The future of general practitioner care in Lower Saxony, Germany: an analysis of actual *vs* target states using a GIS-based floating catchment area method

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Abstract

Ensuring universal and equitable accessibility to healthcare services is crucial for fostering equal living conditions aligned with global and national objectives. This study examines disparities in accessing General Practitioner (GP) care within Lower Saxony and Bremen, Germany, using the two-step floating catchment area method for spatial analysis at street section level, incorporating various transportation modes. Findings are compared with needs-related planning guidelines to uncover spatial disparities and deviations between prescribed guidelines (target state) and empirical findings (actual state). The analysis reveals significant discrepancies, with over 50% of the population inadequately supplied due to accessibility or capacity issues, particularly in rural and some urban areas, challenging assumptions of sufficient urban healthcare provision. This is the first detailed analysis of primary care provision at this granular level in Lower Saxony, exposing substantial gaps between current GP care and planning targets. Fine-grained spatial analysis proves essential for revealing healthcare accessibility inequities and offers a roadmap for targeted policy interventions. Despite limitations, such as not fully capturing real-world dynamics or patient preferences, the study provides valuable insights into enhancing geographically equitable GP care. It contributes to the discourse on achieving equal living conditions through equitable healthcare accessibility, advocating a more refined, localised approach to healthcare planning, emphasizing the importance of detailed spatial analysis for informed decision-making and promoting health equity.

Introduction

The establishment and preservation of equitable living conditions represent foundational principles within the governance frameworks of both the German federal and state authorities (Terfrüchte, 2019). This commitment is directed towards fostering uniform development across all regions of Germany, particularly concerning services deemed of general public interest. Ensuring equivalent living standards has thus emerged as a pivotal concern within the welfare architecture of the Federal Republic of Germany (Kahl & Lorenzen, 2019; Deitelhoff *et al.*, 2020).

Healthcare assumes paramount significance in this global context. The World Health Organization (WHO) Alma-Ata Conference of 1978 heralded health as an intrinsic human entitlement, with primary healthcare designated a cornerstone principle (WHO, 1978). The United Nations (UN) acknowledges that health constitutes a prerequisite, outcome, and barometer of all facets of sustainable development. It underscores that sustainable development objectives are only attainable when populations achieve states of physical, mental, and social well-being. Moreover, the UN underscores the pivotal role of universal health coverage in fortifying health outcomes, social cohesion, and sustainable human and economic progress, committing to bolstering health systems to facilitate equitable universal coverage (UN General Assembly, 2012). Consequently, the UN Sustainable Development Goals (SDGs) enshrined health and accessibility to healthcare facilities as core components of Goal 3 in 2015 (United Nations Regional Information Centre, 2023). Furthermore, the European Commission regards accessibility to healthcare facilities and the operational efficacy of healthcare systems as essential components of general societal interest, serving as crucial safety nets for citizens and fostering social cohesion (European Commission, 2011). Within this framework, ensuring an equitable geographical dispersion of healthcare services, *i.e.*, spatial accessibility to healthcare, emerges as a paramount public health imperative (Stacherl & Sauzet, 2023).

Voigtländer and Deiters (2015) as well as Ozegowski and Sundmacher (2013) highlight regional disparities in the accessibility of care as given by medical General Practioners (GPs) in Germany, with rural and economically weak areas facing longer travel times and higher costs. Gerlinger (2011) points out that an uneven GP distribution leads to oversupply in some regions and (imminent) undersupply in others. The geographic allocation of GPs in Germany is predetermined by the needs-related planning guideline (Bedarfsplanungsrichtlinie in German) set by the Federal Joint Committee (G-BA). This guideline ensures nationwide outpatient care by standardising procedures for needs-related planning and admission restrictions within Statutory Health Insurance (SHI) services, addressing both oversupply and undersupply (Federal Joint Committee, 2023). It forms the basis for needs-related plans, which regulate the number and spatial distribution of SHI-accredited physicians, collaboratively developed by the Associations of Statutory Health Insurance Physicians and regional health insurance bodies (Schweikart & Pieper, 2019). The needs-related planning guideline establishes a framework for medical care planning based on the local physician-to-resident ratio, adjusted by a morbidity factor. In this way, the supply levels within each planning area can be assessed, and establishment opportunities can be determined. The smallest planning unit is the GP planning area, which can consist of up to several municipalities (Thielscher, 2021; Federal Joint Committee, 2023).

The target number of GPs is calculated based on the ratio of inhabitants within the planning area to the regional ratio. Subsequently, the ratio of existing contracted and employed physicians is juxtaposed with this number to ascertain the supply level of medical care provision. Regrettably, this can lead to undersupply or oversupply depending on each particular local situation. Supply levels categorise the ratio of actual GP numbers to target GP numbers within each GP planning area into four classes, dictating further allocation of GP practices. Areas with supply levels ranging from 0-75% are classified as undersupplied allowing licenses for registered doctors to be obtained. Similarly, areas with supply levels between 75-100% (termed imminent undersupply) also permit license acquisition. Up to a supply level of 100-110% (considered regular supply), license acquisition remains possible. However, areas exceeding the 110% threshold are considered oversupplied and are subject to license acquisition restrictions. In cases where specific local healthcare needs are unmet by the existing statutory provision, the approval committee may exceptionally create additional practice positions in such areas. These approvals are granted at the request of a physician under the special needs provision and are geographically limited to address local service requirements or to provide medical services needed to cover qualification-specific service deficits.

If physicians are granted a license within a GP planning area, they may establish their practice in any city or community within that planning area in accordance with the freedom to choose a practice location. The original planning framework does not address the small-scale regional distribution of physicians within each GP planning area (Federal Joint Committee, 2023). Consequently, the free choice of practice location for physicians within the planning areas can engender local spatial disparities in GP supply within planning areas, potentially resulting in local supply deficits despite overall satisfactory supply level in this specific planning area (Schweikart & Pieper, 2019). Despite significant efforts by federal frameworks and local guidelines in Germany at the GP planning area level to ensure equitable spatial accessibility to healthcare services, a critical research gap remains regarding their effectiveness at the micro-regional level, particularly in Lower Saxony and Bremen. The overarching frameworks and guidelines primarily address distribution on a broader scale, focusing on large planning areas and GP-to-patient ratios, while neglecting the nuanced variations that may exist within the planning areas at the local level. This oversight may mask micro-regional disparities in GP care accessibility, potentially resulting in unrecognised pockets of undersupply despite overall adherence to broader planning objectives. Additionally, the freedom of choices of physicians regarding practice location within a GP planning area further complicates the actual availability of healthcare services within designated planning areas.

A nuanced investigation into the small-scale geographic distribution of healthcare resources, specifically GP services, is essential to identify potential gaps between the needs-related plans and the actual healthcare provision landscape, as well as to provide insights into the effectiveness of current planning mechanisms in addressing local healthcare needs and offering actionable recommendations for areas where these plans misalign. This research could significantly contribute to enhancing the precision of healthcare planning and delivery, ensuring that the principles of equitable living conditions and accessibility to healthcare are aligned with objective indicators within these regions. To assess spatial access effectively, a combination of travel effort (accessibility) and capacity (availability) measurements is necessary (Guagliardo, 2004). This idea is based on the work by Penchansky and Thomas (1981), that divides access to healthcare into five dimensions: i) availability, *i.e.*, adequacy of the supply, ii) accessibility, *i.e.*, relationship between location of supply and location if client, iii) accommodation, *i.e.*, adaptability to diverse population needs, iv) affordability, *i.e.*, financial feasibility for accessing care, and v) acceptability, *i.e.*, cultural and social appropriateness. Since the inception of the 20th century and Luo's seminal work introducing the Floating Catchment Area (FCA) methodology, geographical health research has extensively explored the two-step FCA (2SFCA) method (Wang & Luo, 2005; McGrail, 2012; Delamater *et al.*, 2019; Liu *et al.*, 2022), an approach assessing healthcare accessibility by considering both the supply of and demand for services within defined catchment areas.

The necessity for analysis in the context of this paper derives from two key factors. Firstly, while there is research utilizing the 2SFCA method in Germany, these studies focus on different research objectives (Bauer & Groneberg, 2016; Baier *et al.*, 2020;

Bauer *et al.*, 2020; Subal *et al.*, 2021; Rauch *et al.*, 2023). Consequently, a comparative analysis of these findings against existing German needs-related planning guidelines remains absent. Secondly, prior research on accessibility to healthcare using the 2SFCA method has often been conducted on larger geographical scales (McGrail & Humphreys, 2015; Gao *et al.*, 2016; Huang *et al.*, 2019; Tao *et al.*, 2020 Gao *et al.*, 2021; Akakba & Lahmar, 2023; Chen *et al.*, 2023; Guo *et al.*, 2023) or has not included all modes of transportation in their analyses (McGrail & Humphreys, 2015; Langford *et al.*, 2016; Gao *et al.*, 2016; Tang *et al.*, 2017; Huang *et al.*, 2019; Tao *et al.*, 2020 Akakba & Lahmar, 2023; Chen *et al.*, 2023).

Materials and Methods

Study area

The focus area of this report is the German federal state of Lower Saxony, situated in north-western Germany. Lower Saxony shares its borders with the Netherlands to the West, and with the city-states of Bremen and Hamburg, as well as the federal states of North Rhine-Westphalia, Schleswig-Holstein, Mecklenburg-Western Pomerania, Brandenburg, Saxony-Anhalt, Thuringia, and Hesse. Encompassing an area of 47,709.86 km² as of 2021, Lower Saxony is inhabited by a population of approximately 8.1 million as of 2022 (Statistical Office of Lower Saxony, 2021, 2022). Given that the federal state of Bremen is entirely enveloped by Lower Saxony, Bremen is also incorporated into the analysis to illustrate the interdependencies between Bremen and Lower Saxony. This addition brings approximately 570,000 inhabitants and an area of 326 km² to the study area (Statistical Office of Bremen, 2022).

According to data provided by the Federal Ministry for Digital and Transport (BMDV) approximately 61.3% of Lower Saxony's and Bremen's population resides in urban regions, with the remaining 38.7% residing in rural areas (BMVD, 2021). Specifically, 32.5% of the population inhabits metropolises, regional cities, large cities or central cities, while 30.6% resides in small towns or villages. This distribution illustrates Lower Saxony's predominantly rural character, with 62.5% of its area classified as rural and 37.5% as urban (Federal Statistical Office, 2023).

Data

In order to implement the 2SFCA method for evaluating accessibility to healthcare, several datasets were essential, including the locations of GPs, population data at a fine granularity, and comprehensive transport networks covering walking, cycling, driving, and public transport. The datasets used in this study were processed as follows.

GP locations

Datasets were sourced from the Association of Statutory Health Insurance Physicians Lower Saxony and the Association of Statutory Health Insurance Physicians Bremen. These datasets were obtained with approval from the Lower Saxony Ministry for Social Affairs, Labour, Health and Equality. The aggregated dataset encompassed a total of 5,639 GPs, providing information on the care mandate of each practitioner (Association of Statutory Health Insurance Physicians Bremen, 2023b; Association of Statutory Health Insurance Physicians Lower Saxony, 2023).

Population data

Geocoded population location data were obtained from (GfK SE, 2022), detailed down to the street section level. This level represents the finest granularity currently available and is defined as the continuous segment of a street between intersections. It was chosen as a unit of analysis to ensure high granularity in assessing population distribution, allowing for a more detailed examination of accessibility patterns. This dataset included a total of 328,451 inhabited locations with a population of 8,670,930 individuals across Lower Saxony and Bremen.

Transport networks

Networks for driving, cycling, walking, and public transport were created using OpenStreetMap (OSM) street data. These networks, in a node-edge model format, covering the entire regions of Lower Saxony and Bremen, were subsequently modified for routing purposes (Geofabrik, 2023). Additionally, the pedestrian network was integrated with the General Transit Feed Specification (GTFS) data to establish a routable public transport network describing transit schedules, routes, trips and stop data (Fortin *et al.*, 2016; Fayyaz *et al.*, 2017; Brosi, 2023). For the public transport analysis, a Thursday that is not a public holiday was chosen, with schedules evaluated at morning time spots (AM) of 8:00, 8:10, 8:20, 8:30, 8:40 and 8:50 to capture peak travel times.

All data were organised and processed within a PostgreSQL database. The analysis was conducted using ArcGIS Pro (ESRI, Redlands, CA, USA) in conjunction with this database. The timestamp for the needs-related planning data was November 2022, while the status of the GP data was January 2023 and the status of the population locations January 2021.

Methodology

As shown in Figure 1, four methods were employed, three of which can be integrated into a single framework, as they collectively form the necessary steps for computing the necessary 2SFCA method values (Closest Facility Analysis, 2SFCA Analysis and Inclusion of the Modal Split as described in detail in the Results section). In the initial step, a Closest Facility Analysis was conducted to calculate the travel time from each street section point as they represent the most granular basis for residential data to the nearest GP. This information is crucial for defining a threshold representing the maximum acceptable travel time to a GP, serving as one of the input variables for the actual 2SFCA method. Subsequently, based on these thresholds, the 2SFCA method was executed for the modes of transportation (walking, cycling, driving car, public transportation) resulting in four outcome values for each street section point. To amalgamate these four values into an index, a result value per street section point was formed based on the Modal Split of traffic volume utilizing the regional statistical spatial typology. Each street section point was assigned a typology according to the regional statistical spatial typology, a classification system that organises areas based on socio-economic and infrastructural characteristics. From this typology, the Modal Split for transportation modes could be derived. Using the derived Modal Split, the result values for the four transport modes were weighted and summed. Step four in this process involved conducting a hotspot analysis using Getis Ord Gi* statistics to detect statistically relevant areas characterised by low outcome values of the 2SFCA method results and concurrently high population densities.

The 2SFCA method integrates availability and accessibility to evaluate spatial access from both the provider's and the customer's perspectives (Luo & Wang, 2003; McGrail, 2012; Delamater *et al.*, 2019). This family of methods tackles the limitations of traditional container-based indicators for assessing healthcare accessibility, such as static boundaries or the lack of interaction between supply and demand. Particularly noteworthy is that FCA approaches do not confine themselves to administrative boundaries, but also gauge accessibility by defining floating catchment areas that reflect the actual service areas of the population considering their specific locations (Delamater, 2013; Jörg & Haldimann, 2023).

The fundamental principles underlying any FCA include: i) integration of supply and demand by simultaneously considering the location of healthcare providers (supply) and the population (demand); ii) floating Catchment Areas utilise dynamic catchment areas that "float" based on travel time or distance; and iii) mutual accessibility and overlapping catchments by acknowledging that multiple providers can serve overlapping populations and vice-versa (Luo & Wang, 2003).

The 2SFCA method assumes that services within the defined catchment area are fully available to residents, regardless of actual travel times. It considers the interaction between patients and physicians across administrative boundaries based on travel times and calculates an accessibility measure that varies across different areas. Physicians within the catchment area are treated equally, irrespective of actual travel times from population locations (Luo & Wang, 2003). This method does not account for the actual temporal distance between population and physician locations, treating those nearby and on the edge of the catchment area equally (Dai & Wang, 2011).

In a first step, the population numbers of those street section points k within the catchment area with the size d_0 of j are added up for each GP location. Subsequently, the capacity S_j of each GP location is divided by this sum resulting in R_j. In the second step, a catchment area with the size d_0 is also formed for each street section point k, and the R_j from each GP location within it are summed up. Figure 2 shows a conceptual diagram of the approach.

For the calculations in this analysis, the following steps were carried out: Step 1 calculates the GP capacity-to-inhabitants ratio for each catchment area of every GP location j. This was achieved by summing the population P_k within a specified threshold distance d_0 of each GP location j and then computing the ratio of the GPs capacity to population R_j within each catchment area (i.e., $d_{kj}d_0$). The formula for calculating this ratio is as follows:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{jk} \leq d_0\}} P_k} \qquad \text{Eq. 1}$$

where R_j describes the ratio of GP capacity to population within the catchment area of GP location j (*i.e.* where $d_{kj}d_0$); S_j the capacity of GP (derived from the needs-related plans, specifying the regional ratio for each GP planning area, representing the number of residents for whom a GP is planned) at location j; k the street section points including information about the number of inhabitants; P_k the population within the catchment area centered on GP location j (*i.e.*, d_{kj} d_0); d_{jk} the travel time between GP location j and street section point k (as calculated over the routable networks from OSM data); d_0 the threshold below which GP locations are considered accessible (Luo & Wang, 2003).

Step 2 identifies all physician locations j within the threshold travel time d_0 of each street section point k, and then summing the ratio of GP capacity to population R_j at these locations. The formula for calculating accessibility at street section point i is as follows:

$$A_k{}^F = \sum_{j \in \{d_{kj} \leq d_0\}} R_j \qquad \text{Eq. 2}$$

where A_k^F denotes the accessibility to GP care at street section point k based on the 2SFCA method, R_j the ratio of GP capacity to population within the catchment area of GP location j (*i.e.*, where $d_{kj}d_0$); d_{kj} the travel time between street section point k and GP location j; d_0 the threshold below which GP locations are considered accessible. A higher result value of A_k^F indicates better accessibility at a given location (Luo & Wang, 2003).

The choice of the threshold value for the catchment area poses

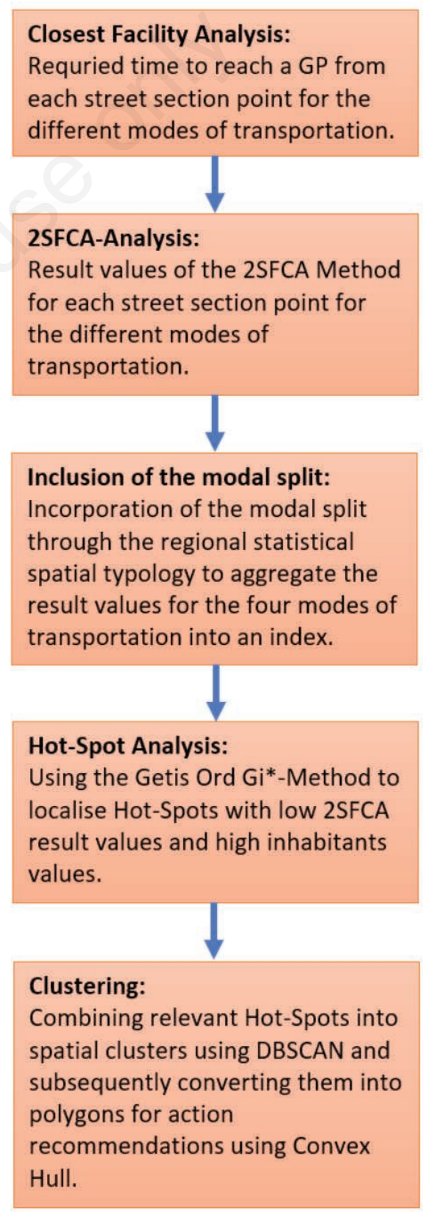

Figure 1. Methodical process.

not only a subjective decision (McGrail, 2012), but also a challenge due to the absence of standardised maximum travel time requirements to reach a GP (Voigtländer & Deiters, 2015). In general, a relatively geographically proximate provision of services is sought (Federal Institute for Research on Building, Urban Affairs and Spatial Development, 2017). Various studies and guidelines suggest threshold values ranging from 10 to 15 minutes by different modes of transportation (Voigtländer & Deiters, 2015; Neumeier, 2017; Federal Joint Committee, 2018). The closest-facility analysis of all street section points within the study area revealed that average travel times to the nearest GP were lower than the threshold values established by the literature. This finding applies to all modes of transport and pertains to the entire regions of Lower Saxony and Bremen. Only walking exhibited longer travel times compared to the literature thresholds. The results are summarised in Table 1. Based on the results of the closest-facility analysis, threshold values for the 2SFCA methodology were adopted from the literature for cycling, public transport, and driving modes, while a threshold of 20 minutes was set for walking mode, due to the results of the Closest Facility Analysis. Based on the different means of transport investigated, the analysis produced four accessibility results for each population location at the street section level. Each street section point was assigned a type according to the regional statistical spatial typology,[1] a classification system, which organises areas based on socio-economic and infrastructural characteristics providing the modal split used for the weighting of

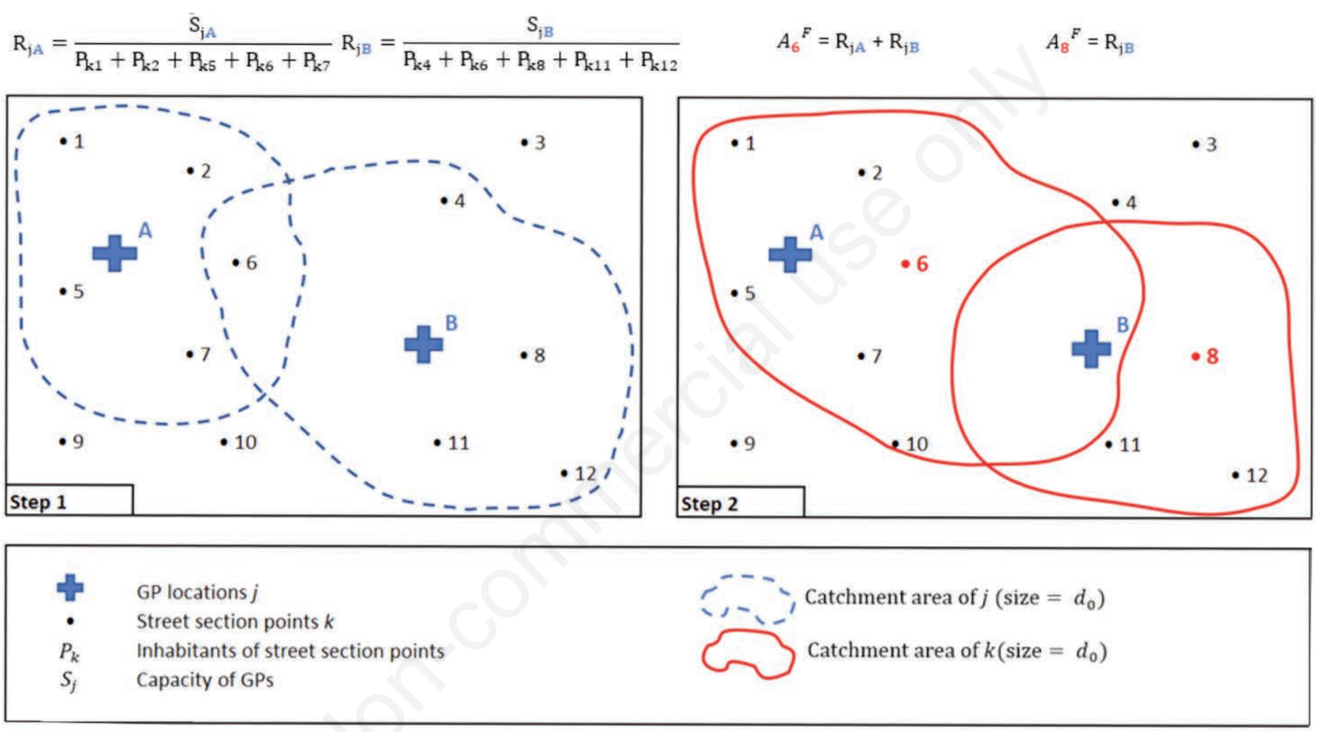

Figure 2. Conceptual diagram of the 2SFCA-Method. Modified According to Park and Goldberg, 2021.

Table 1. Time thresholds for reaching a GP by means of transport.

Transport mode	Defined threshold	Closest facility	Literature thresholds	Reference
Driving	10 min	2.3 min	10 min	Gesundheit Österreich GmbH, 2012
Cycling	15 min	5.7 min	15 min	Neumeier, 2017; Federal Joint Committee, 2018
Walking	20 min	18.4 min	15 min	Pieper and Schweikart, 2009; Federal Joint Committee, 2018
Public transport	15 min	13.4 min	15 min	Neumeier, 2017; Federal Joint Committee, 2018

GP, medical general practitioner.

The regional statistical spatial typology of the BMDV (Federal Ministry for Digital and Transport) is a tool for classifying and typifying regions in Germany. It is based on various criteria, including the population size of cities and regions, their central-place function, the catchment areas of cities, and the location of municipalities in relation to these centers. The typology aims to identify and characterize different types of spatial regions to better understand regional differences and developments, facilitating targeted measures in spatial planning and development (Federal Ministry for Digital and Transport, 2021).

the different transportation modes that were finally combined to form the index for that specific street section point. A result index value of 1 or greater indicates that the population location under study is regularly supplied or oversupplied under the assumptions made regarding accessibility and GP capacities, while a value less than 1 indicates (imminent) undersupply. Based on the previous calculations, which provide results of the current state using the 2SFCA methodology along with the data from the needs-related plans, areas exhibiting high population densities and poor current values of primary care accessibility could be identified. This allowed specific areas to be filtered out, for which recommendations for improving primary care provision can be articulated. Statistical methods, including optimised hotspot analysis by 'density-based spatial clustering of applications with noise' (DBSCAN) and 'convex hull' in ArcGIS Pro, were utilised to generate areas with recommendations for action based on the analysis results. The DBSCAN algorithm is based on density-based cluster analysis and allows for the identification of clusters of any shape and size as well as outliers (noise) in the data. Essentially, points that are closely located and have a minimum number of neighbours within a specified radius make up the cluster, while collection of points not belonging to such clusters are considered outliers (Ester *et al.*, 1996). A convex hull, on the other hand, is the smallest convex boundary that encompasses all points in a cluster, ensuring efficient coverage of the relevant geographical area. Information regarding the number of inhabitants residing in those areas, as well as the regional ratio derived from existing needs-related planning, can be utilised to estimate the required number of GPs in the respective areas.

The optimised hotspot analysis tool operates the Getis Ord Gi* statistic to assess the statistical significance of spatial clusters of either low or high values within a defined neighbourhood. Z-values quantify the deviation from what could be expected under random circumstances, with high values indicating the presence of hotspots (areas of high values surrounded by other high values) and coldspots (areas of low values surrounded by other low values) (Getis & Ord, 1992; Anselin, 1995). Statistically significant hotspots with 99% CL of are derived from values with p-values of ≤ 0.01 and z-scores of >2.58. To aggregate the results of the hotspot analyses into clusters, the DBSCAN was used. The algorithm is based on density-based cluster analysis and allows for the identification of clusters of any shape and size as well as outliers (noise) in the data. Essentially, points that are closely located and have a minimum number of neighbours within a specified radius make up the cluster, while collection of points not belonging to such clusters are considered outliers (Ester *et al.*, 1996).

Hotspot analyses using the Getis Ord Gi* statistic in ArcGIS Pro were conducted for all population locations with a calculated accessibility of <1, indicating (potential) undersupply. To generate clusters characterised by low accessibility to primary care and high population densities, the Getis Ord Gi* statistic was initially computed using the calculated accessibility variable. From the coldspots identified within the 99% confidence interval ($p < 0.01$ and $z < -2.58$), a subset was formed for further analysis. This subset comprised all significant spatial clusters exhibiting poor accessibility. Utilizing this subset as the initial dataset, optimised hotspot analysis was once again performed in ArcGIS, this time utilizing population size as the variable. The result then consisted of spatial clusters comprising hotspots (indicating poor accessibility and high population densities) and coldspots (indicating poor accessibility and low population densities), from which the hotspots were filtered out by the 99% confidence interval. Following the initial identification of clusters derived from the hotspot analyses, these statistically significant clusters – with a low result value for accessibility and a high population count – were subjected to DBSCAN to classify the point clouds. This approach was selected to effectively aggregate points into clusters based on their density, allowing closely located points to be merged into meaningful patterns and trends. For each cluster of points created, a convex hull was generated to serve as the spatial unit for action.

Results

Target state

The current status of the needs-related plans for GP care in Lower Saxony and Bremen is illustrated in Figure 3. The majority of planned areas are categorised as being imminently undersupplied or regularly supplied. Additionally, some planning areas exhibit oversupply, while only two planning areas demonstrate undersupply. The south-eastern region of the federal state (particularly around Göttingen) shows a favourable situation with regular supply or oversupply. Similarly, regions around Hanover, Osnabrück, and Oldenburg also exhibit sufficient supply. In contrast, undersupply is observed in two planning areas located in northern and central Lower Saxony: the Syke planning area south of Bremen and the Bremerhaven planning area. The Bremerhaven planning area is situated north of Bremen and south of the city of Bremerhaven. The findings reveal a distinct urban/rural divide, with rural areas - particularly in the northwest and parts of central Lower Saxony - facing higher levels of undersupply. Urban regions generally have better GP coverage, although certain undersupplied zones persist, even near metropolitan areas. Overall, 58.1% of residents have a supply level exceeding 100%, indicating regular supply or oversupply, while 41.9% are not fully supplied, indicating imminent undersupply or undersupply.

Actual state

The results presented in Figure 4 show the outcomes of the GP-care accessibility analysis using the 2SFCA method and following the categorization of the needs-related planning criteria: i) undersupply: resulting value of 0-0.75; ii) imminent undersupply: resulting value of 0.75-1; iii) regular supply: resulting value of 1-1.1; and iv) oversupply: resulting value greater than 1.1.

The analysis revealed the distribution of GP-care accessibility as follows: i) undersupplied: approximately 2,190,000 inhabitants (25.3%); ii) imminent undersupply: 2,150,000 inhabitants (24.8%); iii) regularly supplied: 870,000 inhabitants (10.0%); and iv) oversupplied: 3,460,000 inhabitants (39.9%).

The analysis exposed higher resulting values indicating adequate supply or oversupply, particularly in urban areas such as cities and villages, contrasting with (imminent) undersupply that was predominantly observed in rural regions. For instance, districts like the south-western of Lower Saxony show regular or oversupply alongside (imminent) undersupply in close proximity.

To further characterise the spatial distribution, the regional statistical spatial typology of the BMDV was employed, assigning a spatial typology to each municipality in Lower Saxony and Bremen. As shown in Table 2, the majority of the undersupplied population (47.3%) is concentrated in small towns and villages.

Those facing imminent undersupply were predominantly found in urban areas and medium-sized towns, accounting for 38.9% of this group. Conversely, regular supply or oversupply is largely observed in metropolises, regiopoles, and central cities, comprising 40.3% of the population. In summary, the analysis utilizing the 2SFCA method underlines the observation according to which urban areas appear to be better supplied, slightly more than half (50.08%) of the inhabitants of Lower Saxony and Bremen do not have full accessibility to GP care within the defined travel time threshold.

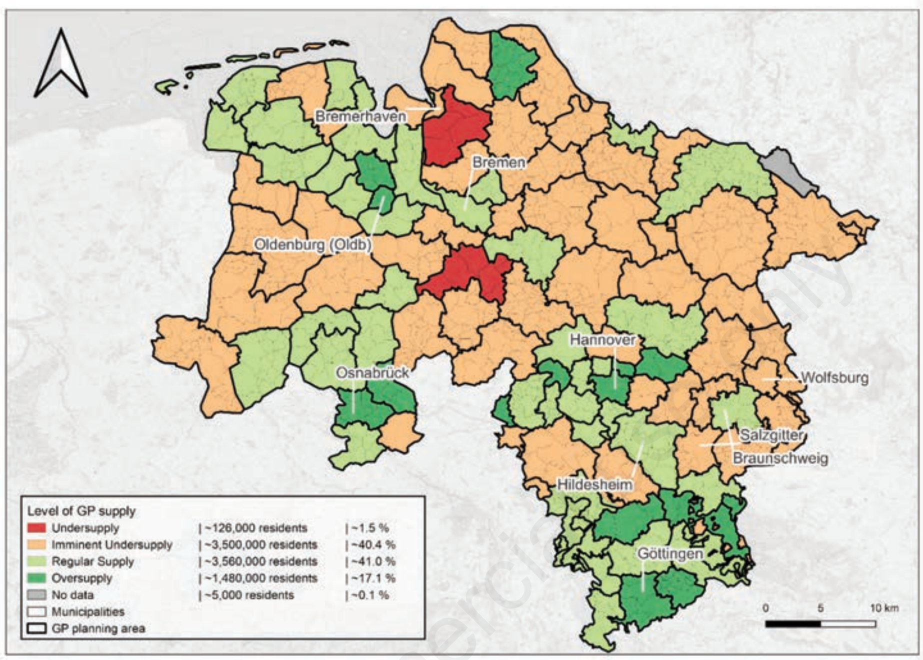

Figure 3. Level of GP Supply at Municipal and Planning Area Level (Association of Statutory Health Insurance Physicians Lower Saxony, 2022; Association of Statutory Health Insurance Physicians Bremen, 2023b; ©OpenStreetMap contributors, 2024).

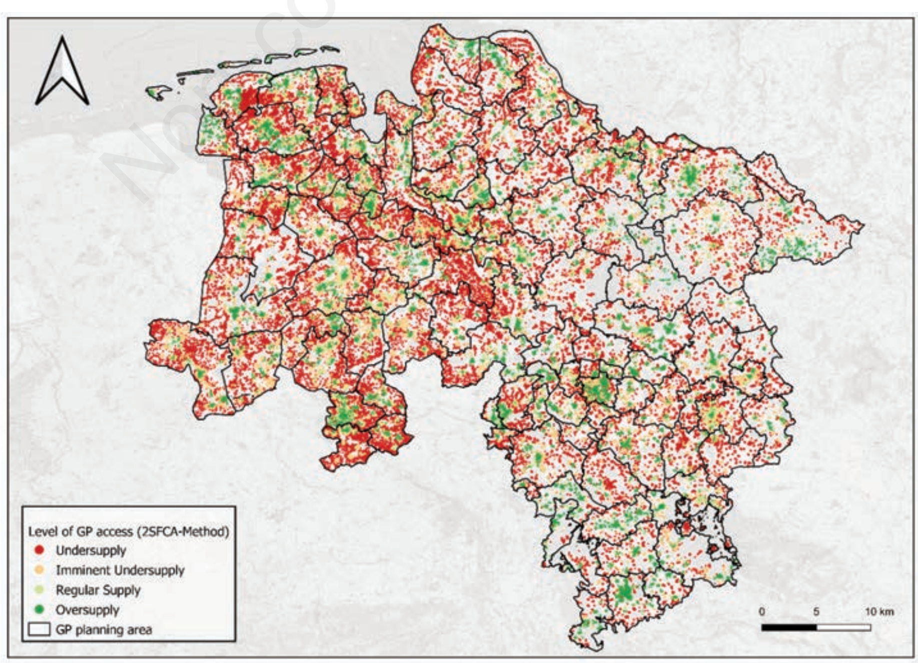

Figure 4. Level of GP access at street section level calculated with 2SFCA method (©OpenStreetMap contributors, 2024).

Deviations between defined guidelines

Indeed, a notable disparity exists between the supply levels determined by needs-related planning and the calculated values for GP care accessibility using the 2SFCA method, as illustrated in Table 3. Significant disparities were evident across all supply levels. The needs-related plans state that the majority of residents inhabit areas classified as either being imminently undersupplied or regularly supplied. These plans suggest that most individuals have mostly satisfactory accessibility to GP care. However, the analysis presents a contrasting scenario: a significant portion of individuals actually reside in areas identified as either oversupplied or undersupplied. This reveals a discrepancy between the planning documents and the conditions calculated through the analysis. While needs-related planning indicates that 41.5% of residents are not fully supplied, *i.e.* (imminently) undersupplied, the analysis shows this to be 50.1%, constituting mathematically more than half of the inhabitants of Lower Saxony and Bremen. To spatially illustrate the deviations between the target (needs-related planning) and actual state (analysis using the 2SFCA method), the supply level from needs-related planning was overlaid onto each street section point corresponding to the GP planning area in which the location is situated. This resulted in four classes representing the deviations, as depicted in Figure 5.

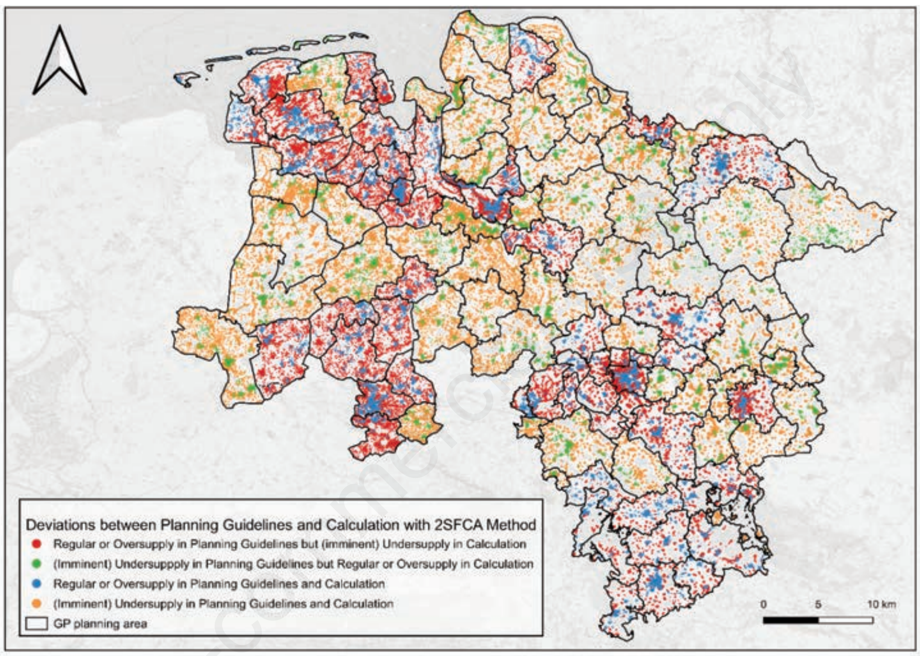

Figure 5. Deviations between planning guidelines and own calculation using the 2SFCA method at street section level (©OpenStreetMap contributors, 2024).

Table 2. Share of inhabitant numbers according to calculated GP supply levels and spatial typology in Lower Saxony and Bremen.

Level of supply	Small towns & villages	Metropolises, regiopoles & central cities	Urban areas & medium-sized towns
Undersupply	47.3%	16.3%	36.4%
Imminent undersupply	28.0%	33.1%	38.9%
Regular supply/ oversupply	25.5%	40.3%	34.2%

GP, medical general practitioner.

Table 3. Comparison of the share of inhabitant numbers based on supply levels and deviations between needs-related planning and the 2SFCA method.

Level of supply	Needs-related planning	2SFCA	Deviation
Undersupply	1.45%	25.26%	- 23.81%
Imminent undersupply	40.44%	24.82%	15.62%
Regular supply	41.04%	10.04%	31.00%
Oversupply	17.07%	39.88%	-22.81%

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The first class encompasses values indicating regular supply or oversupply in established GP needs-related planning but are considered (imminently) undersupplied based on the analysis. This class includes approximately 2,196,000 inhabitants, constituting a share of 25.3%. In spatial terms, 37.1% of these inhabitants reside in metropolises, regiopoles, large cities or central cities, according to Regional Statistical Spatial Typology 17. The two most urban spatial typologies, metropolises with 17.6% and regiopoles with 9.9%, were particularly well represented in our findings. Additionally, 28.9% of inhabitants in this class, who are at least regularly supplied according to needs-related planning, reside in small towns and villages and were considered (imminently) undersupplied based on the analysis. Conversely, there are locations considered (imminently) undersupplied according to existing needs-related planning but are regularly supplied or oversupplied according to the analysis in this report. These locations include approximately 1,490,000inhabitants (17.2%), primarily found in towns or villages of planning areas considered oversupplied or regularly supplied. According to the Regional Statistical Spatial Typology, 49.8% of inhabitants with these characteristics reside in medium-sized cities or urban areas.

Locations that are considered to be at least regularly supplied in both the needs-related planning and our analysis constitute a third class, representing around 2,840,000 inhabitants (32.8%). These locations are predominantly situated in urban areas. This is evidenced by the fact that 52.9% of the inhabitants in this class reside in major urban centres, while only 18.0% are located in small towns and rural areas. The remaining approximately 2,140,000 inhabitants (24.7%) make up the class considered (imminently) undersupplied according to both needs-related planning and the results of our analysis. These locations are primarily found in rural areas, with 69.2% of the inhabitants in this class living in peripheral rural regions, according to the Regional Statistical Spatial Typology.

Recommendations

To provide recommendations for areas, statistically significant clusters with a low result value for accessibility and a high population count were identified. As shown in Figure 6, in this specific case, 33 areas were delineated as having poor actual GP provision while forming clusters with significantly high numbers of inhabitants. Of these 33 delineated sub-areas, one was found to be located in an undersupplied planning area according to needs-related planning guidelines. Furthermore, 15 sub-areas are situated in planning areas at risk of being undersupplied. Conversely, 14 subareas are located in regularly supplied planning areas, with two in

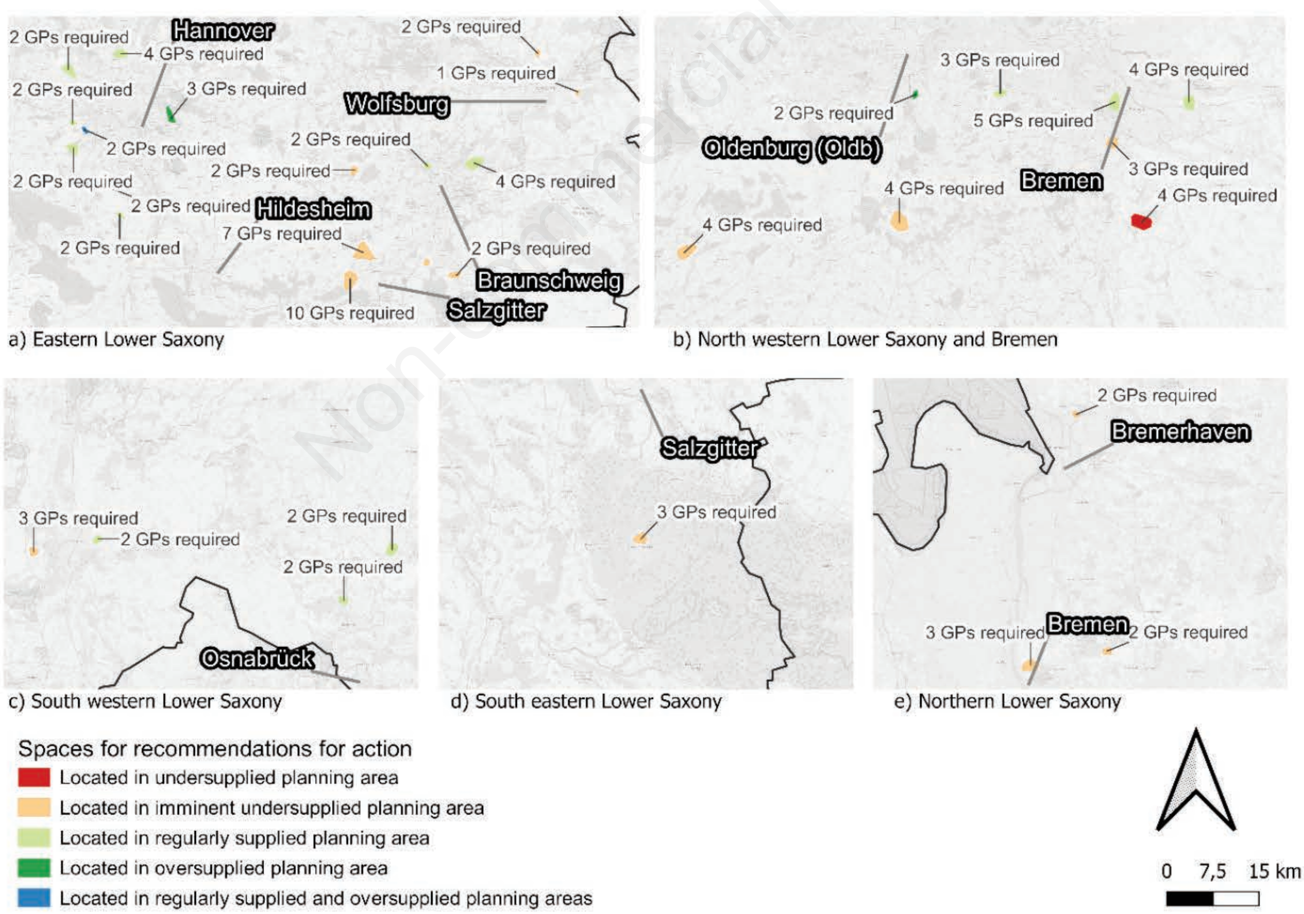

Figure 6. Spaces for recommendations for action regarding GP care in Lower Saxony and Bremen including the required number of GPs (©OpenStreetMap contributors, 2024).

planning areas even considered as oversupplied according to needs-related planning. Seventeen of these targeted areas are situated in eastern Lower Saxony, near Hanover, and an additional eight areas are located in north-western Lower Saxony near Bremen and Oldenburg. Moreover, there are four such areas in south-western Lower Saxony, one in south-east Lower Saxony and another three in north Lower Saxony. Particularly notable are areas in southwest Braunschweig, where ten and seven GPs would be theoretically required, respectively. Both areas are located within a general GP planning region considered to be imminent undersupplied according to needs-related planning. Although classified as regularly supplied according to need related planning, the Bremen district of Rablinghausen turned out to be another area where a large number of GPs is needed. An additional notable observation is the single identified area located within a planning area deemed undersupplied, namely Syke situated south of the city of Bremen, where four GPs would be necessary, the third-highest need among all such areas identified.

Discussion

This study highlights pronounced regional disparities in accessibility to GPs in Lower Saxony and Bremen that was assessed using the 2SFCA method at the street section level. The findings indicate that many residents either face difficulties in reaching available GP services or that sufficient GP capacities are simply not available, with rural areas, villages, and smaller towns particularly affected. While urban areas generally have better GP accessibility, a substantial portion of residents still experiences insufficient care indicating that proximity to urban centres does not guarantee adequate GP services for all. These results align with previous research by Ozegowski and Sundmacher (2013) as well as Voigtländer and Deiters (2015), both studies of whom identified similar regional inequalities in healthcare accessibility across Germany. Furthermore, Gerlinger's observation (2021) that urban areas may experience oversupply, while structurally weaker regions face undersupply is reinforced by this study's findings, a fact that raises questions about the degree to which Germany can claim equal living conditions in terms of GP accessibility.

Comparing the current state of GP care to the targets established by needs-related planning reveals substantial mismatches. Both undersupply and oversupply conditions were found to be more frequent than anticipated in needs-related planning, revealing a substantial gap between the model's estimations and the conditions identified in this study. A significant portion of residents assumed to have adequate accessibility by needs-related planning were found to be classified as underserved by the 2SFCA model used, while others categorised as undersupplied by needs-related planning appeared to in fact have regular accessibility. These findings support Pieper and Schweikart's (2019) assertion that the unrestricted choice of GP locations can lead to uneven supply within planning units resulting in localised deficits that may be difficult to detect at a broader planning scale.

The results suggest that needs-related planning, as currently implemented, may lack the fine-grained approach necessary to fully capture the complexities of GP accessibility. Adopting a more localised planning approach could help address regional disparities, ensuring that GP services are distributed more equitably and that accessibility gaps are minimised. Furthermore, integrating transportation networks and detailed local population data into the planning process would improve the ability to identify underserved areas and guide targeted interventions to improve accessibility. GIS and geostatistical tools prove valuable in pinpointing areas with inadequate GP care and high population densities, aiding in formulating recommendations for action. This study identified several areas where additional GP services are needed, underscoring the potential for geographic analyses to inform more responsive healthcare planning. In regions with lower coverage, establishing new GP practices could help alleviate shortages. In areas that already meet or exceed coverage thresholds, localised assessments would help determine specific needs, potentially allowing for special authorisations to accommodate additional practices where warranted.

Potential limitations

It is essential to acknowledge that this model is an idealised representation and does not capture all the intricacies of real-world conditions. Personal decisions in GP selection, travel complexities, and mobility limitations impact accessibility and are only partially reflected in this model. Additionally, these findings represent a temporal snapshot that may evolve with population and infrastructure changes. Although threshold values in the analysis of this study were determined using closest facility analysis and insights from the literature, they remain inherently subjective. More importantly, the choice of maximum travel times for each transport mode greatly influences the results generated with the 2SFCA. These thresholds, while grounded in standard practices and research findings, are quite restrictive, and can lead to considerable discrepancies in the analysis. The more restrictive the threshold, the more pronounced the variations, resulting in significant fluctuations in the results. Such predetermined metrics can overlook important factors like personal mobility constraints, social and economic barriers and differing personal preferences, potentially oversimplifying the view of healthcare accessibility. To improve accuracy, there is a need to explore more flexible, data-driven approaches that consider the complexity of real-world conditions. Reflection on these issues is vital in the discussion section to ensure a comprehensive understanding of the study's limitations and implications. Another limitation within the context of the 2SFCA method is the reliance on standardised capacities for each general practitioner taken from needs-related plans. While these standardised numbers offer a consistent way to gauge a GP's capacity to serve the population, they may not accurately capture the actual variation in patient load and demand on individual practitioners. This can result in an oversimplification of healthcare accessibility assessments by failing to account for local differences and nuances in healthcare provision and demand.

The choice of street section points as the spatial unit of analysis was motivated by the need for detailed, fine-grained assessments of accessibility to healthcare services, particularly to GPs. This decision stems from the understanding that larger spatial units, such as census tracts or administrative boundaries, typically exhibit less variation than smaller spatial units. Larger units often average out local differences, potentially masking significant disparities in accessibility. For example, within a large spatial unit, areas with excellent accessibility to healthcare might be averaged with areas facing significant deficits, resulting in a misleading representation of overall accessibility. By utilizing smaller spatial units, e.g., street sections, the analysis can capture and highlight these local variations more effectively, enabling a more precise identification of specific areas where interventions may be necessary. However, it is important to acknowledge the potential limitations of this choice. While fine-grained units provide detailed insights into subtle differences in accessibility, they may also highlight variations that, while insightful, may not always be significant from a broader public health perspective. It is essential to weigh these considerations against the advantages of conducting high-resolution analyses. Balancing these detailed insights with broader patterns is crucial to developing effective healthcare planning strategies. Despite these limitations, the analysis provides valuable insights for improving accessibility to GP care in Lower Saxony and Bremen.

Understanding the dynamics of GP distribution over time is essential for making accurate forecasts for future needs. Furthermore, a re-evaluation of the calculations, including the 33 identified areas with recommendations, should be conducted to assess whether the computed values for primary care accessibility improved. This step would be pivotal in evaluating the effectiveness of the proposed measures and the actual impact on the provision situation. Another aspect to consider is the perceived accessibility of GP care. It would be necessary to investigate whether residents in the identified areas with not sufficient accessibility or areas for which recommendations were made actually feel underserved. This notion of "perceived accessibility" can offer valuable insights and should thus be incorporated into future studies to ensure a comprehensive assessment of the provision situation (Baier *et al.*, 2020).

The study stresses the importance of considering small-scale spatial variations in accessibility to healthcare. Traditional needs-related planning methods may not adequately capture localised disparities, leading to suboptimal resource allocation and service provision. Not only can accessibility issues pose significant challenges, but the capacity of healthcare providers is also a critical factor. In regions with high population density, there may be adequate geographic accessibility, yet the healthcare system could be constrained by limited GP capacity. Conversely, other areas may face primary challenges related to accessibility, with longer travel times posing significant barriers to effective healthcare service utilization. By integrating detailed spatial analyses and incorporating community feedback, policymakers can develop more targeted and effective strategies to address these challenges. Additionally, future research should incorporate the concept of perceived accessibility to provide a comprehensive understanding of healthcare provision. Investigating whether residents in (imminent) undersupplied areas perceive themselves as such can offer valuable insights for refining planning strategies and addressing community concerns. In conclusion, addressing the complex challenges of GP care accessibility in Lower Saxony and Bremen requires a holistic approach that considers quantitative metrics. By embracing spatially nuanced analyses and proactive planning efforts, policymakers can work towards enhancing GP care accessibility and promoting equitable healthcare provision for all residents.

Conclusions

GP care accessibility in Lower Saxony and Bremen presents significant challenges. The analysis using the 2SFCA method reveals significant disparities in accessibility to GP care, with over 50% of inhabitants not fully provided with GP care within adequate distance and/or GP capacity. Rural areas bear the effect of this undersupply, although urban areas also exhibit (imminent) undersupply. The comparison with needs-related planning guidelines highlights the limitations of existing frameworks in accurately reflecting the true state of GP care accessibility. Notably, while needs-related planning project only a minor percentage of residents as undersupplied or oversupplied, the 2SFCA analysis identified a considerably higher proportion experiencing such issues. The findings highlight the complexity of the current GP supply situation, with a notable discrepancy between needs-related plans and computed accessibility levels. Despite efforts to regulate GP distribution through needs-related planning guidelines, the reality on the ground suggests a more nuanced and multifaceted picture. Factors such as population distribution and transport infrastructure contribute to the observed disparities in GP accessibility.

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