Primary Health Care:
Digital Data Sources for Spatial Accessibility Analysis

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Key words: Spatial Analysis, Spatial Accessibility, Health Care Service, Infrastructure, Network Analysis, Health care planning, Demographic changes

SUMMARY

In recent years a huge amount of geospatial data has been produced. Data producers include both public administration bodies providing official data, and so called 'prosumers' indicating consumers which become producers. In the meantime prosumers started to generate a huge volume of voluntary data such as volunteered geographic information, in particular. The study uses both types of information, official and voluntary to develop a network-based model that enables to quantify spatial accessibility to primary care on street segment level for both rural and urban areas. In rural area, the analysis revealed variability in accessibility to primary care on street segment level and in urban area, analysis gave evidence for the impact of barriers on footpaths on the way to primary care practices for mobility-reduced people. The paper demonstrates opportunities and limitations of a theoretical model for spatial accessibility calculation on street segment level. It may, especially through its resolution on small scale, enable to better reveal regional inequalities in accessibility to primary health care and help to identify areas that need special attention in future health care planning.

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1. INTRODUCTION

Demographic changes lead to an increase of elderly population that is of impact in various ways. The European Commission addresses the new phenomenon by stating *'Ageing is one of the greatest social and economic challenges of the 21st century for European societies. It will affect all EU countries and most policy areas. By 2025 more than 20% of Europeans will be 65 or over, with a particularly rapid increase in numbers of over-80s. Because older people have different healthcare requirements, health systems will need to adapt so they can provide adequate care and remain financially sustainable.'* (http://ec.europa.eu/health/ageing/policy/index_en.htm)

Access to health care services is widely seen to be a key goal in meeting the health needs of the population (UN, Grad, 2002). Rural and urban areas face challenges with regard to adequately fulfilling the existent health care needs. While ageing of the population generates increasing health care needs, the number of physicians especially in rural areas decreases, due to an ageing of the physicians themselves as well as a lack in offspring and a migration from physicians from rural to urban areas. With regard to access to health care, especially elderly patients in rural areas thereby often face longer travel distances, while elderly people in urban areas may have access problems by barriers and limited mobility. Therefore it is of great interest to better elucidate spatial accessibility to health care in both rural and urban areas.

Primary health care is of special interest, as in Germany, more than 90 % of population has a general practitioner (GP). The GP represents for many people the first contact person when a health problem arises, and is a constant coordinator especially for people with chronic diseases.

In this case study, we applied a statistical approach to determine accessibility to primary health care for a rural and an urban study area on street segment level.

Analyses of accessibility were applied to

1) A rural area of Germany and for this area, transportation by car was considered the main modus of access to primary health care providers. In this analysis, distance and resulting travel time was considered to be limiting constraints of access.
2) An urban area of Germany and for this area, walking was considered as the main modus of access to primary health care practices. In this analysis, reduced walking mobility as well as barriers on 'walking ways' were considered as limiting constraints of access.

2. METHODS

2.1 Rural and Urban Study Area

The rural part of the study area is located in the Eifel region. In this region the population density typically reaches the order of only 100 inhabitants per square kilometer, with low points of less than 50 inhabitants per square kilometer. The urban part is located in the Ruhr Metropolis, the largest urban agglomeration of Germany. The study area in this region is a densely populated area with 6500 inhabitants per square kilometer.

2.2 Data

Location of Medical Practices

The large majority of physicians working in ambulatory health care hold an affiliation with the statuatory health insurance. Statuatory health insurance covers about 88 percent of the population (Kuhn and Ochsen, 2009). The addresses of GPs' practices located in the study areas were obtained from the local associations of statutory health insurance physicians.

Road Network Data

Recent studies verify that the quality of Open Street Map (OSM) Data on the road infrastructure in many regions is sufficient for high quality analysis (Neis et al, 2012). Free and easy access to seamless data, reasonable topological consistency of the road network, a good measure of completeness for the speed attributes gave reason to use OSM network data as a base data set for the analysis. The network routing was based on the values of the 'maxspeed' tag of the OSM data for the study area. Missing values of the 'maxspeed' tag were substituted by default values for the urban and rural road segments.

Footpath Network Data

While the OSM data is good to use in case of the road network the footpaths are not completely contained. Therefore the network of footpaths, based on OSM data and aerial photos, was digitized for this study.

Barriers on 'Walking Ways'

The accessibility in the urban study area was measured by collecting barriers on the footpaths, like potholes, roots of large trees, benches in the middle of the path or stairs as well as ground indicators like guiding plates for the blind. This data was collected by a mobile App using the GPS-Sensor of smartphones. As a result all footpaths could be classified concerning their accessibility.

2.3 Determination of Small-area Level Accessibility

Spatial access in practice takes place almost exclusively along the edges of networks, such as road networks and public transportation lines (by car, rural) or footpath segments (by walking, urban). For calculation of accessibility in the rural part of the study area, transport by car was presupposed. We used an approach based upon road network analysis and according to the simple principle 'the closer the doctor, the more likely he or she will be chosen' a weight function was used to take into account the attractiveness of the respective practice.

For calculation of accessibility in the urban part of the study area, walking by foot was presupposed. Thus, the study concentrated on the footpaths and access to primary health care in walking distance. In the following section the single steps of the method will be described in detail.

Step 1: Calculation of catchment areas for all medical practices.
For rural areas Kucharska et al (2014) stated a reasonable distance of 10 kilometers between patients and medical practices. Following their work and assuming that travel time might be more important than the bare distance is we defined three corridors *c(5), c(10), c(15)* of spatial accessibility, with travel time *t*

$$\begin{aligned} t(5) &= 5 \text{ minutes} \\ t(10) &= 10 \text{ minutes} \\ t(15) &= 15 \text{ minutes} \end{aligned} \tag{1}$$

For analysis in the rural study area, the road network analysis was performed with the three classes of travel time, using the maxspeed tag values of the OSM data set. As an example, Figure 1 shows the catchment area by travel time of a medical practice located in the rural town Hillesheim.

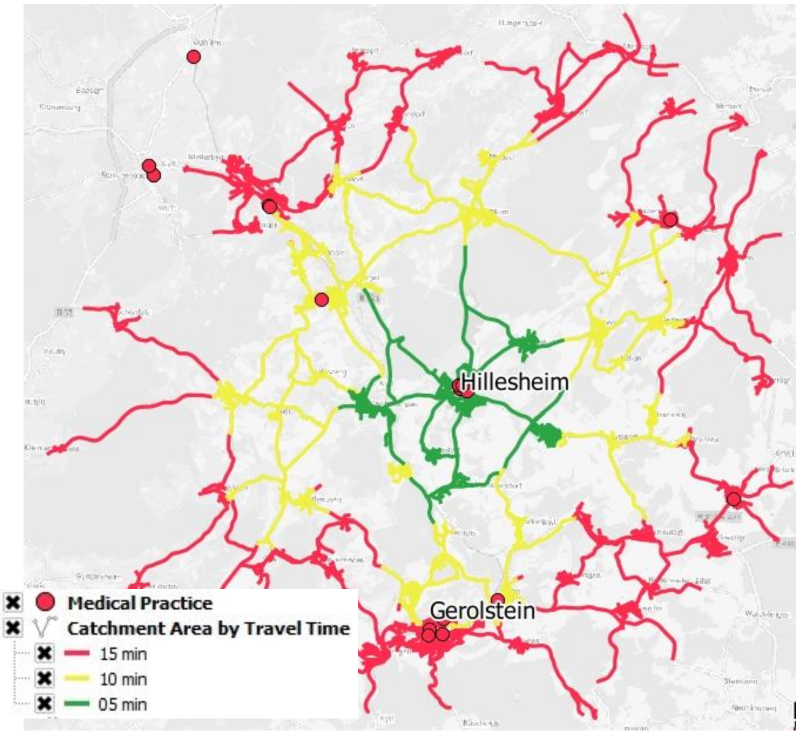

Figure 1: Catchment Area by Travel Time in the Rural Part of the Study Area

For analysis in the urban study area, two different scenarios were realised - one for non-mobility reduced and one for mobility-reduced people: for non-mobility reduced people, we assumed an average walking speed of 4,8 km/h. This resulted in calculated corridors of

$$
\begin{aligned}
&c(5) = 400m \\
&c(10) = 800m \qquad (2) \\
&c(15) = 1200m.
\end{aligned}
$$

For mobility-reduced people we assumed an average walking speed of 2,4 km/h. This resulted in the corridors of

$$
\begin{aligned}
&c_{mr}(5) = 200m \\
&c_{mr}(10) = 400m \qquad (3) \\
&c_{mr}(15) = 600m.
\end{aligned}
$$

Step 2: Intersection of road segments and corridors.
The spatial intersection of calculated *c(5), c(10), c(15)* corridors for all medical practices *m* in the study area results in a number of *3 x m* attributes for all road segments (rural area) and footpath segments (urban area), respectively, with the attribute value indicating if a segment takes part in a *c(5), c(10), c(15)* corridor of a medical practice *m*. In that way, road segments (rural area) and footpath segments (urban) bore full information which corridors they are part of.

Step 3: Incorporating attractivity of primary care practices.
A linear decrease of attractivity with increasing distance from the physician’s practice can be modeled by attaching different weights *p* to the the catchment corridors *c(5), c(10), c(15)* (see step 1),

$$
\begin{aligned}
&p(5) = 3 \\
&p(10) = 2 \qquad (4) \\
&p(15) = 1
\end{aligned}
$$

Step 4: Quantification of local accessibility to primary health care by score values.
Summing up the weights *p(i)* of all catchment areas, in which a certain road segment (rural) or footpath segment (urban) takes part in, yields the overall score value *S(k)* of the road segment (rural) or footpath segment (urban) *k*. If a segment takes part in *2 c(5)* corridors, in *3 c(10)* corridors and in *4 c(15*) corridors, for instance, then its score value amounts to $S(k) = 2 \times 3 + 3 \times 2 + 4 \times 1 = 16$. Figure 2 gives a graphical presentation for the centre of a rural town. The higher the score value *S(k)* of a location, the more opportunities exist for the population to access different medical practices. In that way, *S(k)* gives a small-area level measure for the accessibility of primary health care, on road segment (rural) or footpath segment (urban) level.

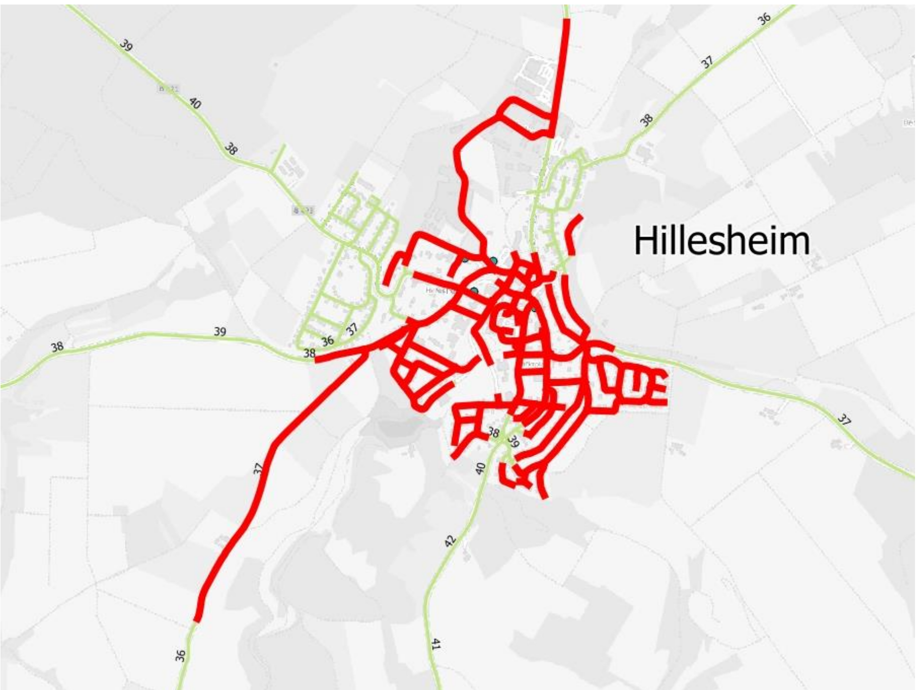

Figure 2: Score value 37 in the the rural town Hillesheim for the street segment marked in red:
All persons residing along the street segment of Hillesheim marked in red color can reach
8 medical practices within 5 min by car,
2 medical practices in between 5 and 10 min,
9 medical practices in between 10 and 15 min,
*S = 8*3+2*2+9*1 = 37*

Step 5 (optional): Integrating barriers in the calculation of catchment areas
If the study area is not too large, collected barriers can be used for the calculation of the catchment areas. These catchment areas can be used for accessibility analysis for mobility reduced people.

Following the method described in section 2.3 the spatial accessibility of primary health services was calculated for non mobility reduced people and for mobility reduced people alike. The accessibility for mobility reduced people was calculated following equation (3). The analysis in that case was performed assuming that all patients had reduced mobility. The routing was done by using the footpath network including the identified barriers.

Figure 3 shows the resulting catchment areas of medical practices in the urban part of the study area for mobility reduced people.

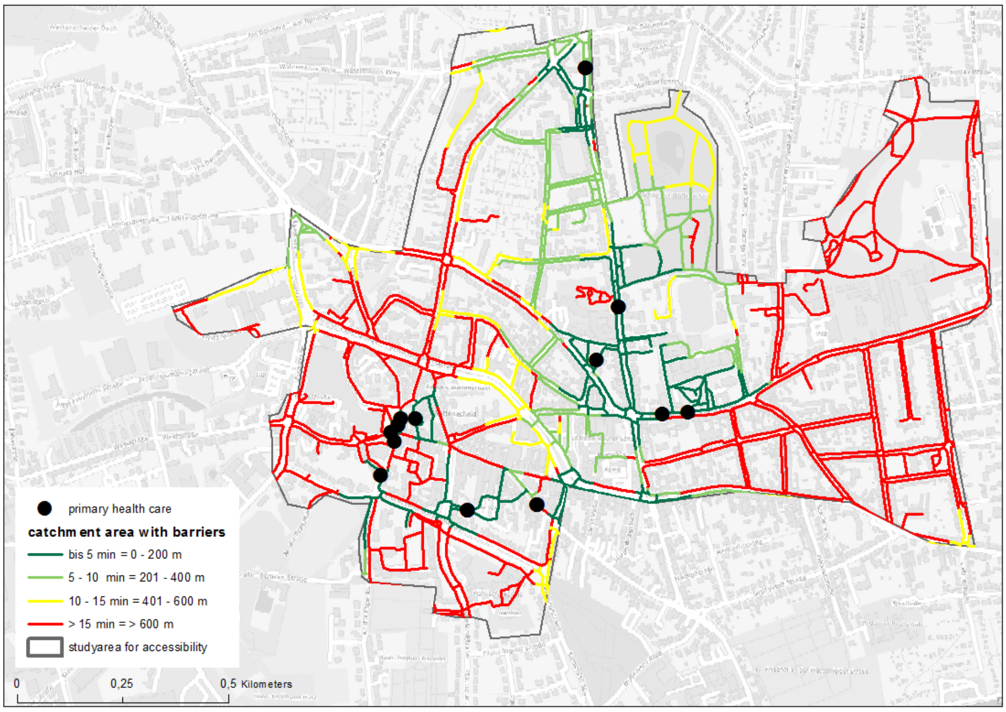

Figure 3: Catchment Areas of Primary Health Care for Mobility Reduced Patients within 5 min, 10 min and 15 min Walking Time

3. RESULTS

3.1 Accessibility to Primary Care Practices in the Rural Part of the Study Area

Figure 4 shows the calculated score values for the rural town Euskirchen located in the West of the study area. As can be seen from that example even the population of a rural area may have a wide choice of spatially accessible medical practices, with score values amounting up to 150. In some street segments colored in dark green, for instance, more than 30 medical practices are accessible within 5 min, 10 more practices within 10 min, 30 more practices within 15 min (S = 30*3 + 10*2 + 30*1 = 140).

However, at the end of the scale we identified areas with score values even as low as 2. In such remote areas no medical practice can be reached within 10 minutes or less travel time (see Figure 5).

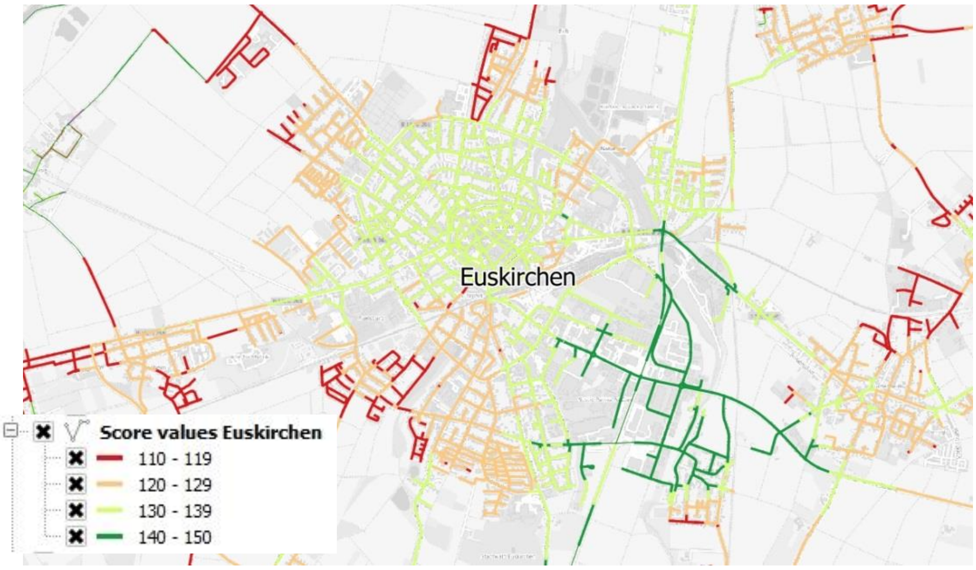

Figure 4: Example of a Rural Town with high Accessibility Score Values: Euskirchen (50.000 inhabitants),

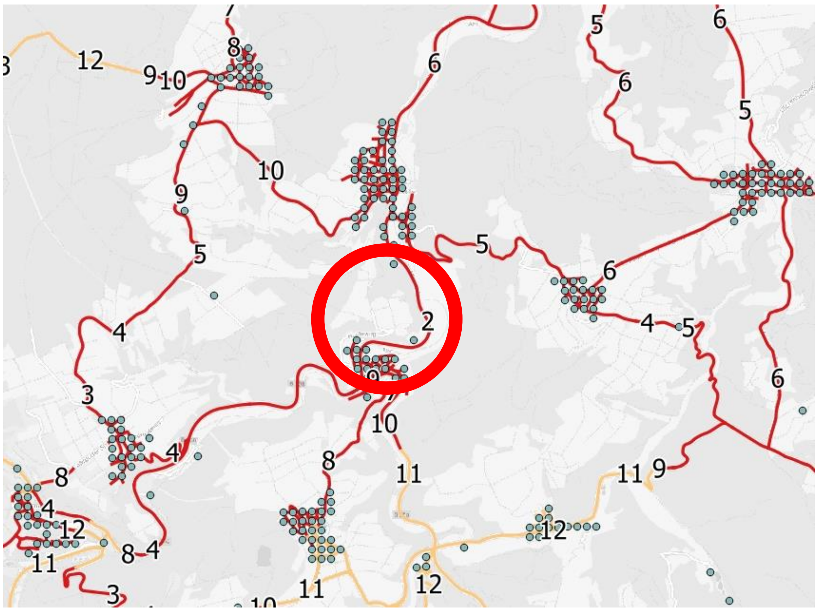

Figure 5: Example of Rural Villages with Low Accessibility Scores in the Vicinity of Nurburg Ring,
The score value of 2 indicates that no medical practice can be reached within 10 min travel time, but only 2 practices within 15 min time

3.2 Accessibility to Primary Health Care in the Urban Part of the Study Area

The accessibility in the urban study area was analysed with and without integration of the barriers in the footpath network. Also the two different speeds for fully mobile and mobility-reduced people (see equation (3)) were used.

Assuming barrier free walk ways the average score for the accessibility of primary health care in the urban area amounted up to more than 100 for people with full mobility (Figure 6).

In strong contrast to that Figure 7 shows a sharp drop of score values when taking the existing barriers into account The score values decreased till numbers of 12 when barriers on the footpaths and a reduced mobility were taken into account.

The comparison of Figures 6 and 7 clearly demonstrates the large influence of barriers on the accessibility of health care services for mobility reduced persons, in particular. In the presented study self-reported data on barriers were used (see section 2.2). When using general purpose data such as Open Street Map (OSM) this issue has to be addressed separately.

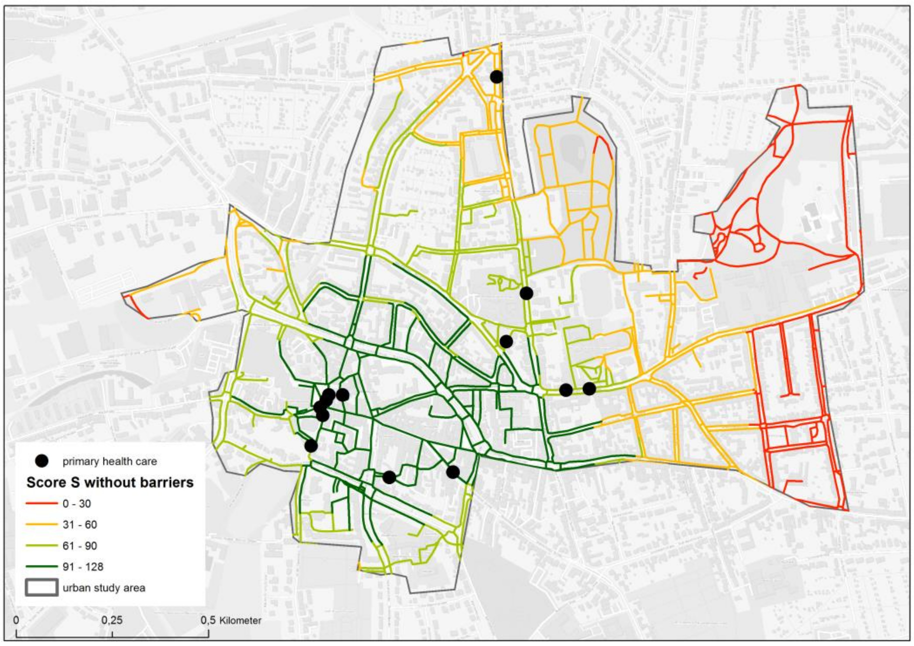

Figure 6: Calculated Score Values S for each Footpath Representing the Accessibility of Primary Health Care in 5, 10 and 15 min without Barriers

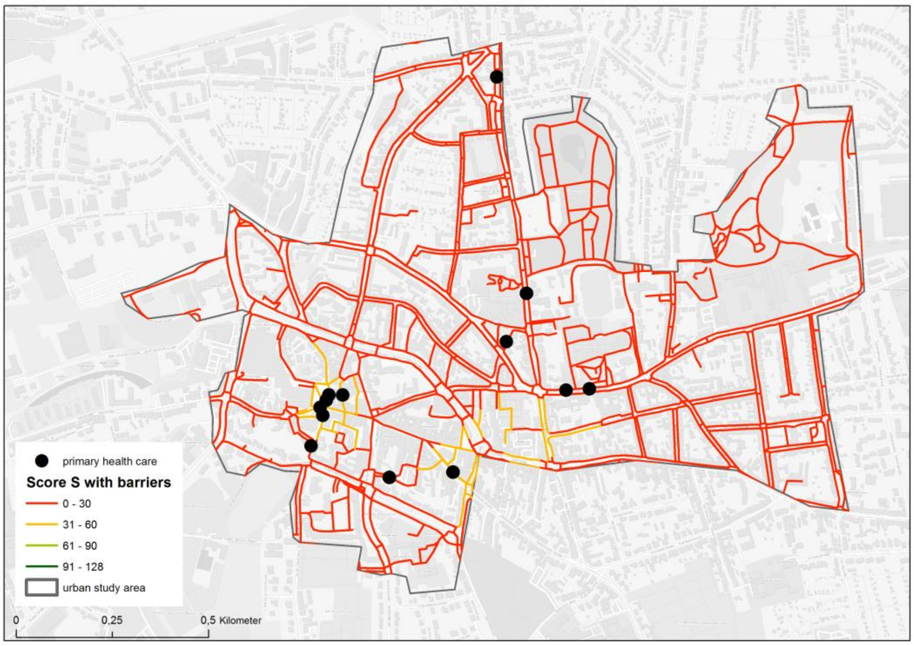

Figure 7: Calculated Score S for each Footpath Representing the Accessibility of Primary Health Care in 5, 10 and 15 min with Barriers

4. DISCUSSION

People move from a starting point such as their home to a destination point such as a physician by using routes such as footpaths, roads, public transportation lines, and so forth. In the case of our analysis, we predefined the three corridors of catchment area of a primary care practice as well as the weights that were applied to the three corridors. These assumptions co-determine the values to be obtained for the accessibility index itself. In Germany, where the analysis was performed, a representative population survey revealed that for 90% of surveyed people, the distance to their GP amounts less than 10 km (Schang et al, 2016). We thus assume that our definition is not too far from reality. With regard to the lowest accessibility score values found in our analysis it can be stated, that compared with large surface areas such as Australia, primary care is still quite accessible.

However, while in different settings the absolute numbers might in- or decrease by different user-defined corridors and weights, the method on a small-area level has the capability to indicate relative regional inequalities in accessibility of primary care independent from the absolute level of accessibility and might also serve for displaying and comparing several, slightly modified scenarios.

As can be seen from the results for the urban study area, the accessability of primary health care by foot depends extremely on the accessibility of the footpath network and thus barriers affect the results of the analysis. But the effort to collect barrier-data is really high. Some cities may have the necessary information in their spatial data infrastructure. In this cases, the analysis of barrier-free footpaths can contribute to the planning of primary health care.

In both cases the quality of the underlying source data is an issue of utmost concern. The quality of the analysis' results completely depends on its completeness, its up-to-dateness, its geometrical, thematical, logical accuracy and consistency, to name the most important parameters. In our study area the level of accuracy was considered to be sufficient for most data. Other data such as the location of barriers on footpaths had to be captured as a part of the project. Generally speaking the approach places high demands on input data. The data situation, therefore, has to be investigated as part of any project using the presented method.

5. CONCLUSIONS

Elderly people may, now and even more in future, face accessibility problems to primary care in both rural and urban areas. As primary care is asked to be reachable and accessible for the broad population, and the population is ageing and thereby will face a higher need of care, health care planning should consider potential accessibility problems. Previous methods worked on administrative district level thus not reaching a small-area level. The proposed method seems to be capable to reveal the distribution of accessibility to primary care on street segment level both for rural and urban areas and thereby may enable to better identify areas that need special attention with regard to accessibility of primary health care.

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BIOGRAPHICAL NOTES

Anne Dahlhaus finished her medical studies at the Ruprecht-Karls University of Heidelberg. She performed her doctoral thesis in Vienna, Austria and started her work as a scientific assistant at the Goethe University Frankfurt in 2010. She worked in qualitative and quantitative chronic care research, with a focus on multimorbidity and cancer research. Since 2012, she extended her research field to analysis of GP catchment areas and research on health care planning. In 2016, she completed her Master of Science in Epidemiology at the Gutenberg-University of Mayence.

Ulrike Klein got her diploma in geomatics at the University of Applied Sciences in Hamburg and her doctoral degree in Geography at Kiel University, both in Germany. From 2009 to 2012 she was director of the Centre for Geoinformation at Kiel University and from 2009 to 2014 she was also director of an engineering company for geoinformatics and surveying. Since 2014 she is professor for geoinformatics and applied geodesy at Bochum University of Applied sciences. She is member of the DVW - German Association of Geodesy, Geoinformation and Land Management working group 2 – Spatial Information and Spatial Data Management and national delegate for FIG Commission 3.

Hartmut Müller got his diploma and doctoral degree at Karlsruhe University, Germany. After 8 years of research he turned into the marketing and software development departments of international enterprises for 6 years. Since 1991 he is professor at Mainz University of Applied sciences. Since 1998 he is a director of i3mainz, Institute for Spatial Information and Surveying Technology. In the DVW – German Association of Geodesy, Geoinformation and Land Management he is past chair of working group 2 –Spatial Information and Spatial Data Management. In FIG he is the Chair of Working Group 3.1 Spatial Information Management.

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