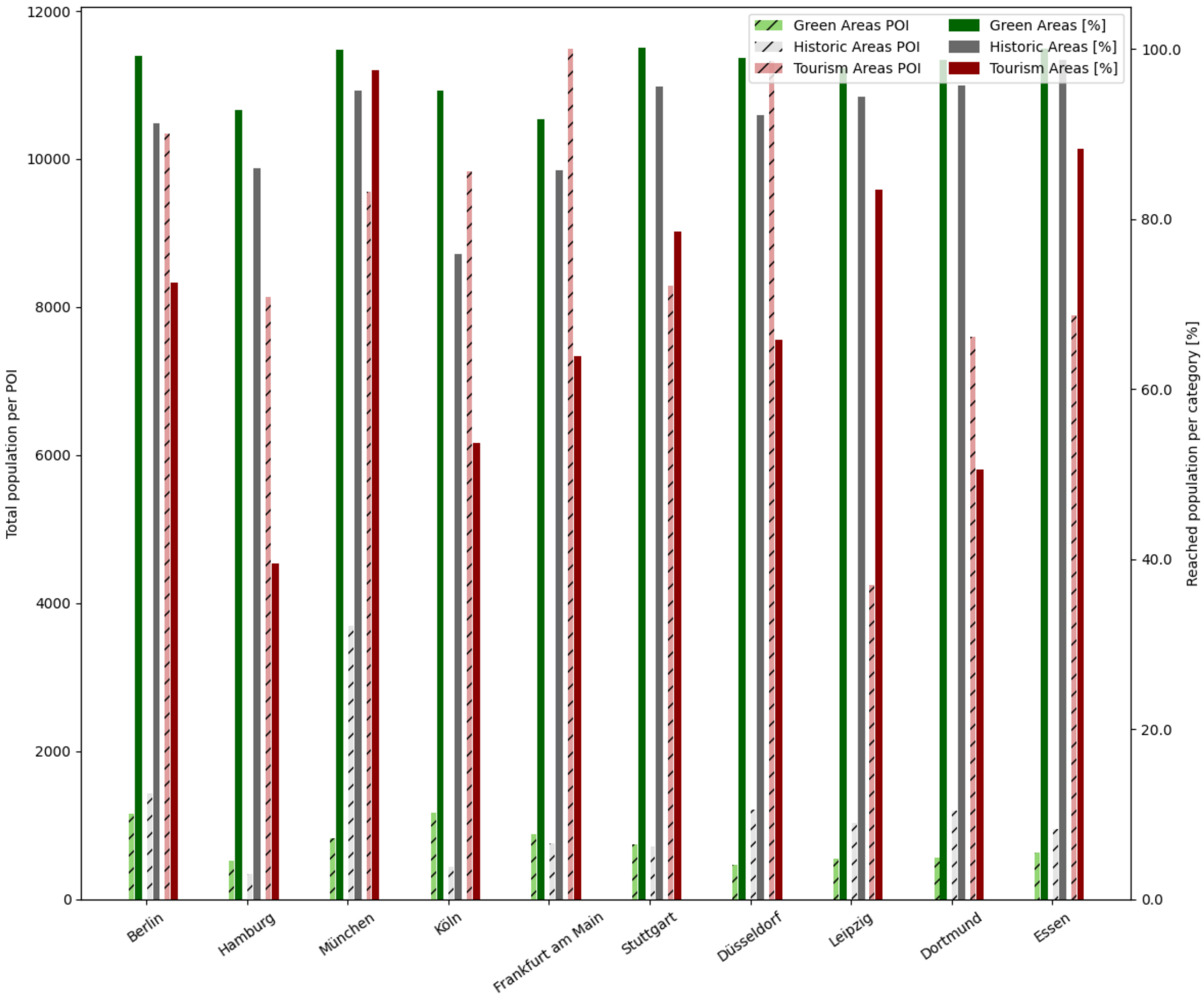

Figure 10. Reached Population 7.5 minutes cycling.

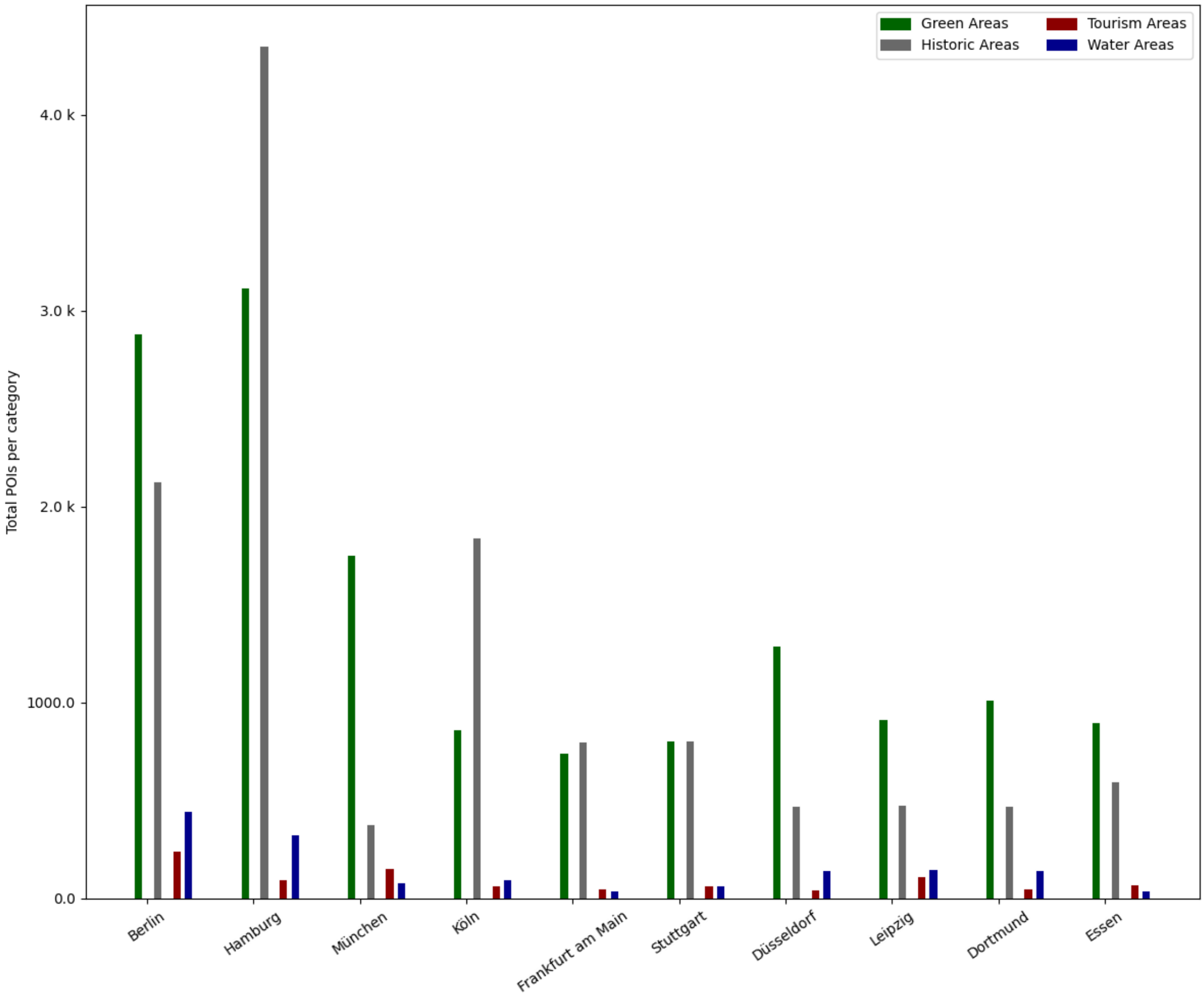

Figure 11. Total POIs per city per category.

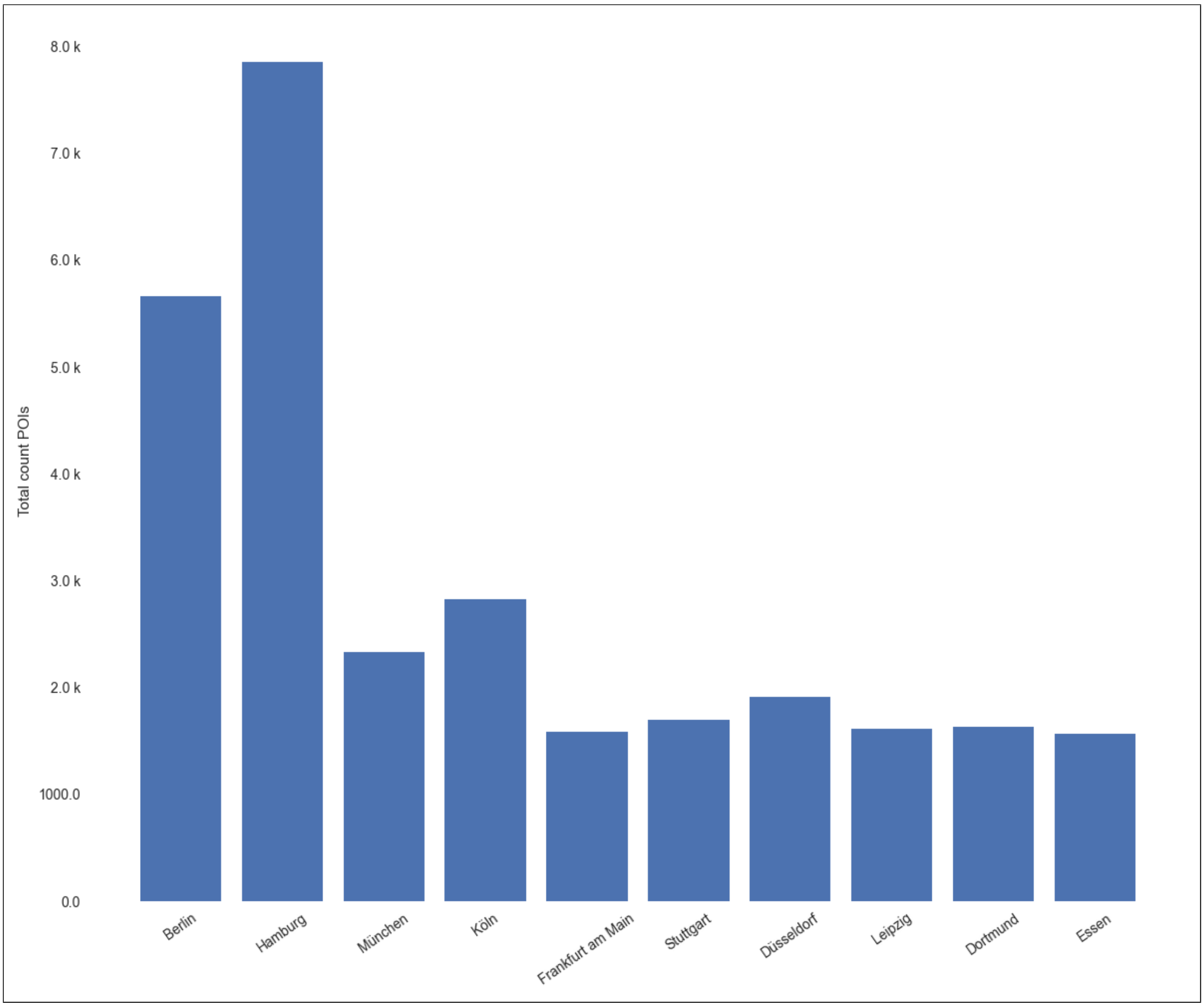

Figure 12. Total POIs per city.