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Spatial Accessibility to Pediatricians in Switzerland An Improved Application Approach of the MHV3SFCA Method

GEO 511 Master's Thesis

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Abstract

Background: Primary care is widely seen as the most important form of healthcare provision to maintain population health. Its effectiveness, however, depends on the adequate spatial distribution of primary care facilities. In recent years, access to primary healthcare services has received a great deal of attention in the field of health geography, with most of this research focused on general practitioners. Although pediatricians in residential practices form an indispensable part of the Swiss primary healthcare system, little is known about the spatial accessibility to pediatric practices, and with mounting anecdotal reports about inadequate supply, it is an important issue to address.

Methods: Floating Catchment Area (FCA) methods are frequently used to assess spatial accessibility to healthcare services. The main advantage of FCA methods is their independence from arbitrary administrative spatial entities, while simultaneously accounting for competition between the demand for a given supply's capacity (availability) and travel distances between populations and supplies (reachability). FCA methods are highly interdisciplinary and incorporate statistical, econometric, and geographical ideas. Since their inception in the early 2000s, a number of substantial advancements have been achieved, with the Modified Huff-Based Variable Three-Step FCA (MHV3SFCA) method currently being among the most sophisticated. By further improving the MHV3SFCA, this thesis compares it to the current application approach and integrates continuous distances from the National Passenger Transportation Model (NPVM). This makes it possible to determine optimal variable catchment sizes and to enhance the travel times—usually assumed to be by car—as it takes public transport into account as well.

Results: Spatial accessibility to and supply density of pediatric practices in Switzerland are characterized by significant disparities. Large urbanized areas generally have higher spatial accessibility, also seen in certain remote locations. In contrast however, the relatively densely populated Swiss Plateau is inadequately supplied in many areas. Overall, there is a tendency for francophone and Italian-speaking areas to have better spatial accessibility and supply density than German-speaking areas, with the canton of Bern remaining a notable exception. However, only about 35% of the population reaches the recommended supply density of approximately 1 full-time equivalent (FTE) pediatrician per 1,000 inhabitants (median: 0.65 FTE's across Switzerland). The inclusion of public transport increases accessibility to pediatricians, particularly for intermediate (suburban) areas. The MHV3SFCA method achieves a correlation of 0.86 ($p<0.001$) when compared to its previous application approach. A limitation poses the completeness of the data especially regarding the delineation of the primary care pediatric workforce.

Conclusions: For the first time, an assessment of spatial accessibility to pediatric primary care for our youngest is being conducted in Switzerland. We have found significant spatial disparities in access and supply density throughout the country. This information may assist policymakers in making informed decisions regarding healthcare provision. The approach developed presents a cost-saving and easily transferable alternative with unique advantages over the previous application approach of the MHV3SFCA method.

Keywords: Healthcare access, primary care, pediatrics, spatial accessibility, GIS, floating catchment area, multi-modal

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I am proud to present this work to the inclined reader, whom I much encourage to continue reading, as this topic never ceased to fascinate me, even after a year of working on it. Reaching this point took me a lot of endurance, setbacks, uncountable hours of painstaking work, and train rides to Neuchâtel. But without serious supervision this project would not have come about either. I would therefore like to express my sincere gratitude to the following individuals who have been instrumental in the completion of my master's thesis:

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List of Abbreviations

2SFCA	2-Step Floating Catchment Area
BFS	Federal Statistics Office
E2SFCA	Enhanced 2-Step Floating Catchment Area
FCA	Floating Catchment Area
FME	Swiss Family Doctors and Pediatricians
FMH	Swiss Medical Association
FTE	Full Time Equivalents
GIS	Geographical Information System
GP	General Practitioner
iFCA	integrated Floating Catchment Area
IT	Individual Transporta
MAS	Medical Ambulatory Structure
MAUP	Modifiable Areal Unit Problem
MH3SFCA	Modified Huff-based 3-Step Floating Catchment Area
MHV3SFCA	Modified Huff-based Variable 3-Step Floating Catchment Area
NPVM	National Passenger Transportation Model
OBSAN	Swiss Health Observatory
PT	Public Transport
RQ	Research Question
SA	Spatial Accessibility
SDI	Supply Density Index
SPAI	Spatial Accessibility Index
STATPOP	Statistics of Population and Households of the BFS

1 Introduction

"Indeed, the question of physician shortages is also a geographic one." *(Hudec, 2018, p. 5)*

Switzerland's approach to healthcare provision stems from the understanding that healthcare access is a fundamental right for all its residents. The backbone of the Swiss healthcare system consists of a network of resident primary care physicians. The study of disparities in spatial accessibility to primary healthcare has long been an issue of health geography. Recently published studies by the Swiss health observatory (OBSAN) have addressed the spatial distribution of access to primary healthcare. Pediatricians play an important role in the provision of primary healthcare. Mounting anecdotal reports suggest an insufficient provision of primary pediatric healthcare (Hehli and Minder, 2022; Hehli and Tribelhorn, 2022; Hudec, 2018; Zuercher, 2018). However, to date, disparities in spatial access to primary care pediatricians have not been systematically researched in Switzerland. This master's thesis aims to address this issue.

1.1 Embedding the Research

Article 25 of the UN Universal Declaration of Human Rights states: "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including [...] medical care and necessary social services [...]." Furthermore it is stated that "motherhood and childhood are entitled to special care and assistance. All children [...] shall enjoy the same social protection" (*Universal Declaration of Human Rights* 1948).

Goal 3 of the Sustainable Development Goal (*Transforming our world: the 2030 Agenda for Sustainable Development* 2015) ensures healthy lives and promotes well-being for all at all ages. Subgoals 3.7 and 3.8 demand appropriate access to quality healthcare services and facilities. Ensuring good health and well-being of humans starts with providing appropriate care for our young and youngest. Researchers have clearly established (Aartsen *et al.*, 2019; McCrory *et al.*, 2015; Stafford *et al.*, 2015) that health and living conditions during childhood strongly affects health and livelihood outcomes during adulthood and hence bear importance for multiple SDG's (Goal 1, 2, 3, 8, 9, 10). Marmot *et al.* (2008, p. 1662) conclude that pediatric primary care policy has the unique opportunity insofar as "investments during the early years of life have the greatest potential to reduce health disparities within a generation". Guyer *et al.* (2009) found highly compelling evidence for the positive correlation of adverse health events during childhood, such as tobacco exposure, injury, obesity and mental health with health problems across the entire life span. Haas, Glymour and Berkman (2011) found in a trajectory study that poor health during childhood in part leads to diminished earnings during the entire work life of adults as well to the earlier onset of chronic diseases in adulthood and lessened labour force participation. A Swiss longitudinal study on the importance of childhood for adult health and development has been started (Wehrle *et al.*, 2020).

Furthermore has been established that late therapeutic intervention or no intervention at all can have serious consequences for a child's physical, intellectual and emotional development into adulthood (Barbaro and Dissanayake, 2009; Bennett and Guralnick, 1991; Kalkbrenner *et al.*, 2011; Weber and Jenni, 2012). Poor health during childhood leads to lessened educational attainment which in turn is a major determinant for labor market outcomes. adequate access to healthcare providers during childhood and adolescence is therefore crucial for a human's entire lifespan (Boardman *et al.*, 2002).

1.2 Pediatrics

Pediatrics is the branch of medicine that involves the medical care of infants, children, adolescents, and young adults. The field of pediatrics includes the detection, prevention, rehabilitation and aftercare of all physical, neurological, psychological and psychosomatic diseases, behavioral disorders, behavioral problems, developmental disorders and disabilities of infants, toddlers, children and adolescents from the beginning to the end of their somatic development; including prenatal diseases, neonatology, social pediatrics and vaccinations (Niethammer, 2009). Therefore, the main task of pediatricians is the ensuring of physical and mental-psychological health of children and adolescents. Every child should be able to fully develop their physical and mental potential and achieve the best possible quality of life. Pediatrics takes not only a curative but also a highly preventative approach. A unique aspect of pediatrics is the limited ability of the child to communicate along with the mediatory and intermediate role that caretakers play (Hoffmann *et al.*, 2015). Pediatric care and assessments are crucial for monitoring a child's need for treatment and interventions. Therefore, adequate access to the network of pediatric healthcare is of paramount importance for the well-being of our next generation. In Switzerland this network consists of pediatric (primary) healthcare by resident practices as well children's hospitals. This work will be focused on pediatric practices. Nonetheless, an overview pediatrics in Switzerland is given.

1.2.1 Pediatrics in Switzerland

According to a study conducted in Switzerland, approximately 50% of all visits to a pediatric practices are related to acute or chronic illnesses and accidents (Jenni and Sennhauser, 2016). The main focus lies on infections, skin conditions, respiratory tract issues, and gastrointestinal problems. Around 25% of cases involve parents seeking guidance on health, development, and education. Consultation topics encompass a wide range and cover practically all areas of the child's and adolescent's life (Table 1) The remaining 25% of visits are dedicated to pediatric checkups (Weber and Jenni, 2012). These checkups aim not only to identify diseases and developmental problems at an early stage, but also to provide parents with preventive advice on various topics.

Consultation Topics
Developmental and behavioral issues
Growth, thriving, and breastfeeding
Play behavior
Language development
Movement patterns and motor skills
Potty training
Nutrition and eating habits
Sleep and crying patterns
Parenting questions and family problems
School readiness and difficulties
Vaccination questions
Medication inquiries
Insurance-related inquiries
Teeth and oral hygiene
Travel advice
Puberty topics and adolescent problems
Media usage
Accident prevention

Tab 1: Consultation topics in Swiss pediatric practices. Adapted from Jenni (2022)

Healthcare for children and adolescents in Switzerland is provided by: (1) Resident primary care pediatricians and general practitioners (Primary care providers); (2) Pediatric hospitals, with primary care by general pediatricians (emergency), secondary care by pediatrics specialists, tertiary care (universities and highly specialized institutions); (3) Normal hospitals without pediatric services;(4) Mental healthcare providers working in child and adolescent psychiatric units affiliated with universities or cantonal institutions, as well as those in private practices (including child and adolescent psychiatrists and psychologists); (5) Specialist children's surgeons in hospitals and private practices; and (6) Non-physician professionals (nurses, medical office assistants health advisors, occupational therapists, physiotherapists, social workers, speech therapists, nutritional advisors, midwifes, special needs teachers, and others). (Jenni and Sennhauser, 2016)

In 2019, according to the society of Swiss doctors (FMH, 2022), 2,719 physicians were working with children or adolescents (Pediatrics, Child and Adolescent Psychiatry and Psychotherapy, Pediatric Surgery), of which 1,720 worked in practices and 976 in hospitals. Of those, pediatricians are the largest group (total: 1,920, practices: 1,186, hospitals: 720). In 2014, of general practitioners reported that 10–15% of their patients were children, thus the former are responsible for a significant proportion of healthcare provided to children and adolescents (Hostettler and Kraft, 2015). In addition, 32 pediatric hospitals and departments are providing secondary and tertiary healthcare (Jenni and Sennhauser, 2016).

There are various professional organizations of pediatricians in Switzerland, with the umbrella organization being the Foederatio Paede-medicorum helveticorum (fPmh) within which the SGP, Swiss Society for Pediatric Surgery, and Swiss Society for Child and Adolescent Psychiatry and Psychotherapy are organized. Pediatric primary care is represented by Haus- und Kinderärzte Schweiz (MFE). Furthermore, in the German speaking part of Switzerland, lobbying for primary care pediatricians is organized by Kinderärtze Schweiz. Furthermore 12 pediatric sub-specialties were recognized by the Swiss Institute of Medical Education (Jenni and Sennhauser, 2016).

1.2.2 Pediatric Primary Care in Switzerland

In Switzerland, pediatricians serve as the primary healthcare providers for children and conduct well-child visits during the early years. Previously, primary care was primarily provided by primary care pediatricians and general practitioners operating in private practices. Hospitals were primarily responsible for inpatient care and specialized treatments. The future of pediatric healthcare provision is increasingly centralized, due to economic pressures and the change in young professionals' work environment preferences (Jenni and Sennhauser, 2016; Niethammer, 2009). The introduction of working time directives for hospital physicians has led to more resident positions in teaching hospitals, attracting young physicians to pediatrics. The increase in female pediatricians entering primary care is expected to offset the upcoming retirement of male pediatricians, with approximately half of male primary care pediatricians reaching retirement age around 2025 (Jenni and Sennhauser, 2016). Between 2007 and 2014 the number of female primary care pediatricians has increased from 325 to over 550 while the number of their male counterparts remained stable at around 425 practitioners. This change in gender distribution is also being accompanied by a shift in preferred working settings. Contrary to older (male) pediatricians, young (female) pediatricians largely prefer part-time work and shared practices over full-time and sole private practices (Hostettler and Kraft, 2015; Jenni and Sennhauser, 2016). Due to the age (and gender) structure of the current pediatric workforce, Jenni and Sennhauser (2016) expect dramatic a decrease in physicians working in private residential practices, as the age demographics of pediatricians indicate that half of all full-time male pediatricians in single private practices will retire within the next 10 years.

Around 80% of preschoolers consult a primary care pediatrician. However, as children get older, general physicians gradually take over their care, with non-pediatricians seeing every second adolescent by the age of 11. Jenni and Sennhauser (2016) report a sharp decline in the number of visits between 2007 and 2014 by the population under 18 years of age, particularly in rural areas, due to a shortage of GPs. This is due to non-pediatricians (general practitioners) registering a drop in visits by almost one third of children and adolescents. This could only be partly compensated by a slight increase in visits to primary care pediatricians. This can be attributed to the growing number of pediatricians entering primary care, especially female practitioners. The researchers attribute the decline of general practitioners involved in primary pediatric care to the ever increasing shortage of primary care general practitioners. Hostettler and Kraft (2023) write that a problematic picture can be seen with general practitioners; their density of 0.8 full-time equivalent per 1,000 inhabitants has been below the recommended value of 1 for years[1] They report that the trend of decreasing physician workload as persistent and that fewer physicians are working in solo practice. Although a slight increase in pediatricians is expected in the near future, studies on unwarranted variation have shown that a greater number of available health services does not automatically lead to an better healthcare provision (Weinhold *et al.*, 2022; Wennberg, 2014; Wennberg and Gittelsohn, 1973). This relies also heavily on a suited spatial allocation of the respective services. While some areas might be oversupplied others might face physician shortages and is often related to socio-economic circumstances.

Swiss pediatricians and general practitioners report that the lack of pediatric (primary) care providers is becoming increasingly untenable in certain areas (Hehli and Minder, 2022; Hehli and Tribelhorn, 2022; Hudec, 2018; Zuercher, 2018). Especially demanding is the lack of free working pediatricians, and even more so in rural areas (Jenni & Sennhauser, 2016). Due to financial incentives and working conditions, many young doctors choose to work in well-paying specializations instead of primary care (Sturny, 2020). It is difficult or even impossible for retiring pediatricians to find practitioners to succeed them, due to a change in the younger generation's working hours preferences. Hence many full-time working pediatricians have to be replaced by multiple part-time working practitioners. This problem is especially acute in rural areas, where entire regions can be left without coverage (Hehli & Minder, 2022; Jenni & Sennhauser, 2016). In cities the problem still persists, although to a lesser extent. With both parents often working and less understanding from employers', families face high time pressures, but are often forced to accept big distances and/or long waiting times. This leads to an ever increasing demand in Pediatric Emergency Departments of Hospitals, some of which were reported being on the brink of collapse (Plüss, 2022). A sinking threshold for the utilization of emergency services by families, is partly due to the shortage of pediatricians and family doctors as pädiatrie schweiz writes (2022).With access to pediatric services in private practices in communities identified to become to an increasingly pressing issue, it is crucial to analyze such significant challenges.

1.3 Access to Healthcare

Access to healthcare is generally understood as a complex and multidimensional issue, and despite many conceptualizations, the notion remains difficult to define (Guagliardo, 2004; Khan and Bhardwaj, 1994; McIntyre, Thiede and Birch, 2009). This is also reflected in the fact that many different and not so different attempts have been made. In order to understand access to healthcare, the following presents the most relevant frameworks of how access to healthcare is conceptualized and measured by researchers.

In the late 1960s and early 1970s, medicinal sociologist Ronald Andersen developed together with colleagues a

Pediatrician/Child Ratio	Source
1/2,000 – 1/1,200	FOPE II 2000
1/1,500	Shipman, Lurie and Goodman (2004)
1 FTE/1,000	Swiss Society of Pediatrics (SGP) in Zuercher (2018)
1 FTE/1,000	FMH (Hostettler and Kraft (2023)
>1/4,000 = low >1/2,000 = high Avg: 1/2,149	Cervigni *et al.* (2008)
<1/3,000 = shortage area >1/1,000 = high supply	Shipman *et al.* (2011)
1/2,094 = median in 34 European countries	Laufer *et al.* (2014)
1/1,300	Laufer *et al.* (2014)

[1] Suggesting an adequate ratio of pediatricians per 1,000 children is not the aim of this work, as there are various drawbacks associated with this metric as later explained. Nonetheless, it can be noted that various scholars have addressed the question of the optimal amount of physicians per capita. While there is no consensus on the universally accepted "ideal" ratio of pediatricians to children, certain guidelines have been established. However, neither the nominator nor denominator are standardized. Some measures simply use the amount of pediatricians (some including others excluding specializations) while others use full time equivalents to measure workforce. Also, some include children until 14 years of age while others include even 19-year-olds.

widely adopted framework conceptualizing access to healthcare (Aday and Andersen, 1974; Andersen, 1968; Andersen and Newman, 1973). In essence the Behavioral Model of Health Services Use identifies determinants (personal and societal) that influence health service consumption and thus health outcomes and customer satisfaction. Going through considerable adaptation and further development in four phases (Andersen, 1995) the Behavioral Model of Health Services Use retains a focal point on the political dimension and takes rather global approach. It evolved from an approach based on the idea that people use health services in a function of their predisposition to use services, factors which enable or impede use, and their need for care, to an interaction and feedback driven model.

Penchansky (1976) critiqued Andersen's approach for losing specificness in its attempt to achieve comprehensiveness in measuring access (Andersen, 1995). Following his criticism of the common conception of access being all factors that influence healthcare use, Penchansky (1977) went on to develop an approach that focuses on the interaction between on the supply-side and demand-side of the healthcare system and that describes the fit between characteristics and expectations as a measure for access. Penchansky and Thomas (1981) identify five key dimensions, namely: Availability, Accessibility (termed Reachability for clarity by Jörg and Haldimann (2023), Accommodation, Affordability, and Acceptability. These five dimensions are commonly divided into spatial and aspatial dimensions (see Fig 1) (Khan, 1992). Aspatial factors that influence access can consist of financial, cultural but also language barriers or facilitators (Guagliardo, 2004). These factors can be mapped through the Accommodation, Affordability and Acceptability dimensions.

1.3.1 Potential and Realized Access

To avoid confusion between the ability to get care, the act of seeking care, the actual utilization of care, and indicators thereof, researchers started early on to distinguish between stages of access, that is between potential and realized (sometimes called revealed or actualized) access to healthcare systems and the disparity between them (Andersen and Aday, 1978). Andersen (1995, p. 4) states that "Potential access is simply defined as the presence of enabling resources. More enabling resources provide the means for use, and increase the likelihood that use will take place. Realized access is the actual use of services." This is an *a posteriori* analysis of health service utilization measured in the effective behavior of the patients, which is why realized access is sometimes also labelled as revealed access. Potential access meanwhile is *a priori* knowledge gained through analysis of the configuration of the healthcare system or the spatial distribution of supply and demand. It is important to note that, in terms of potential access, it does not matter which service provider is being used by a particular patient in a particular case.

For the purposes of this thesis, any reference to "access to healthcare" shall mean potential spatial access, as it is the goal of this work to measure potential access to pediatric practices. This research approach thus can be placed in the upper left corner of Fig 2.

1.3.2 Non-Spatial Dimensions Shaping Access to Pediatricians in Switzerland

Based on Commonwealth fund international healthcare system Profile report (Sturny, 2020) the most important regulatory related facts shaping access to healthcare for children are summarized in the following: Switzerland's universal healthcare system is highly decentralized, with the cantons playing a crucial role in its operation. Funding for the system comes from enrollee premiums, taxes (mainly at the cantonal level), social insurance contributions, and out-of-pocket payments. Residents are required to purchase insurance from private nonprofit insurers or have the option to choose private for-profit insurers.

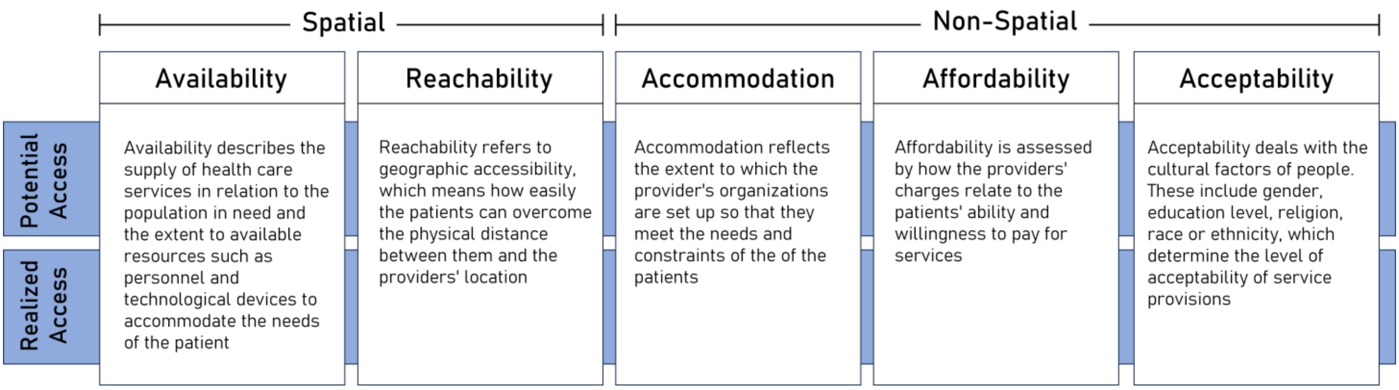


Fig 1: Healthcare accessibility dimensions after Penchansky and Thomas (1981), modified by Jörg and Haldimann (2022).

		Stages	
		Potential	**Realized**
Dimensions	**Spatial** Availability, Reachability	Studies of distance and availability that do not consider utilization measures	Utilization studies that consider spatial factors
	Aspatial Accommodation, Affordability, Acceptability	Studies of affordability, culture and other non-spatial factors that do not consider utilization measures	Utilization studies that consider affordability, culture and other non-spatial factors

Fig 2: Typology of healthcare access studies, combining dimensions and stages; modified after Guagliardo (2004) & Khan (1992)

Apart from the standard coverage model that offers basic coverage with unrestricted doctor selection, there are different alternatives that impose limitations on provider choice. These alternatives include health maintenance organizations (HMOs), family doctor models requiring an initial consultation with the family physician as the gatekeeper for any illness, and call-center models where patients call a consultation hotline before visiting a doctor. In 2016, 65.7% of insured individuals opted for one of these alternative insurance plans.

Mandatory health insurance is offered by competing non-profit insurers on cantonal exchanges and is not sponsored by employers. These insurers are supervised by the Federal Office of Public Health. The over 50 insurers on the exchanges provide policies for three distinct age groups: children up to age 18, young adults aged 19 to 25, and adults aged 26 and above. Each age group has six different deductible levels. Under mandatory health insurance, insurers must offer a minimum annual deductible of CHF 300 for adults and a zero deductible for children up to age 18. Insured individuals can opt for higher deductibles, up to CHF 2,500 for adults and CHF 600 for children, resulting in lower premiums. Additionally, insured individuals are required to pay a 10% coinsurance for all services (except for maternity care and some preventive services), with a maximum of CHF 700 per year for adults and CHF 350 for children up to age 18. The yearly out-of-pocket spending for children under 18 is thus limited to CHF 950. Income-based subsidies for mandatory health insurance premiums are offered to certain individuals or households by both the federal government and the cantons, with varying income thresholds across different cantons. In 2016, approximately 27.3 percent of residents received individual premium subsidies.

For children under 18, covered costs include expenses for durable medical equipment, such as wheelchairs or hearing aids, glasses, contact lenses, and dental care, whereas these costs are not covered for adults. Children or young adults in school (up to age 25) are exempt from copayments for inpatient care. Residents can opt for voluntary health coverage to pay for services not covered by mandatory health insurance, ensuring free choice of hospitals or doctors and preferred hospital accommodation. Additionally, supplemental private insurance can be purchased for services not covered by mandatory health insurance, providing greater choice of physicians and better hospital accommodations.

Although not the main focus of this work, non-spatial dimensions, especially insurance regulations but also other factors such as , play an important role in shaping access to the healthcare system.

1.3.3 Spatial Dimensions

The spatial dimensions encompass Availability and Reachability. Availability describes the interrelation between supply and demand of healthcare services, which can most easily be expressed by a supply to demand ratio, usually of the number of supply points per 1,000 inhabitants. Reachability, on the other hand, can be understood as the spatial proximity (metric or travel time) between supply and demand origins—thus, how easily supply points can be reached. According to research, reduced accessibility, characterized by longer distances to pediatricians, negatively impacts the frequency of consultations (Field and Briggs, 2001; Kalkbrenner *et al.*, 2011; Murphy and Ruble, 2012).

Khan (1992) adds to this an important distinction by differentiating between spatial access and spatial patterns of access. Spatial access is defined by spatial dimensions and thus has a direct geographic manifestation (pattern). But aspatial dimensions may also have a geographic expression and can thus form spatial patterns of access: i.e. poorer regions (financial), areas with a heightened migration (language) or the presence of certain religious beliefs (cultural). As this thesis is written by a geographer, it focuses upon the spatiality of access to primary healthcare services for children as expressed by the dimensions of availability and reachability.

1.4 Spatial Accessibility

Measuring and assessing the spatial dimensions of access has been the goal of many attempts for over 40 years of research. Therefore, the following section does not seek to be an exhaustive review, but rather an attempt to convey the contours and most important concepts relevant to this work.

In the mid-80s, Joseph and Phillips (1984) distinguished "regional availability" in their approach to assessing access from "regional accessibility" (Reachability), both of which can be seen as measures for access itself. As mentioned before, availability is most often reliant on a supply/demand ratio of some sort. These ratios have been used by policy analysts as a measure for the adequacy of healthcare provision, indicating spatial suboptimal distribution of services, areas of current and future manpower shortages, or to set minimal standards for provision (Fryer *et al.*, 1999; Guagliardo, 2004; Khan, 1992). Both the numerator and the denominator of this simple ratio have undergone refinement, just as full-time equivalents (FTE's) are now used instead of simple amount of physicians available. Alternatively, the number of treatments served or visits demanded are used in the ratio. The denominator can reflect the populations at risk as an improvement. But caution is advised as the former can express potential access measures, and the latter realized access. Both versions continue to find application in Switzerland i.e. FMH-Ärtzestatistik (FMH Verbindung der Schweizer Ärztinnen und Ärzte, 2023) or the Swiss Healthcare Atlas (Obsan, 2023).

Despite the simplicity and therefore popularity of the ratio approach, it suffers from a number of fundamental issues. One of these is generally known as MAUP (modifiable area unit problem), meaning that—depending on the aggregation of the spatial unit—widely differing conclusions can be drawn. Variations in availability within smaller subareas are at risk of being overlooked entirely.

Furthermore, where the aggregate spatial units are some sort of political entities (i.e. cantons, municipalities, counties, statistical areas, health service areas, or census tracts), these which might be entirely unsuited for the purpose, as they depend on a defined geographic entity of analysis with delimited areas and only consider healthcare supply and demand within the same entity (Jörg and Haldimann, 2023; Parenteau and Sawada, 2011). Khan (1992) brings up another issue, which is that they disregard the potential mobility of patients across subarea boundaries and how this affects the service availability within the component units of a functional region. This can cause over- or underestimation of the potential availability of healthcare services. This leaves us with a difficult decision as Luo and Wang (2003, p. 866) write: "The higher the aggregation level of rational service areas (that is, the larger the areal unit), the more serious the internal variation problem is, but the less serious the permeability problem is."

Hospital Services Areas (HSA) (Haynes, Wertli and Aujesky, 2020) are defined as the catchment areas of hospitals, as used by the Swiss Health Care Atlas, aim to circumvent the MAUP. They are delineated based on observed patient flows and therefore better reflect how the population actually utilizes care services. Still, supply/demand ratios based upon HSA do not consider the interdependence between multiple regions.

Of particular significance is that all the measures discussed so far do not consider space or distance as a discriminating factor when assessing the relative Availability of services. Consequently, one could argue that these measures do not truly capture the potential spatial access to services (Khan, 1992).

Early established indicators measuring reachability include, for example, the distance to the nearest supply location or the number of suppliers reached within a certain radius. These measures of potential Reachability however either (a) do not take into account the spatial availability component (i.e. demand to supply ratios) and thus measure "place access", or (b) are statistically not comparable across regions (Khan, 1992). For a detailed discussion of the drawback of such measures see Jörg, Lenz and Wetz (2019). While the differentiation between Availability and reachability can be beneficial, in urban areas where multiple service locations are prevalent, it is essential to consider both dimensions simultaneously. This integration is referred to as "spatial accessibility" (SA) (Guagliardo, 2004). According to Khan (1992, p. 278) a measure of potential SA needs to encompass Availability as well Reachability and hence meet the following requirements:

1) be a population-based measure, and not simply a measure of place access;
2) reflect the relative geographic mobility of a non-captive consumer population based on a realistic assumption about utilization behavior, and thus incorporate both distance-decay and distance range elements;
3) incorporate a weighted estimate of the potential availability of each provider;
4) yield standardized scores capable of being compared across regions; and
5) be general and flexible enough to be usable in a variety of contexts.

1.5 Floating Catchment Area Methods

But the difficulty lies precisely in the aspect of incorporating both spatial dimensions and this is where most measures fail. A promising approach to an integrated measure of SA was found in gravity-based methods initially developed by Weibull (1976) and adopted by Joseph and Bantock (1982), which set the starting point for the development of a number of approaches that can be attributed to the Family of Floating Catchment Area (FCA) methods. In principle, all FCA methods work along the following ideas (Jörg, Lenz and Wetz, 2019, p. 25):

1) define and operationalize the relevant supply and demand;
2) quantify the relationship between supply and demand (availability); and
3) operationalize the spatial relationship between supply and demand (accessibility) across distance (spatial accessibility) and within floating catchment areas regardless from organizational units in the form of an index

Designation	Authors
E2SFCA – Enhanced Two-Step Floating Catchment Area Method	Luo and Qi (2009)
Optimized 2SFCA	Ngui and Apparicio (2011)
KD2SFCA – Kernel Density Two-Step Floating Catchment Area Method	Dai and Wang (2011)
3SFCA – Three-Step Floating Catchment Area Method	Wan, Zou and Sternberg (2012)
V2SFCA – Variable Two-Step Floating Catchment Area Method	Luo & Whippo (2012), McGrail and Humphreys (2014)
EKD2SFCA – Extended Kernel Density Two-Step Floating Catchment Area Method	Polzin, Borges and Coelho (2014)
EKD4SFCA – Extended Kernel Density Four-Step Floating Catchment Area Method	Polzin (2014)
EV2SFCA – Enhanced Variable Two-Step Floating Catchment Area Method	Ni *et al.* (2015)
Multi-Transportation Mode 2SFCA – Multi-Transportation Mode Two-Step Floating Catchment Area Method	Mao and Nekorchuk (2013)
M2SFCA – Modified Two-Step Floating Catchment Area Method	Delamater (2013)
E3SFCA – Enhanced Three-Step Floating Catchment Area Method	Luo (2014, 2016)
CB2SFCA – Commuter-Based Two-Step Floating Catchment Area Method	Fransen *et al.* (2015)
iFCA – Integrated Floating Catchment Area Method	(Bauer and Groneberg, 2016)
MH3SFCA– Modified Huff Model Three-Step Floating Catchment Area Method	Jörg, Lenz and Wetz (2019)
MHV3SFCA– Modified Huff Model Variable Three-Step Floating Catchment Area Method	Jörg and Haldimann (2023)

Tab 2: Overview of FCA methods, based on Jörg, Lenz and Wetz (2019)

Tab 2 shows a selection of different FCA methods developed so far. Not all of them will be discussed, nor will it be done in a detailed manner, but rather a selection will name the most important for this thesis. Detailed reviews and comparisons of FCA methods can be found in Vo, Plachkinova and Bhaskar (2015) Jörg, Lenz and Wetz (2019), Jörg and Haldimann (2023).

1.5.1 Development of FCA Approaches

The first accessibility measures that can be assigned to the family of Floating Catchment Area (FCA) Methods were basically supply/demand ratios, with the difference that, instead of the fixed borders of a geographic entity, a floating catchment of a defined radius (e.g. 25 km) originating in a centroid was used (Peng, 1997). The number of physicians "caught" within that radius was divided by the population residing in the same area (usually also geo-located at the centroid of the respective spatial entity e.g. county, state, etc.). The underlying assumption is that all services within the catchment area will be readily available to its residents. However, this assumption does not come without severe drawbacks. For instance, the distance between a physician and a resident within the catchment area may surpass the acceptable travel time threshold, since the diameter of catchment is double the set radius. Accordingly, not all services that fall within a radius will be available to all residents within that catchment (Luo and Wang, 2003).

Radke and Mu (2000) improved upon this by reversing the logic of floating catchments around centroids of areas but instead assume floating catchments around physicians. The approach calculates the ratio of service providers to residents in a service area centered around each provider's location and adds up these ratios for residents residing in regions where the services of multiple providers overlap. This approach was synthesized by Luo and Wang (2003) into the general framework of gravity-based approaches established by Weibull (1976) and adapted to the purposes in health geography by Joseph and Bantock (1982), termed the Two-Step Floating Catchment Method (2SFCA). Furthermore, Luo and Wang (2003) suggested using travel times instead of straight-line distances.

The 2SFCA method works by capturing all population points P_i within a maximum service radius d_{max} of a provider S_j. Populations where the distance d_{ij} between i and j is less than 30 minutes are considered caught by (i.e. as being customers of) S_j. Step 1 is completed by building the supply demand ratio R_j of the capacity S_j. (e.g. number of beds in a hospital or full-time equivalents in a general practice) divided by the sum of the caught populations $\sum P_i$. Step 1 is executed for all supply locations j. In Step 2, the catchments are calculated around each Population P_i and all the demand supply ratios R_j are added up that are within a 30-minute radius from that population point. The resulting measure is the spatial accessibility index (SPAI), which is calculated for each population (see Formulation 1).

2SFCA *(Luo and Wang, 2003)*	
Step 1 supply demand ratio (R_j)	$R_j = \frac{S_j}{\sum_{i \in \{d_{ij} \leq d_{max}\}} P_i}$
Step 2 spatial accessibility index ($SPAI_i$)	$SPAI_i = \sum_{j \in \{d_{ij} \leq d_{max}\}} R_j$
S_j = *Supply capacity j* P_i = *Population at location i* d_{ij} = *Distance between i and j* d_{max} = *Maximum radius/maximum catchment size*	

Formulation 1: Generalized calculation formula 2SFCA

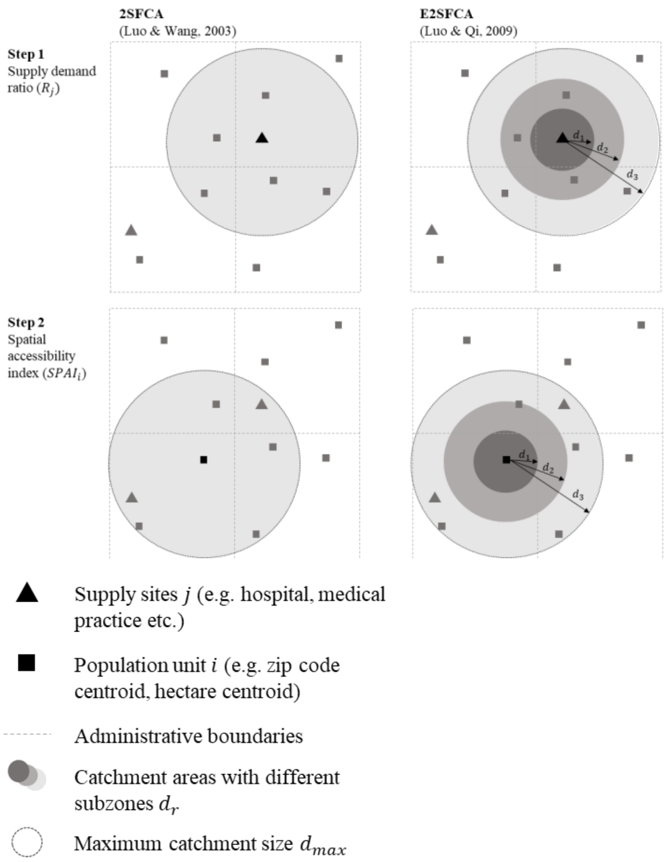


Fig 3: Visual comparison of the 2SFCA and E2SFCA method. Source: Jörg and Haldimann (2023)

However, the 2SFCA method comes with two major limitations, which triggered a series of improvements and the development of an entire nomenclature around the family of FCA methods. A significant drawback of the 2SFCA method is its binary treatment of distance (see requirement list by Khan, above). It treats all healthcare services within the defined maximum catchment size d_{max} as equally accessibly (Luo and Qi, 2009; McGrail and Humphreys, 2009; Wang, 2012). This means that a supply point just 5 minutes was equally likely to be utilized as a provider 30 minutes away. To address this issue, Luo and Qi (2009) introduced the Enhanced Two-Step Floating Catchment Area (E2SFCA) method. In this variant, the catchment radius of 30 minutes was divided into three subzones where each subzone was assigned a distance weight (Fig 3). The weighted distance $f(d_{ij})$ was then used in both steps. In step 1 the population P_i is multiplied by $f(d_{ij})$, while in step 2, to represent the likelihood of service demanded depending on the distance to it, each supply demand ratio R_j within reach of P_i is also multiplied by $f(d_{ij})$. The second major drawback is the overestimation of demand from suppliers. In both the 2SFCA and E2SFCA methods, the demand from population *i* to provider *j* remains unaffected by the presence of other providers within the catchment area, thus the method neglects supply competition. Wan, Zou and Sternberg (2012) proposed the Three-Step Floating Catchment Area (3SFCA) approach to tackle the issue of overestimating demand. By adding a preliminary step, they introduced a selection weight that depends on the distance between population i and a specific supply j as well as on the distance between population i and all other supplies within the catchment area of i. This weight is then used in the two following steps.

Much like the 3SFCA approach, the E3SFCA technique developed by Luo (2014, 2016) also addresses the issue of overestimating demand within the E2SFCA method. In contrast to using a selection weight, the E3SFCA method employs the Huff model[2] (Huff, 1963, 1964) which assumes a positive impact of a supply site's Fsize (or attractiveness) and a diminishing impact of distance. Just as the selection weight functions in the 3SFCA method, the Huff probability is applied during the second and third steps of the E3SFCA approach to simulate demand patterns between population units *i* and service providers j.

A drawback recognized by Delamater (2013) in the E2SFCA and (E)3SFCA methods is their exclusive consideration of distances between population and supply sites in a comparative sense, assuming an ideal arrangement for the entire system in each instance. This also means that regions cannot be compared to each other, and hence the method failed to meet requirement 4 set by Khan (1992). The M2SFCA method (Delamater, 2013)

[2] The Huff model was initially employed to investigate consumer behavior concerning their selection of shopping centers. The original study indicated that the selection and appeal of a shopping center were consistently influenced by its size (Huff, 1963). In a similar manner, the capacity of healthcare services provided can also play a role in the likelihood of demand from a supplier. Larger healthcare facilities typically possess greater capacity, which can result in quicker appointments and a wider range of services to choose from.

addresses this and allows for an overall assessment across regions. However, as Jörg and Haldimann (2023) show, Delamater's approach can lead to the overestimation of distance effect in certain situations. Furthermore, Delamater choose to forgo the inclusion of a supply-competition mechanism based on the argument that his method seeks to measure potential demand.

Instead of using fixed catchment sizes, some scholars (Bauer and Groneberg, 2016; Luo and Whippo, 2012; Ni *et al.*, 2015; Tao, Cheng and Liu, 2020) argued that variable catchment sizes allow to model the behavior of patients better. Two reasons for employing flexible catchment sizes rather than predetermined ones have been identified. The first one is that, when assessing a hierarchical system, providers of more sophisticated treatments (hospitals and tertiary suppliers) have a bigger catchment area (Tao, Cheng and Liu, 2020). This follows the central place theory within healthcare provision (Smith, 1986). The second reason is that individuals with limited nearby

options tend to be more willing to travel longer distances. But the reverse argument can also be made for individuals who already have an ample supply nearby, have no need to travel to providers further out. The idea of variable catchment areas, which has been introduced in the V2SFCA method by Luo and Whippo (2012) and the EV2SFCA method by Ni *et al.* (2015), was further refined and combined with the advancements of the three-step approaches by Bauer and Groneberg (2016) into the iFCA method. The iFCA approach produces adaptable effective catchment sizes using empirical data. Nonetheless, in real-world applications, this strength can also pose a challenge due to the need for continuous distance data, which might be arduous or costly to acquire (Jörg and Haldimann, 2023).

	Traditional Indicators			**FCA methods**					
Properties	Simple supply/demand ratios	Distance to the nearest supply	N° of reachable supplies within max radius.	2SFCA	E2SFCA	3SFCA	E3SFCA	M2SFCA	**MHV3SFCA**
Consideration of demand competition	✓	✗	✗	✓	✓	✓	✓	✓	✓
Results are independent of the analysis unit (e.g. administrative boundaries)	✗	✓	✓	✓	✓	✓	✓	✓	✓
Dependencies among the analysis regions are reflected in the results	✗	✗	✗	✓	✓	✓	✓	✓	✓
Consideration of multiple supply options.	✓	✗	✓	✓	✓	✓	✓	✓	✓
Consideration of relative distance differences (within the max. radius)	✗	✗	✗	✗	✓	✓	✓	✓	✓
Accounting for supply competition	✗	✗	✗	✗	✗	✓	✓	✗	✓
Consideration of both relative and absolute distances	✗	✗	✗	✗	✗	✗	✗	✓	✓
Constant total demand per population	✓	-	-	✗	✗	✗	✗	✗	✓
Variable catchment sizes	✗	✓	✗	✗	✗	✗	✗	✗	✓

Comments: (-) = not applicable

Tab 3: Comparison of selected Accessibility measures and their properties, adapted from Jörg, Lenz and Wetz (2019)

1.5.2 The MHV3FCA Method

Based on the existing FCA methods described above, Jörg, Lenz and Wetz (2019) introduced the MH3SFCA method and later Jörg and Haldimann (2022; 2023) a synthesized approach called the Modified Huff Based Variable Three-Step Floating Catchment Area (MHV3SFCA) method which combines the strength of previous measures and adds some elements to make the underlying assumptions more realistic. The MHV3SFCA will be the method employed in this work, albeit with some improvements on the exact methodology, making it possible to fully exploit the strengths of the MHV3SFCA method. The MHV3SFCA method will be explained in full detail later, while here it is only described in contrast to the FCA methods discussed so far (see Tab 3).

The MHV3SFCA approach combines (Jörg, Lenz and Wetz, 2019, p. 7):

1) The benefits of (E)3SFCA methods by introducing supply competition via the Huff Model;
2) addresses absolute distance disparities akin to the M2SFCA and iFCA methods without overestimating distance impacts;
3) integrates flexible effective catchment sizes as suggested by the iFCA method; and
4) relies on the assumption of an overall population demand that remains unaffected by reachability (constant demand).

This leaves us with a method that is potentially capable of fulfilling all requirements set by Khan (1992). The applications and implementations of the MHV3SFCA approach to date are discussed in chapter 1.6.

1.6 Relevant Studies on Spatial Accessibility

1.6.1 FCA Method Applications

Of particular relevance to this work are the previous use of FCA methods in a primary care context, especially the application of the MH(V)3SFCA approach in Switzerland and Germany. Jörg, Lenz and Wetz (2019), after introducing the MH3SFCA method, showed its exemplary application by analyzing the spatial access to outpatient primary care in Switzerland. The spatial resolution, based on the available data for demand, is on the hectare (100m x 100m) level, which represents a very high spatial resolution. Most other studies using FCA methods rely on spatial units much larger than that (census tracts, municipalities or counties). Distances between supply and demand are not measured continuously, but in subzones. A maximum radius *dmax* of 20 minutes was chosen, along with a subdivision into four subzones (0–5, 5–10, 10–15, and 15–20 minutes). Travel time distances are calculated using the ESRI World Routing Service, assuming transport by car. Due to data artefacts and particular situations such as car-free municipalities, an extensive algorithmic (and in certain cases manual) treatment is necessary. The same procedure has been applied by Lenz *et al.* (2020) to measure spatial access to animal healthcare in Switzerland.

In her master's thesis, Grüebler (2021) analyzed spatial accessibility to pediatricians and early intervention therapies in the Swiss canton of Zurich, using the 3SFCA and MH3SFCA methods (the preceding version of the MHV3SFCA). Using demand data on the hectare (100m x 100m) level allowed for a very high spatial resolution. Travel time matrices between demand and supply origin were calculated with the ESRI Network Analyst tool, the maximum travel time distance being set at 20 minutes, measured continuously. The drawback was that only a maximum of 1,000 origins could be calculated at once, requiring relatively arduous work stitching multiple travel time matrices together (Grüebler, 2021). This might be manageable for the analysis of a relatively small area. Considering that this work aims the assess access to pediatric practices in all of Switzerland and with a higher travel time threshold, her approach would be unsuitable in this case.

A similar approach was chosen by Subal, Paal and Krisp (2021) when analyzing spatial access to general practitioners in Swabia, Germany with the MH3SFCA method. Although the study area encompassing approximately 10,000km^2 (roughly four times smaller than Switzerland, in terms of both area and population) they also choose a spatial resolution of 100m x 100m. Given the relatively large study area, they furthermore chose a continuous approach to measuring travel time distances, arguing that depending on the research purpose (e.g. nationwide SA assessment vs. planning new healthcare sites), either a discrete respectively continuous approach might be more suitable. They mainly criticize that the assignment of Gaussian weights to the average subzone distance (i.e. d=2.5 for 0–5 minutes) assumes accessibility to be equal within subzones. The travel time distance matrices between demand and supply locations were calculated using OpenStreetMap data, while admitting that the crowdsourced data is of varying quality and contains high uncertainties. Regarding catchment sizes, they set a limit of 30 minutes, based on the available literature (Voigtländer and Deiters, 2015) which states that the determined limit is the longest acceptable travel time (albeit by public transport).

McGrail, Humphreys and Ward (2015) found that the maximum tolerable distance for health related travels vary significantly between rural areas near and far from towns (51 vs 32 minutes). This mean that the assumption uniform catchment is faulty because individuals living in thinly populated rural regions are willing to travel greater distances compared to those residing in densely populated rural areas when seeking primary healthcare services during emergencies. The iFCA method developed by Bauer and Groneberg (2016) and addresses this, as it individually calculates the catchments for each population and adapts the distance decay function according to the distribution of supply sites. In a case study they use in Berlin they use city districts as spatial units and continuous travel time data.

Jörg and Haldimann (2022; 2023) integrated the concept of variable catchment sizes with their MHV3SFCA method. In Jörg and Haldimann (2022), they applie d the MHV3SFCA method to assess spatial access to resident general practitioners in Switzerland. They employed the same approach to generate the travel distance data as in Jörg, Lenz and Wetz (2019), but using a set of extended distance subzones (0–10 minutes, 10–20 minutes, 20–30 minutes, and 30–60 minutes), following other researchers that also have added a fourth distance zone, for studies that include rural areas. Further on, this will be referred to as the OBSAN-approach. Access to pediatric practices is currently being assessed with the same approach as in the above (von Rhein, Haldimann and Jörg, 2023). However, spatial precision (hectares instead of census tract) most often means a trade-off on temporal precision (continuous vs sub-zones). R. Jörg, in personal conversation, stated that the generation of the data is rather costly in regards to time and money, which is why they refrain from using continuous data.

1.6.2 Spatial Units of Reference and Aggregation Methods

Selecting the adequate spatial analytical unit is of great importance, as it carries important implications. The operational spatial resolution (see Fig 4) is critical for minimizing aggregation errors (Apparicio *et al.*, 2008; Apparicio *et al.*, 2017; Hewko, Smoyer-Tomic and Hodgson, 2002). The occurrence of aggregation error stems from the dispersion of individuals around the centroid of spatial entities. As distance measures (travel time, travel distance, etc.) are often measured from one centroid to another, and sometimes to facilities, Apparicio *et al.* (2017) point out the importance of using a population weighted centroid instead of the spatial unit centroid, besides using spatial units smaller than census tracts (e.g. census tracts or dissemination areas). This accounts for the distribution of the population and ensures the minimization of aggregation errors.

In Switzerland, a promising opportunity poses the data from the National Passenger Transport Model (NPVM) (ARE, 2017, 2020a). The NPVM has been established to model passenger traffic and assess the effect of traffic planning interventions. Based on 7,978 traffic zones with population weighted centroids (based on hectare population), a detailed road and public transport network (including timetables), the NPVM offers continuous distance and travel time matrices for travel by individual motorized traffic as well as for travel by public transport. The traffic zones (see Fig 4) vary in area sizes, but are established by using diverse input data such as infrastructure networks, water boundaries, construction zones, and structural data of population and employees.

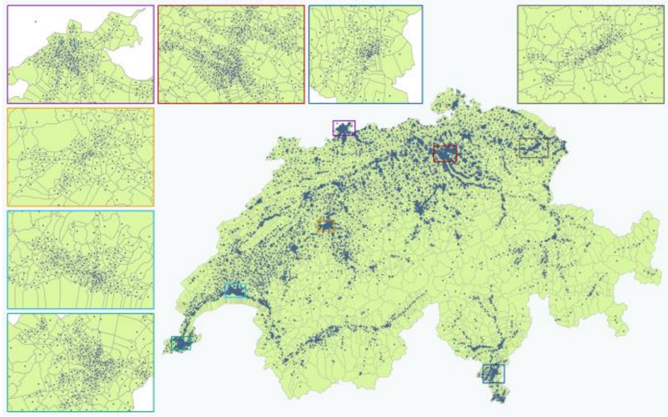


Fig 4: NPVM zones and their population weighted centroids (EBP, 2017).

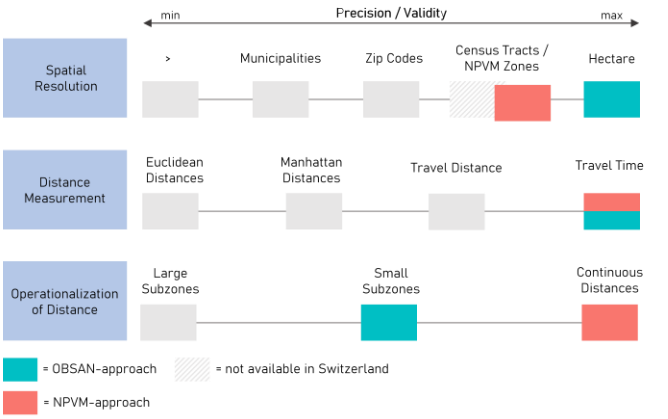


Fig 5: Precision & validity of different operationalizations, based on Jörg, Lenz and Wetz (2019).

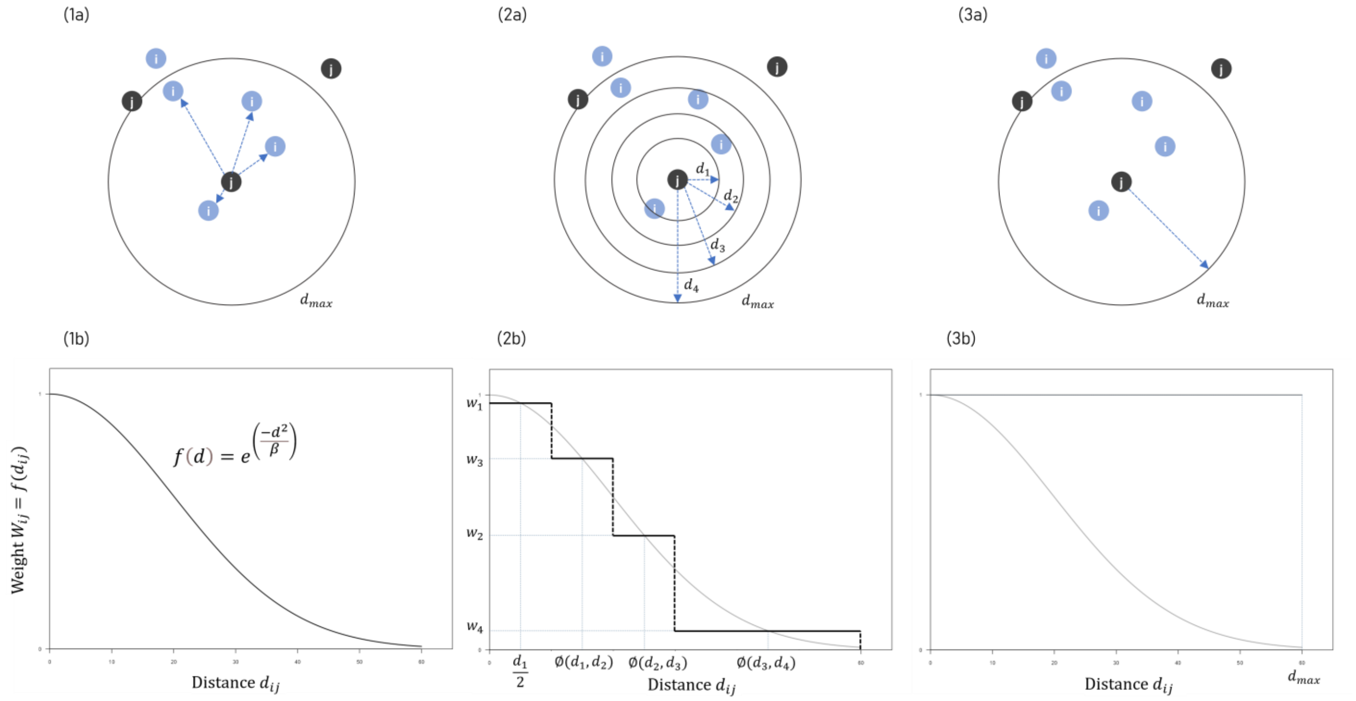
The traffic zones are conceptualized to accommodate an average number of inhabitants + employees of 1,235. US Census tracts are stated to have an optimum size of around 4,000 inhabitants (United States Census Bureau, no date) or about 5,000 inhabitants in Canada (Apparicio *et al.*, 2017). Thus, using the NPVM zones still allows for a higher spatial resolution than using census tracts (see Fig 5).

Furthermore, the implementations of the MHV3SFCA method so far do not make use of all the advantages it offers. When using the variable catchment sizes, the choosing of maximum search distance *dmax* becomes much less important, while a new variable gains all the more importance. Setting the fulfillment requirement for the “expansion” of the catchment sizes, that is the amount of necessary physicians *(Q)* to be reached by a population. The previous studies employing the MHV3SFCA method required the minimum of physicians reached to be at least one. This is due to the discrete operationalization of the travel time distances in subzones. Setting another minimum Q led to big jumps in the distance traveled, often overshooting the required Q by far, leading to the distribution of demand to faraway physicians and between too many of them, resulting in implausible accessibility indices (based on personal conversation with R. Jörg). Using the continuous NPVM data would allow for the integration of those aspects.

1.6.3 Distance Decay

An important but often overlooked aspect of FCA approaches is the incorporation of a distance decay function $f(d_{ij})$. One straightforward method of representing the impact of distance decay is by using a discrete variable. This is exemplified in the binary method (i.e. implicit in the 2SFCA method), where populations within a specific spatial unit or catchment area are assumed to have uniform access to a service (function value is 1), while no access is assumed outside the unit or catchment (function value is 0). The next simplest approach to distance decay is the assumption that the likelihood of interaction between i and j decreases in a linear way with increasing distance. However, real-life travel behavior much more closely follows a downward shaped S-curve. Thus, the elasticity of demand is lower for short and long travel times, whereas for medium-length trips the willingness to travel further declines faster (Vries, Nijkamp and Rietveld, 2009). Most often in FCA studies a Gaussian function is used to model such a relation (Grüebler, 2021; Guagliardo, 2004; Jörg and Haldimann, 2023; Jörg, Lenz and Wetz, 2019; Luo and Qi, 2009; Luo and Whippo, 2012; Subal, Paal and Krisp, 2021; Vo, Plachkinova and Bhaskar, 2015). In addition, the gravity function (Weinhold *et al.*, 2022), the exponential function and logistic function (Bauer and Groneberg, 2016; Wang, 2014), and even linear decay functions (Higgs *et al.*, 2017; McGrail and Humphreys, 2014) have also been used as distance decay functions in FCA method studies (Tab 4).

FCA approaches that make use of discrete subzones within the catchment area will also often use discrete weights for each subzone that are determined using a continuous distance decay function (see Fig 6).



Above: Schematics illustrating different forms of distance measurement: (1a) continuous measurement of distance between supply and population locations within the maximum radius ($dmax$), (2a) distance measurement based on three subzones (resulting in discrete categories, e.g., 0-10, 10-20, 20-30, 30-60 minutes), (3a) binary conceptualization of distance according to 2SFCA (1=within d_{max}; 0=outside d_{max}).
Below: Distance weighting functions for operationalizing the relationship between distance and accessibility: (1b) Gaussian function, (2b) step function based on a Gaussian function, using the subzones' means to derive distance weights, (3b) binary-discrete step function (corresponds to the conceptualization of distance in 2SFCA).

Fig 6: Types of Distance Measurement and Corresponding Distance Weighting Functions. Source: author’s representation based on Jörg, Lenz and Wetz (2019) & Wang (2012)

A seldom discussed limitation of most subzones application is of geometrical nature. A problem inherent to many FCA approaches using subzones, is that within the subzone, the median distance between the inner and outer radius is used to calculate the distance weight. For the base catchment (0–10 minutes) the distance weight is calculated for 5 minutes. However, assuming a random spatial field and a circular catchment, the average distance between the origin of the demand (center of the circle) and all supplies is not half of the circle's radius. This is based on the relationship between a circle's radius and its area ($A = \pi r^2$). Therefore, the appropriate distance weight for subzones should follow this formula.

Function/Family	Equation
Gravity function	$f(d) = d^{-\beta}$
Exponential function	$f(d) = e^{-\beta \times d}$
Gaussian function	$f(d) = e^{\left(\frac{-d^2}{\beta}\right)}$
Logistic function	$f(d) = \frac{1}{1 + e^{-\beta \times (d - mean)}}$
β = Friction coefficient	

Tab 4: Distance Decay Functions applied in FCA methods

Setting the friction coefficient β of the decay functions is often a deliberate choice by the author, more or less based on empirical findings, and has long been part of the academic dispute (Bauer and Groneberg, 2016). This has been addressed by Bauer and Groneberg (2016) with the iFCA method which calculates for each population i, based on the median distance to all providers j, a unique cut-off distance (resulting in variable catchment sizes). The steepness of the distance decay function is determined by the standard deviation of the distances to all providers j. Hence, populations with a lower median distance also have less incentive to travel further, thus resulting in a smaller catchment area. A bigger spread (SD) of distances increases the likelihood of providers further away being utilized. For a comprehensive discussion of distance decay functions, see Bauer and Groneberg (2016).

Overall, variable catchment sizes are out of the discussed reason preferable and is why this work applies this approach too.

1.6.4 Travel Modes

Most often the motorized individual transport is assumed to be the most feasible and readily available means of transportation across the entire study region. All FCA method related studies so far conducted in Switzerland assumed cars to be the only means of transportation (Grüebler, 2021; Jörg and Haldimann, 2022; Jörg and Haldimann, 2023; Jörg, Lenz and Wetz, 2019; von Rhein, Haldimann and Jörg, 2023). Therefore, in most FCA approaches, distance is often defined as network travel times by car rather than by any other mode of transport. But cities and rural areas vary greatly in their distribution of modal share of transportation, which in turn may affect access to healthcare providers significantly. Nonetheless, some studies assessed the use of alternative transportation means. Apparicio et al. (2017) compared different modes of transportation and their correlation with accessibility measures, finding that the correlation between bus and car is approximately 0.8 in Montreal. This can be explained by the fact that the connection to the public transport network is distributed much more unevenly than it is for other modes of transport. Furthermore, contrary to route selection by individuals for each case, public transport networks are not specifically designed to link customers and healthcare providers in the fastest way. Not too surprisingly, other network travel time distance measures (bicycle and walking) were shown to have a correlation coefficient above 0.95 for an area with little topographic variability. These correlations are global and the authors showed that in spatial terms they can vary quite drastically. In suburbia, correlations are lower, but higher in urban centers. Higgs et al. (2017), using a two-step FCA method (E2SFCA), have shown in a study area in South Wales that different travel modes influence the relationship of supply and demand of healthcare services for primary care.

A few authors have conceptualized multimode FCA methods, although in differing ways. Ni *et al.* (2019) applied an multimode E2SFCA approach in Nanjing (China). Based on a patient survey, they used revealed modal shares for hospitals trips differentiated by metric distances classes. A similar approach can also be found in

Mao and Nekorchuk (2013) using a 2SFCA method. The cumulative accessibility is computed through a weighted measure of accessibility, which factors in the travel mode and the number of individuals who can access each provider. This is done using the number of households with cars as a proxy. This approach ensures that a population's accessibility is not solely influenced by the geographical distribution of healthcare facilities, but also takes into account the composition of the population in terms of transportation methods. Tao, Cheng and Liu (2020) assumed that in a hierarchical setting (primary, secondary, and tertiary providers), patients use bikes to reach primary healthcare providers, because of their proximity, but use cars to reach secondary and tertiary providers.

1.7 Research Questions

Based on the reviewed relevant literature above and the identified research gaps, this chapter establishes the research questions (RQ) that will be addressed in this work.

Despite the many anecdotal reports (see chapter 1.2) from pediatricians voicing concerns about the pressing lack of pediatric primary healthcare provision in some regions in Switzerland, there is currently no nationwide rigorous assessment of spatial access to pediatric practices. This is addressed with the first RQ.

> **RQ I:**
> What are the disparities in the distribution of potential spatial accessibility to pediatric practices in Switzerland?

To address this question, the state-of-the-art MHV3SFCA method will be employed. As noted above, there is currently a manuscript in preparation (von Rhein, Haldimann and Jörg, 2023) that aims to address the same question. The approach of thesis differs from the planned publication in that it aims to use the MHV3SFCA method to its fullest capabilities and thus improve on its current application approach in Switzerland. This is the omission of the division of the *dmax* into subzones and adopting a continuous approach. Doing so allows for the omission of the very strict assumption that each population travels just far enough to reach at least one supply location. This however leads to another question: How is the variable catchment size to be determined, how many supply locations should be taken into account when determining the variable catchment size. Having continuous distance data available would also allow for the use of the iFCA method as introduced above. For this study, the MHV3SFCA is preferred due to its advantage over the iFCA with regards to having a constant demand uninfluenced by the availability of supply locations. Another advantage is that the results can be better compared to the ones from von Rhein, Haldimann and Jörg (2023) (see RQ III).

Besides offering distance matrices for transport by motorized individuals means (car, motorbike, etc.) the NPVM also offers a travel time matrix for public transport. Previous approaches considering a multimodal approach rely either on revealed access or on data about car ownership or usage. Furthermore, calculating spatial access exclusively using network travel times by public transport might be rather inconclusive due to the unrealistically assumed demand behavior.[3] Even though Switzerland has one of the densest public transport networks and hence offers a viable alternative to travelling by car, cities and rural areas vary greatly in their distribution of modal share of transportation which in turn may affect access to healthcare providers significantly. In some areas, i.e. inner cities, reachability between demand and supply points might be better by public transport. In rural areas, reachability tends to be poorer by public transport than by car.

This approach to multimodality operates under the assumption of rational customer behavior, implying that patients possess prior knowledge about the shortest routes to each supplier. Research Question II (RQ II) seeks to ascertain the regions where potential accessibility to pediatric practices improves or declines when patients and their caregivers are informed and make rational choices regarding their mode of transportation.

> **RQ II:**
> What are the effects on potential accessibility to pediatric practices when public transportation is taken into account as an alternative travel mode?

The MHV3SFCA method is arguably able to fulfill all the requirements set by Khan (1992) (see chapter 1.4), although the current OBSAN-approach requires labor- and time-intensive procurement of travel time matrices. Furthermore, these matrices have to be calculated for each application of the method. By using the readily available travel time matrices from the National Passenger Transport Model (NPVM), an approach can be developed that is general and flexible enough to be usable in a variety of contexts. The use of the NPVM Zones permits a spatial resolution that is still higher than FCA approaches using census tracts. The third Research Question (RQ III) aims to establish a benchmark for this approach against the currently used method. This can be achieved by comparing the results of this study with preliminary results of von Rhein, Haldimann and Jörg (2023).

> **RQ III:**
> Can the distance matrices and zone structure from the NPVM be a viable alternative to study specific distance matrices?

[3] According to statistics about the mobility behavior of the Swiss population from the BFS (2023b), travel by car is the most common. More than two-thirds (69%) of the daily distance was covered by car in 2021, with one-fifth (20%) using public transport. Walking and cycling accounted for only 9% of the distances, but made up 47% of the daily travel time. Compared to the previous survey in 2015, the share of public transport distances has decreased by 5 percentage points. The main reason for this was undoubtedly the Covid-19 pandemic. Data from the 2015 Mobility Micro-Census revealed that for the travel purpose "Service and accompanying path" out of the 1.85 km that the average person traveled per day, 1.69 km were traveled by car, whereas only 0.09 km by public transport and 0.06 by bike or on foot according to BFS (2017c).

2 Methodological Approach

2.1 Study Area

Nestled in the heart of Europe, Switzerland is a landlocked federation consisting of 26 cantons. Duties and responsibilities in the Swiss healthcare system are allocated among the federal, cantonal, and municipal governments. The cantons hold a high degree of sovereignty regarding many political aspects, including the organization of healthcare provision. Each of the 26 cantons has its own constitution and assumes the role of licensing providers, coordinating hospital services, advancing health via disease prevention measures, and providing financial support to institutions as well as individual insurance premiums. The Swiss Conference of Cantonal Health Ministers plays a crucial role in coordinating policy decisions. The federal government is responsible for system financing, ensuring the quality and safety of pharmaceuticals and medical devices, coordinating public health initiatives, and promoting research and training (Sturny, 2020).

Switzerland covers an area of 41,291 km^2 of which 14,097 km^2 are uninhabited (rocks, glaciers, lakes, etc.). As of 2019, Switzerland had a population of 8.6 million, resulting in a population density of 208.4 (316.4, if uninhabitable areas are excluded) inhabitants per square kilometer (BFS, 2020a). In the same year, 84.8% of its population was living in urban areas whereas 15.2% lived in rural areas (Britannica, 2023). Most of the Swiss population lives in the Swiss Plateau, spanning from Geneva northeast to St. Gallen between the Jura and the Alps. The alpine valleys are sparsely populated, hosting only a few medium-sized centers. As of 2019, there were 2,212 municipalities, a number that three decades ago was above 3,000 (Avenir Suisse, 2016). This strong increase in municipal mergers showcases once more that administrative entities are unsuited for a reliable unit of analysis of healthcare provision, as they are constantly modified (see MAUP in 1.4).

2.2 Data Sources

The demand and supply data as well its processing is the equivalent to von Rhein, Haldimann and Jörg (2023). This is to ensure that RQ III can be addressed in the best possible way.

2.2.1 Demand

The demand data should ideally provide a close representation of the objective, potential needs. The challenge, of course, lies in the fact that the potential demand is a latent construct and therefore not directly observable in a population (Kaiser and Krähenbühl, 2020). Taking this uncertainty into account, the term used in the following is not "supply need", but rather the "(need-adjusted) demand population" (see also Jörg and Haldimann, 2022).

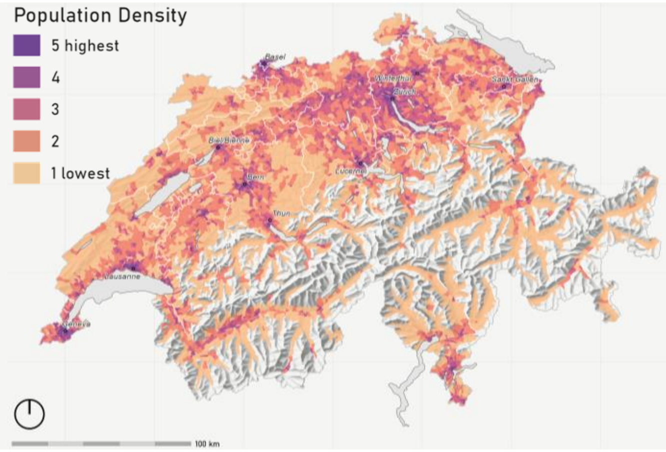


Fig 7: Study Population Density, Children under 15 years, per NPVM zones. Unproductive (uninhabited) land excluded in calculations and shown in grey. Data: BFS, 2019

Starting point is the permanent resident population[4] aged 0–14 years[5] by hectares The spatial resolution is very high (100m by 100m raster) and is from the statistics on population and households (STATPOP[6]) published by the federal statistics office (BFS). The data collected is based on geolocated individual households in cohorts of four years.[7] Fig 7 shows the distribution of the population based on the density by NPVM zones.

Based on a model for demand estimation, established in Jörg and Haldimann (2022) that corrects demand by different factors, need adjusted demand is calculated. It is

[4] The permanent resident population does not include foreigners with a short-stay permit for less than 12 months and individuals in the asylum process with a total residency duration of less than 12 months.

[5] Although pediatrics include the provision of healthcare until the end of somatic development and therefore possibly longer than for 15 years, the next statistical category includes persons up to age 19. As the age of children increases, healthcare provision by pediatricians shifts drastically to provision by general practitioners

[6] This data is publicly available with some restrictions. For data protection reasons, absolute values from 1 to 3 must not be disclosed in standard analyses and are always assigned the value of 3 BFS (2020b). For this analysis, a data protection agreement has been signed for the usage of the unrestricted data.

[7] The percentage of geocoded households exceeds 99% and is in no municipality lower than 90%. Individuals/households without an address in the municipality or individuals/households cannot be accurately geocoded. To maintain the completeness of the survey, these individuals have been assigned to the so-called center coordinate of the municipality (collective hectares) on a municipality-wide basis. The resulting partially increased counts of individuals/households on collective hectares can lead to unwanted influences as municipalities are often divided in multiple NPVM zones BFS (2020b). This can be neglected here, considering that most of those cases concern adult individuals.

applied as well in von Rhein, Haldimann and Jörg (2023). It takes into account demand stemming from tourism and cross-border patients. Furthermore, differences in demand according to population structure and disease burden of the population (morbidity) are taken into account by means of a demand weighting. Using a Poisson-Generalized Linear Model[8] (Poisson-GLM), the demand weights are then calculated as follows. Predictors for utilization of outpatient pediatric services (billing data of SASIS SA) used in the model are: age group, gender, annual deductible (high/low), hospitalization in the previous year (yes/no), medication costs of more than CHF 5,000 in the previous year (yes/no). The resulting regression model was then used to estimate the need-adjusted volume of benefits per insured person by age group, sex, and municipality of residence. Finally, demand weights were derived from the estimated demand differences and applied to the population data (von Rhein, Haldimann and Jörg, 2023). For further details, see Jörg and Haldimann (2022).

The demand adjustment furthermore accounts for the amount of overnight stays according to the accommodation statistics (HESTA, 2019) of the BFS. This data is also on a hectare basis and the share of children staying overnight is assumed to be that of the resident population. Lastly the demand is adjusted by the inclusion of health insurance services (OKP) for patients from foreign countries (particularly cross-border commuters[9]) is incorporated by utilizing the billing information available in the SASIS AG data repository. Tourism and cross border demand are quantified using equivalents based on the resident population. As a result, the supply-demand relationship can be represented as the “number of children of the demand population”. In total accounting, the 3% of demand stemming from tourist and cross-border patients would be negligible. But viewed spatially, tourism can become a relevant factor for regions like Zermatt or Gstaad (mountain villages with a relatively small permanent population but a high amount of overnight stays) In cities located near the border, such as Basel and Geneva, cross-border demand is relevant due to the high amount of cross-border commuters (Jörg and Haldimann, 2022; von Rhein, Haldimann and Jörg, 2023). In total 1,335,177 person in demand population, whereby the resident population of children under 15 years constitutes 97% of this population (see Tab 5).

Demand Population	**n**	**%**
Resident Population $<$ 15 y	1,294,918	97%
Tourism	32,618	2%
OKP Cross-Border Demand	7,641	1%
Total Need Adjusted Demand	**1,335,177**	**100%**

Tab 5: Need adjusted demand population

2.2.2 Supply

Analogous to von Rhein, Haldimann and Jörg (2023), the relevant supply (private pediatric practices) is identified. For this purpose, the structural data on medical practices and outpatient centers (MAS) of the Federal Statistical Office (BFS) were used as the main data source. Due to a less than desirable response rate to this survey, data of the medical statistics of the Swiss Medical Association (FMH) were also linked. In this way, physicians not taking part in the MAS could be added. For the purpose of delimiting primary care pediatrics, the analyses in this thesis refer exclusively to physicians working in outpatient practice with the main specializations of “pediatric and adolescent medicine”, and active as of December 31 2019. Hospital outpatient care services were not included. Pediatricians not active in primary care according to MAS data were excluded, as well as pediatricians aged over 75 years in the FMH data. All pediatricians were then geocoded using the practice address details. Their capacities were taken into account according to the individual workloads and expressed in the form of full-time equivalents (FTE). For pediatricians with missing information, the workload was estimated by imputation, which resulted in 1,332 pediatric practices[10] with a total of 935.2 FTE’s.

2.2.3 NPVM Data

The development of the Swiss National Passenger Transportation Model (NPVM) has led to a host of new publicly available data (see ARE, 2020b). For this study, two data sets are of relevance: the NPVM zone structure developed by EBP (2017) and the matrices for travel times between the NPVM zones by car as well by public transport. The NPVM zones are designed on the premise of an underlying gravity model approach for destination choice. Therefore, the NPVM zone structure represents the spatial resolution of this analysis. In contrast to, say, US census tract or administrative units (i.e. municipalities), they are purposely delineated for traffic analysis and are designed to contain a relatively stable population.

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[8] The Poisson-GLM method has three key advantages. First, the method always provides nonnegative predictive values for service utilization. Second, no distributional assumption is necessary with respect to the outpatient volume of services; it is simply assumed that the conditional expected value corresponds to an exponential function. Third, the method provides an unbiased estimate of the unconditional mean because the model always includes a constant (von Rhein, Haldimann and Jörg (2023); Jörg and Haldimann (2022)).

[9] This is relevant due to the fact that cross-border commuters are required to be insured in Switzerland as well their non-working family members BAG (2023a).

[10] Due to a data protection agreement, no locations of pediatric practices are shown in this study on any map.

Using diverse input data (infrastructure networks such as railways and highways, highly frequented areas such as shopping centers, water boundaries, construction zones, and structural data of population and employees, as well as municipality borders), 7,978 zones were delineated (7,965 in Switzerland, 13 in Liechtenstein and 2 enclaves). For this study, only the 7,965 for Switzerland were considered, due to the availability of the demand data. Due to the above stated criteria for delineation, the zones vary in size considerably. Cities contain considerably more zones (Zurich 308, Basel 141, etc.) than municipalities in rural areas where there is sometimes one zone per municipality. Zones might appear very big in rural or mountainous areas, but in such cases the actual inhabited area is much smaller. To lessen this distorting effect, unproductive areas (data obtained from BFS) are subtracted from the total area for later cartographic visualization. The number of NPVM zones as well municipalities remain the same, hence only some of the geometries are changed.

The NPVM zone data includes attributes that allow for regional analysis such as the "Urban/Rural Typology 2012", municipality and canton. The Urban/Rural Typology classifies the NPVM zones into three categories (urban, intermediary, and rural), as seen in Fig 8. This typology was developed by the BFS (2017b). In addition to urban and rural categories, an "intermediate" type was therefore also defined, which exhibits both urban and rural characteristics. Thus, the "rural center municipalities" from the municipal typology were assigned to the urban/rural category of "intermediate", while the "low-density peri-urban municipalities" were assigned to the "rural" category. The urban/rural typology is derived from the municipal typology with nine categories (Tab 6).

Municipal Typology	Urban/Rural Typology
• Urban municipality in a large agglomeration • Urban municipality in a medium-sized agglomeration • Urban municipality in a small agglomeration or outside an agglomeration	Urban (16% of total area)
• Peri-urban municipality with high population density • Peri-urban municipality with moderate population density • Rural center municipality	Intermediate (21% of total area)
• Peri-urban municipality with low population density • Rural centrally located municipality • Rural peripheral municipality	Rural (63% of total area)

Tab 6: Area typology according to BFS (2017b); the left column is attributed to NPVM zones in delivered data.

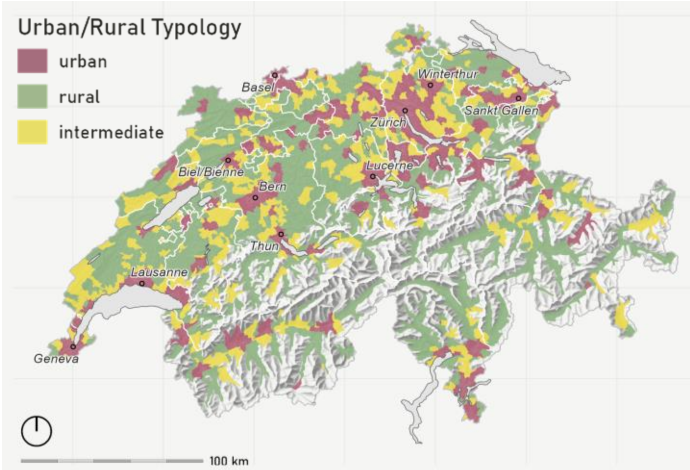

Fig 8: "Urban/Rural Typology 2012". Source: BFS (2023c)

Because the zone structure follows the borders of the Swiss municipalities, they are also attributed the corresponding municipality name and number. However this attribution stems from the year 2015 (EBP, 2017) and since then a significant number of municipalities have undergone mergers with neighboring municipalities. To ensure consistency throughout the analysis, the zones were reattributed with the municipality structure and geometries as of 2019 (data received from BFS). No municipalities have switched their cantonal affiliation.

The NPVM data also includes zone-centroids that correspond to the weighted population center within each zone using a synthetic population. Those centroids were then connected to the nearest node or stop in the relevant public transport network using a time/cost propagation function. Travel times between zones were calculated in VISUM using the road network in an uncongested state. The public transportation service is based on the infrastructure network of the Federal Office of Transport (FOT), the timetable system of the Swiss Federal Railways (SBB), and the HAFAS timetable for other public transportation. This includes, in addition to railways, the entire tram and bus network in Switzerland. The resulting travel times matrices encompass values from each zones' centroid to all other zones' centroids (approximately 64 million connections) and are symmetrical (ARE, 2017). The data is available publicly (VM-UVEK, 2019).

2.2.4 Geoprocessing of Demand, Supply, and NPVM zones

Demand: The data is available as point data, i.e. each hectare has its data attributed to the point location. This point is set to be at the lower left corner of each hectare. Although we do not know the true gravity point of the population within the hectare, it's likely that the center of each hectare is a better representation of it. Therefore, all raster points were moved north and east by 50m. This is done so that the later intersection with the NPVM zones is likelier to represent the true distribution of the population (see Fig 9).

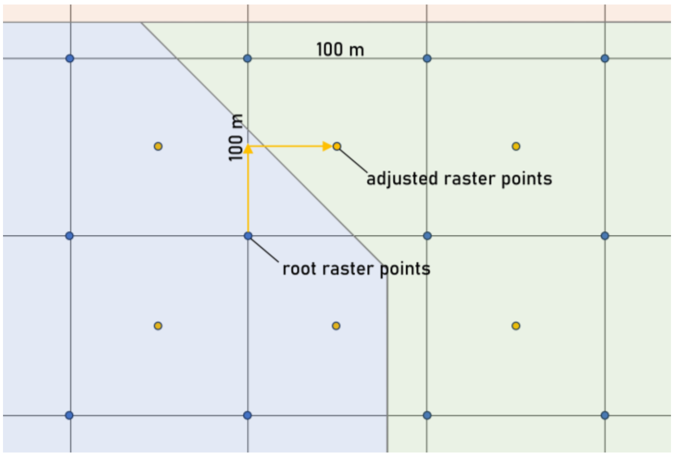

Fig 9: Raster root point adjustment and NPVM zones overlaid (schematic).

In the next step, each raster point is intersected with the shapefile containing the NPVM zones. Due to the root point adjustment, very few raster points (93) are now outside of any zone boundary. These data points are joined to the nearest NPVM zone. The 365,336 raster data points are now attributed with their zone ID. All demand data points are then grouped by zone ID and added up within each zone, resulting in 7,964 zones[11]. Fig 9 shows the adjusted need population per NPVM zone.

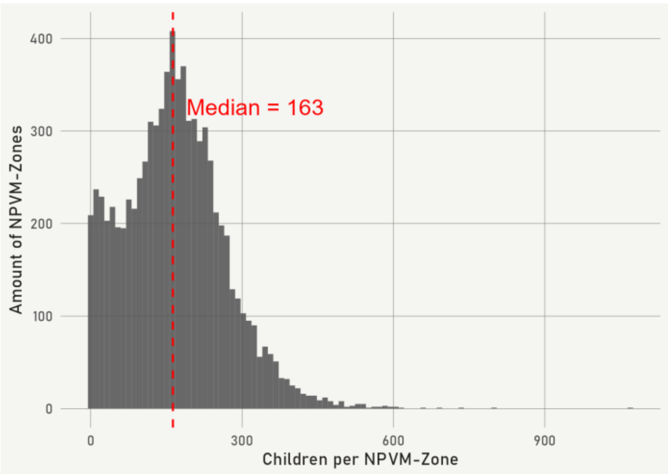

Fig 10: Distribution of children per NPVM zone.

Based on the design principle of the NPVM zone structure, each zone contains roughly the same amount of people. This refers to a synthetic population consisting of resident population and workers. Fig 11 shows the cumulative distribution of the adjusted demand population (relevant population for this study) across the NPVM zone using a Lorenz curve (Lorenz, 1905). The dashed diagonal line represents an absolute equal distribution, i.e. every zone contains the same amount of demanding inhabitants. The solid line represents the actual distribution. The Gini coefficient (Dodge, 2008) indicates the uniformity of the distribution: 0 stands for perfect uniform distribution (no difference area between dashed and solid line) and 1 for complete inequality (entire population in one zone).

Fig 11: Lorenz curve and Gini coefficient for the demand adjusted population

The FTE's per supply data point are intersected with the zone data in equal manner. Overall, the total 1,332 pediatric practices are spread out over 663 NPVM zones (see Fig 12). The maximum FTE's per zone is 9.5 and the minimum 0.1, with an average of 1.5 FTE's per zone with a supply.

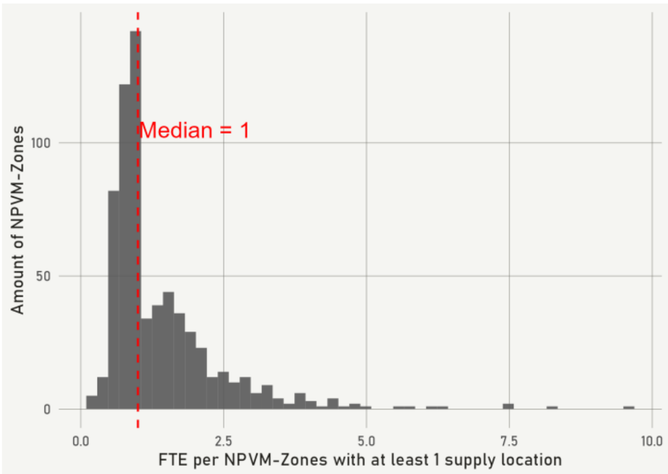

Fig 12: Distribution of FTE across zones with at least one pediatric practice.

[11] One NPVM zone had no hectare point within it (Papillorama-Noctu-rama, a recreational park). It was excluded from further analysis.

2.2.5 NPVM Distance Matrices

As mentioned before, the distances between the NPVM zones have been verified using Google (ARE, 2017). However, intrazonal travel (origin and destination within the same zone) are not of importance in the ARE traffic modeling software, as they are not modelled. However, for the case at hand they do matter. Although the travel time matrices are delivered (VM-UVEK, 2019) with diagonal values (intrazonal travel times), those are only approximations (the shortest travel time to the neighboring zones). For some zones, e.g. remote areas, the intrazonal travel times are therefore highly implausible. To alleviate this problem, all intrazonal travel times are set to 10 minutes. Similar to this data processing, the minimal travel times for between each zone is also set to 10 minutes. Setting these minima as well the intrazonal travel times to 10 minutes follows the rationale that every trip is associated with some amount of fixed costs i.e. getting ready, leaving the house etc. Moreover, taking the car for very short trips is not common in Switzerland, even if the trip would be slightly shorter. Thus 10 minutes is a reasonable choice for minimum trip length and trips within the same zone. This procedure is applied to both transport modes.

The next task at hand is to create a matrix that only holds entries for the origin–destination (OD) connections between demand and supply zones (7,964 x 663). This matrix will be used for the FCA calculations. The R code for the travel time manipulations and the generation of the OD-matrix can be found in Appendix B.1.

2.3 THE MHV3FCA Method

To calculate the spatial accessibility index (SPAI) the MHV3SFCA method is applied. It consists of three steps as Jörg and Haldimann (2023, pp. 4–5) write:

Step 1: The demand probability is calculated for each combination of population i and service provider location j. The demand probability $Huff_{ij}$ depends on the capacities of the service provider S_j and the distance $f(d_{ij})$ between population and service provider as well as alternative care offers (supply competition) within the relevant catchment area of population i (see the sum in the denominator):

$$Huff_{ij} = \frac{S_j f(d_{ij})}{\sum_{j \in \{d_{ij} \le d_i^{rel}\}} S_j f(d_{ij})} \; \boldsymbol{I}\left(d_{ij} \le d_i^{rel}\right)$$

I(.) is an indicator function that take on the value of 1 if the condition in parentheses is true, and 0 otherwise. To approximate realistic patient behavior, the relevant catchment area d_i^{rel} is calculated separately for each population i and depends on how many offers can be reached within the same distance, as well as the number of relevant supply offers Q.

$$d_i^{rel} = \min_{0 \le d_r \le d_{max}} \left\{ d_r \,\middle|\, \sum_j \boldsymbol{I}\left(d_{ij} \le d_r\right) \ge Q \right\}$$

Q represents the minimal number of supply sites j which are considered as relevant options for population i. The maximal relevant catchment size d_i^{rel} is derived by the minimum distance where the condition $\sum_j \boldsymbol{I}\left(d_{ij} \le d_r\right) \ge Q$ holds true. In other words, d_i^{rel} refers to the distance where the number of supply sites within a given distance radius d_r is greater than or equal to the predefined threshold Q[12]. The demand probability for all supply sites further away is zero, even when there are still more supply locations within d_{max}.

Step 2: Based upon the demand probabilities and $Huff_{ij}$ calculated in step 1, the supply ratio R_j is determined for each supply site j as follows:

$$R_j = \frac{S_j}{\sum_{i \in \{d_{ij} \le d_{max}\}} Huff_{ij} P_i}$$

The supply ratio R_j is given by the supply site capacity S_j divided by the sum of population demand P_i of all locations i within the maximum catchment size d_{max} multiplied by their probability $Huff_{ij}$ to seek service from supply j.

Step 3: The spatial accessibility index $SPAI_i$ is calculated for each population unit i as the sum of the supply ratios R_j of all sites j reachable for population i within the maximum catchment size d_{max}, multiplied by the respective huff probabilities $Huff_{ij}$ and distance weights as computed by the distance decay function $f(d_{ij})$:

$$SPAI_i = \sum_{j \in \{d_{ij} \le d_{max}\}} Huff_{ij} \, R_j \, f(d_{ij})$$

[12] Q is to be determined separately (see section 2.3.3 and Appendix A).

2.3.1 Distance Decay Function

As previously discussed, distance plays a crucial role when determining the likelihood of a person at point *i* demanding a service at location *j*. As argued, this relationship is not linear, hence a function $f(d_{ij})$ is used in FCA methods to convert the absolute distances d_{ij} into distance weights between 1 and 0. As discussed above, the most common function employed is the Gaussian function:

$$f(d) = e^{\left(\frac{-d^2}{\beta}\right)}$$

The friction coefficient β determines the extent of the function, representing the maximum catchment size. To ensure comparability of the results for RQ III, the maximum possible catchment size d_{max} is set to 60 minutes (see also literature review). Based on various studies (Bauer and Groneberg, 2016; Jörg, Lenz and Wetz, 2019; Kwan, 1998; Wang, 2007; Wang, 2014), the coefficient is then derived from the condition $d_{max} \cong 0.01$. This ensures that the distance weight at the maximum radius is close to zero. In this way, it is also ensured that all pediatric practices outside the maximum radius are considered unreachable and thus correspond to a distance weight of zero. Solving the above function for the condition $d_{max} \cong 0.01$ results in:

$$\beta = \frac{-60^2}{log(0.01)} = 731.73$$

Although the NPVM matrices would allow for a continuous OD distance pair, a combination of a step and continuous function is applied. The reason for this decision is that, up to a certain range, people are unlikely to discriminate based on the distance between them and the nearest services. This goes alongside the argument that some sort of fixed cost is attributed to every trip (see 2.2.5). This range is referred to as base catchment and is set at 10 minutes and is why all min. travel times were set to 10 minutes. Within the base catchment, other attracting factors such as facility capacity will gain more importance. Fig 13 shows how the distance weights are derived.

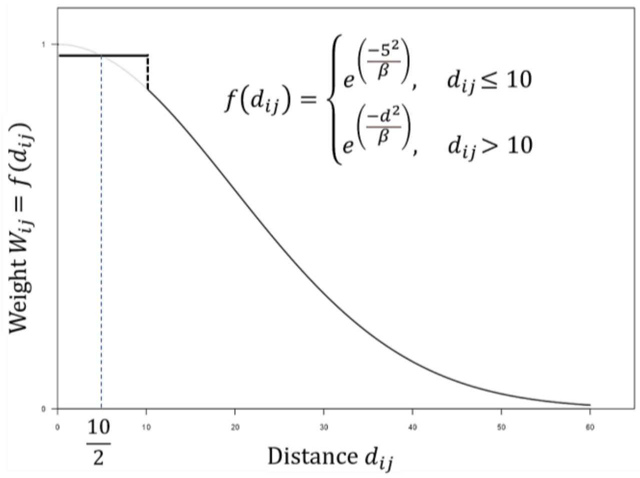

Fig 13: Distance Decay Function applied to calculate distance matrix.

2.3.2 Maximum Catchment Size

The maximum catchment size d_{max} is a global variable that holds true for the entire study area. It denotes a global travel time maximum up to which a population looks to fulfill its required *Q*. Optimally all populations within the study area reach the required *Q* before being "stopped" by the d_{max} condition. As discussed above, d_{max} holds much less importance than in other FCA methods that do not feature variable catchment sizes. Taken to the extreme, d_{max} could be relaxed to the point where all populations fulfill the *Q* requirement. However, this would—especially in rural area with few supply locations—lead to unrealistically large catchments, and therefore diffusely spread demand across an unreasonably large area. The main purpose of the d_{max} condition is to prevent this. Optimally the maximum catchment is set to a value that allows each population access to at least one supply location. Setting $d_{max} = 60\ min$ leaves 57 out of the 8,964 populations (NPVM zones) without access to at least one pediatric practice. Those 57 populations are located in the easternmost parts of Switzerland, such as the Engadin Valley, Val Poschiavo, Val Bregaglia and Val Mustair. These relatively remote areas are cut off from the rest of Switzerland by a mountain chain, and are only accessible over mountain passes or railway car transporters through a tunnel. The inhabitants of said areas are not left without primary pediatric care, rather the provision is organized differently (Spital Oberengadin, 2023). Instead of private residences, pediatric practices are integrated in the local hospitals, which explains why these practices are not included in the supply data. Under those circumstances $d_{max} = 60\ min$ remains a sensible choice, but the results for these areas must be interpreted cautiously.

2.3.3 Relevant Catchment Sizes

The benefit of the MHV3SFCA method is that every population (hectare or, here, NPVM zones) has its own custom catchment size. More specifically, the catchment size d_i^{rel} is determined by the required *Q*.

The OBSAN-approach assumes perfect customer rationality and set $Q = 1$. As reported above, they choose this specific *Q* also for practicality reasons. The NPVM-approach used here differentiates from the OBSAN-approach in two aspects of how patients' demand is distributed among the suppliers. The first is the difference of the spatial resolution. NPVM zones are bigger and therefore may contain many more children than mere hectares. Given $Q = 1$, in some situations the entire population is sent to only 1 practice, which can in turn have a strong effect on the SPAI. In reality this behavior is rather unlikely. In contrast, on the hectare level, patients' travel time is different (actual or computational differences) for each raster point and we get a smoother distribution of the demand across different supply sites.[13] The second aspect is with regards to the difference in travel time resolution. Meanwhile, in a continuous distance implementation, two or more supply locations are unlikely to have the exact same travel time to a population. The population would therefore only travel exactly as much as necessary to reach the closest supply point, regardless of whether another option is just one minute further away and regardless of the availability at the first supply point. Although no research is available, such patient behavior is arguably unrealistic. To the contrary, it can be argued that patients consider n supply sites, so that they have access to adequate healthcare. Choosing the adequate number for Q depends on the distances used, research area, and researched facility type. An analysis has been performed for the research topic and determined that a Q of 6 is adequate. The full analysis can be found in Appendix.

2.4 The SDI

The Supply Density Index (SDI) as introduced by Jörg and Haldimann (2022, p. 19) can be used as an additional measure to the SPAI. The SDI can be interpreted directly as a ratio between the capacities of the service providers and the number of persons in the demand population, analogously to demand/supply ratios. The SDI thus expresses the number of full-time equivalents per 1,000 persons. However, unlike PPRs, the SDI takes into account interdependencies between regions using the Huff model. The supply density index (SDI) can be calculated as follows:

$$SDI_i = \sum_{j \in \{d_{ij} \le d_{max}\}} Huff_{ij} \ R_j \ 1000$$

With the exception of the third step, the SDI is calculated in the same way as the SPAI, except that the SDI ignores distances in the third calculation step. Specifically, the SDI is the sum of the supply/demand ratios R_j of all service provider locations weighted by the respective demand probability $Huff_{ij}$. To express FTE's per 1,000 demand population, a multiplier is applied.

2.5 Implementation in R

The starting point was the implementation of the MH3SFCA method (Jörg, Lenz and Wetz, 2019) in the R package "fca" by Grüebler, Unterfinger and Jörg (2021). The code was adapted to correspond to the MHV3SFC method. First, a function defining the relevant catchment sizes was implemented, which are then calculated given the origin–destination matrix, Q, base catchment size, and the search increment. This increment, default 1 minute, can be set arbitrarily to a smaller or larger value without substantially affecting the runtime performance. Setting search increments to steps of 1 minute were chosen so as to mitigate, although not entirely alleviate, the problem that if another supply location is just 10 seconds further way, it would be ignored if Q is already met. This also corresponds with the idea that Q is seen as a minimum, not an exact requirement. Another function, using the origin–destination (OD) matrix and the relevant catchment sizes, creates a binary matrix that indicates whether a certain supply location is reachable by the specific population. The distance weights are calculated according to Fig 4 using the distance function from the FCA R Package. The weight matrix together with the indicator matrix are then used in the adapted FCA function to calculate the SPAI and SDI. The relevant functions and calls can be found in appendix B.

The implementation of the MHV3SFCA method in R has been evaluated using the simulation systems as described in Jörg and Haldimann (2023) and has been found to deliver equal results. It was also investigated whether any supply locations faced no demand at all. This condition does not apply to any of the supply points. Lastly, because the NPVM matrices are in fact an approximation for intrazonal travel times, it was checked whether any populations demand purely intrazonal (OD pair in same NPVM zone), which could potentially be problematic. Naturally, this depends on the selection of Q. With the selected Q, no populations rely entirely on a supply location within the same NPVM zone. For further details, see Q analysis in in Appendix A

All results including maps and graphs were computed in R (version 4.2.2 2022-10-31 ucrt) using RStudio (RStudio 2022.12.0+353 "Elsbeth Geranium" Release: 2022-12-03). Data handling was accomplished using the "tidyverse" package (version 1.3.2). For spatial operations the "sf" package (versions 1.0-9) was used. For plotting package "ggplot2" (version 3.4.1) was utilized together with spe-

[13] Based on personal correspondence with R. Jörg, although hectare data points are fairly close to one another, they may in some circumstances be connected to the routing network in unexpected ways, resulting in different travel times.

cific extensions choropleth maps such as "ggspatial" (version 0.1.4) "ggrepel" (version 0.9.3) for labels, while "gghalves" (version 0.1.4) was used for creating more informative boxplots. Colors for the choropleth maps and graphics depicting SPAI values are based on the "viridris" package (version 0.6.2). The colors for maps and graphics regarding the SDI are based on the idea of a diverting color scale with an optimum in between both ends of the scale. The colors were picked manually according to this design principle. A complete list of R packages used can be found in appendix B.

2.6 Interpretation of SPAI and SDI

Unlike the SDI, the SPAI values of the MHV3SFCA method are dimensionless, but thanks to the methodological advancements of the MHV3SFCA method, the calculated measures can be compared across the entire regions and also between different study regions. In general, however, it can always be assumed that the SPAI will be higher (Jörg, Lenz and Wetz, 2019, p. 25) if:

1) demand at a location is lower;
2) more health services are available;
3) their capacities are greater; and
4) services are closer or more accessible in spatial terms.

The most relevant result produced will be maps that convey the results in an easily understandable and interpretable way. To allow adequate interpretation, the reader must be able to determine which values signify good or bad spatial accessibility. Frequently (Dai, 2010; Dai and Wang, 2011; Grüebler, 2021; Jörg and Haldimann, 2022; Jörg and Haldimann, 2023; Jörg, Lenz and Wetz, 2019; Lenz *et al.*, 2020; Luo, 2014, 2016; Luo and Qi, 2009; Luo and Wang, 2003; Tao *et al.*, 2018), the SPAI values are segmented into categories according to their value distribution (such as quintiles or terciles, representing low, medium, and high ranges). Subsequently, the evaluation of the SPAI values is predominantly conducted within a relative context (for instance, comparing accessibility across different regions). Quantiles are calculated with ease and are easy to read and interpret. Furthermore, they are not prone to the influence of outliers. Akin to von Rhein, Haldimann and Jörg (2023) and other previous applications of the MH(V)3SFCA, the results will also be mapped used quintiles (five categories, each containing 20% of the traffic zones) The first quintile (bottom 20%) have the worst SA, whereas the fifth quintile has the best SA. Other classifications, such as equal interval or Jenks natural breaks, can also be suitable.

As the SDI has a dimension (FTS's per 1,000 inhabitants) it is suitable to guide visualization on reference values. As discussed above, the FMH recommends 1 primary care pediatrician FTE per 1,000 inhabitants. Around this value band of ±20% is accounted to be in the same category. As the severity of potential under provision is of higher interest, three categories show values below the recommended optimum (spectrum), and one category shows areas with a higher than optimal supply density. This procedure is similar to the scale chosen in Jörg and Haldimann (2022).

While it is possible to express the accessibility index as well as the service density index at the level of administrative regions (municipalities, cantons, etc.), they are nevertheless consistently based on calculations conducted at a finer spatial resolution (NPVM zones or hectares), meaning that they still ignore administrative boundaries for the SPAI and SDI calculations. The code for the aggregation can be found in Appendix B.

2.7 Multimodal Accessibility

The approach to account for multimodality as outlined in RQ II involves incorporating the NPVM travel time matrix for public transport. Under the presumption of perfect rationality, inhabitants choose whichever means of transport is fastest, given the origin and destination location. To achieve this, the travel times between each zone and all other zones are compared between the two distance matrices, picking the minimum travel time for each connection, resulting in a new matrix containing the fastest possible travel times. This matrix is then used to perform the MHV3SFCA analysis using the same parameters ($Q = 6$, $d_{max} = 60\ min$), besides visualizing the SPAI-values it is analyzed how catchment sizes are affected, as well as differences in the amounts of pediatric practices reached (R code in Appendix B). Lastly, a map is produced that shows where spatial accessibility changed notably (10%) when public transport is taken into account.

2.8 Comparative Analysis of OBSAN and NPVM Approaches

To address RQ III, the results of this thesis are compared to the SPAI values from von Rhein, Haldimann and Jörg (2023) also employing the MHV3SFCA method, but with the same methodology as in Jörg and Haldimann (2022), called the OBSAN approach (hectare level resolution, purpose-specific calculated distance matrices using distance subzones, $Q = 1$, $d_{max} = 60\ min$). Because their SPAI values are calculated for each hectare raster point, results must be aggregated to a spatial resolution that allows for comparison. To do so, the hectare results are aggregated to NPVM zones as well as municipalities by a weighted population of children under 15 + overnight stays of children under 15 years (hereinafter: "relevant population"). After the aggregation of the SPAI values, the aggregated spatial units are again divided into quintiles.

The R code for aggregation functions is found in Appendix B. Maps visualizing the SPAI values using quintiles for both methodological approaches allow for a first assessment. Furthermore, scatterplots will be used to plot the two SPAI value sets against each other for a visual analysis and the identification of potential outliers.

A quantitative comparison is also made using Pearson's r coefficient testing for linear correlation, which is widely used for the comparison of results from different FCA methods (Jörg, Lenz and Wetz, 2019) and accessibility measures, including different distance measurements (Apparicio *et al.*, 2008; Apparicio *et al.*, 2017). The Pearson correlation coefficient (r) is the most common way of measuring a linear correlation and is expressed as a number between −1 and 1, indicating the strength and direction of the relationship between two variables.

The Pearson correlation test requires a normal distribution of the variables compared. Evaluating the normality of data is a fundamental step, as the assumption of data normality is a key requirement for parametric testing, including Pearson's r. There are essentially two ways to assess normality: visual examination and numerical evaluation, including the application of statistical tests (Bland, 2015; Campbell, Machin and Walters, 2007). Statistical tests offer the benefit of an impartial determination of normality; however, they may exhibit drawbacks such as reduced sensitivity with small sample sizes or excessive sensitivity with large sample sizes. Visual interpretation, on the other hand, allows for a more subjective assessment of normality, especially in cases where numerical tests might prove overly or insufficiently sensitive. Both approaches will be considered, visually by using histograms and Q-Q plots, as well numerically by employing the Kolmogorov-Smirnov test. The Kolmogorov-Smirnov test is typically applied when the sample size (n) is greater than or equal to 50. The null hypothesis states that the data is drawn from a population that follows a normal distribution. If the p value (P) exceeds 0.05, the null hypothesis is accepted, indicating that the data can be considered as emanating from a normally distributed population. In case of non-normality of the distribution due to skewedness, the Pearson's correlation is also shown without outliers. As Altman and Bland (1995) as well Ghasemi and Zahediasl (2012) state, the violation of the normality condition is not a major issue for samples with more than 100 observations.

Because the comparison of the mapped SPAI values divided into quintiles is rank-based, a Spearman's Rho test is also performed. The advantage of the Spearman correlation is that a normal distribution is not a prerequisite for the test. The test states the following hypothesis: $H0$: $rho = 0$. There is no correlation between the ranked pairs. $H1$: rho $<>$ 0. The ranked pairs are correlated. The rho values indicate the strength of the correlation and its direction ($1 > rho > -1$)

3 Results

This section presents the results generated by the approach described above, and shows a comprehensive analysis of the data collected on the potential spatial accessibility to pediatric practices in Switzerland. The outcomes are presented in the order of the research questions. The main contribution to the result section are the choropleth maps revealing the distribution SPAI and SDI across Switzerland accompanied by complementary graphs and statistics.

3.1 Spatial Accessibility to Pediatricians in Switzerland

First, spatial accessibility results (SPAI values) are presented at two different levels of spatial resolution. Fig 14 shows the SPAI's at the NPVM zone level at which they were also calculated using the MHV3SFCA method specified, while Fig 15 shows the SPAI's aggregated to the municipal level. The SPAI's are depicted using quintiles, where bright orange represents the 20% of the spatial units (NPVM zones or municipalities) with the lowest spatial accessibility (SA). The highest quintile is shown in dark magenta. An overview map of Switzerland and table explaining cantonal abbreviations can be found in Appendix C.Fig 14 shows that areas with high SA are relatively concentrated in areas around the biggest cities. Noteworthy points are the relatively higher SA in most of the French-speaking parts of Switzerland, especially between Lake Geneva and Lake Neuchâtel; as well as the difference in SA between the French- and German-speaking parts of the canton of Valais.

NPVM zone level: Apart from a cluster of high SA around the cities of Bern and Burgdorf, the canton of Bern shows poor SA, especially in mountainous areas. A low SA area which is especially apparent shows up on at the border of the canton of Lucerne and Bern (Entlebuch and the Napf area). Low SA is seen in large areas of the German-speaking part of the Swiss Plateau (Mittelland), with an SA in the lowest two quintiles (Lucerne, Solothurn, Argovia, Schaffhausen), contrary to the metropolitan areas around Zurich—including Winterthur and around Basel—which show a high SA. Furthermore, in the Italian-speaking part of Switzerland (Ticino), the more urban areas around Locarno, Lugano, and Mendrisio show a good SA. Finally, in mountainous areas there is a disparity between the east and west, particularly in central-eastern alps spatial accessibility levels in the upper quintiles, including regions such as Schwyz, Glarus, and Grisons. Western parts of the alps are notably lower including regions in the Cantons of Vaud, Bern and the upper Valais.

Municipal level: The map showing aggregated SPAI values in Fig 15 presents a very similar situation to the one described above. Of particular note is the observation that regions characterized by high to very high Spatial Accessibility (SA) values appear to be of larger extent. This phenomenon is primarily attributable to the presence of urban centers which typically feature a high number of NPVM zones: Zurich, for example, has 308 NPVM zones but constitutes a single municipality, and many of its zones have a high SA (4^{th} or 5^{th} quintile). Consequently, during the aggregation process, the number of zones in such areas drops significantly, in contrast to zones with lower SA, which tend to encompass larger geographic areas, frequently entire municipalities. As a result, the aggregation creates the impression that a larger geographic area features high SA values.

Median *(Mean)*	SPAI	SDI (FTE's/1,000 pop)	Catchment sizes (mins)	Supplies reached (FTE's)
Overall	**0.0003822** ***(0.0004162)***	**0.6494** ***(0.7108)***	**21.00** ***(23.02)***	**6.000** ***(6.574)***
Rural	0.0003121 *(0.0003259)*	0.6276 *(0.6575)*	29.00 *(32.39)*	6.000 *(6.226)*
Intermediate	0.0003822 *(0.0004162)*	0.6118 *(0.6630)*	24.00 *(25.76)*	6.000 *(6.515)*
Urban	0.0005482 *(0.0006275)*	0.6667 *(0.7516)*	16 *(18)*	6.000 *(6.744)*

Tab 7: Summary statistics of MHV3FCSA method measuring SA to private pediatric practices; median and mean given for overall area and per area typology

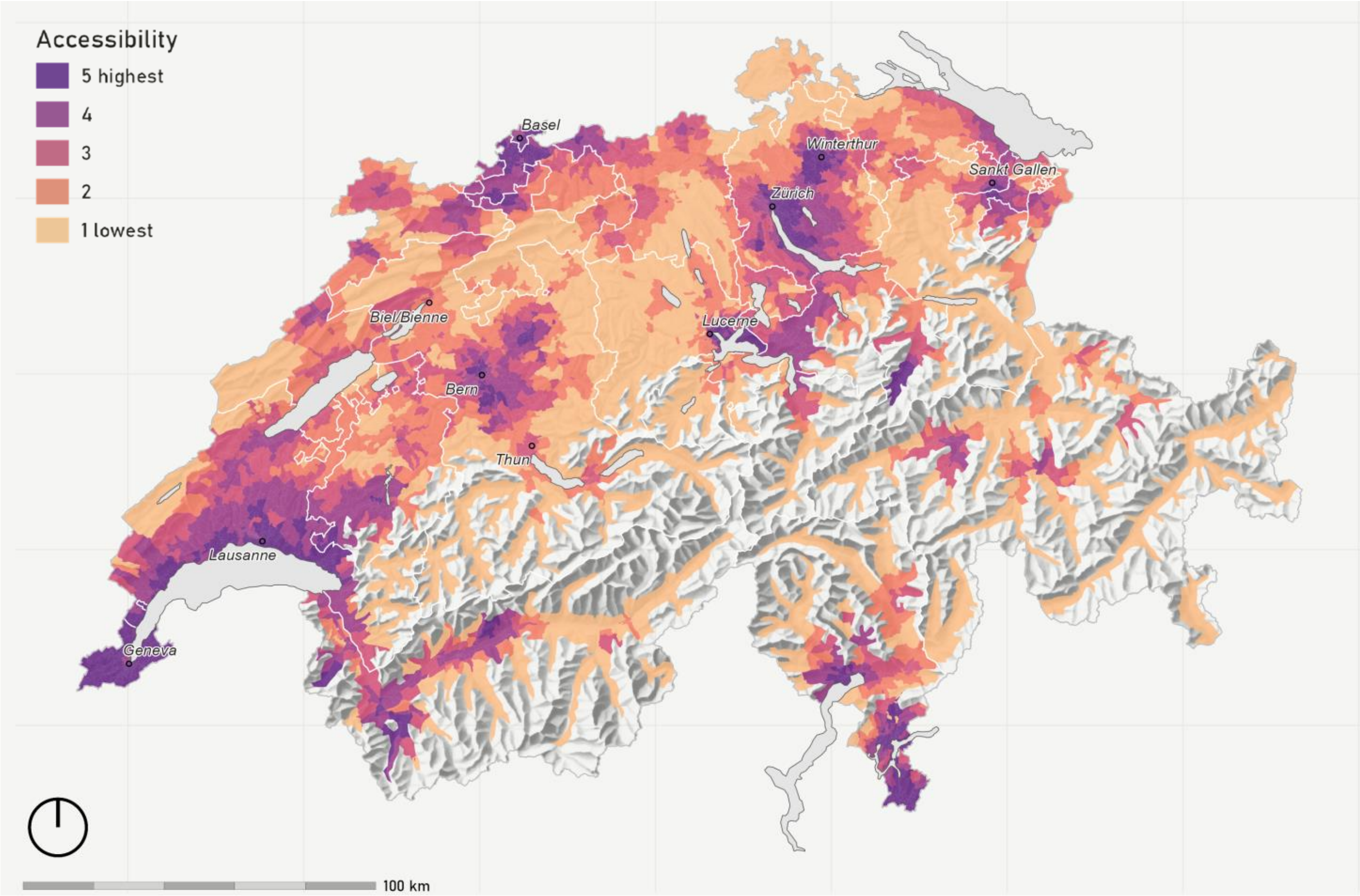

Fig 14: Spatial accessibility to pediatric practices by NPVM zones in quintiles.

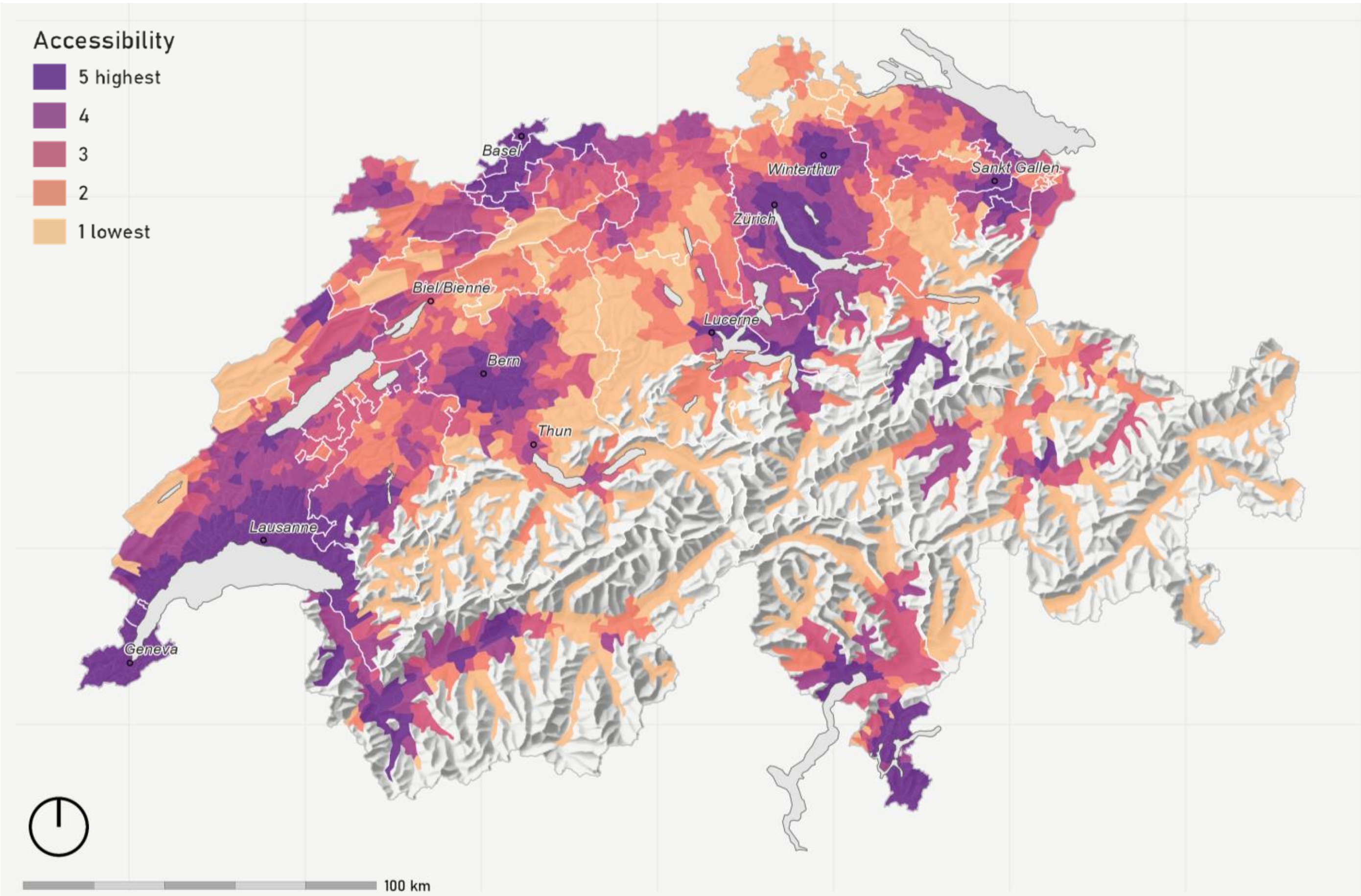

Fig 15: Spatial accessibility to pediatric practices by municipalities in quintiles.

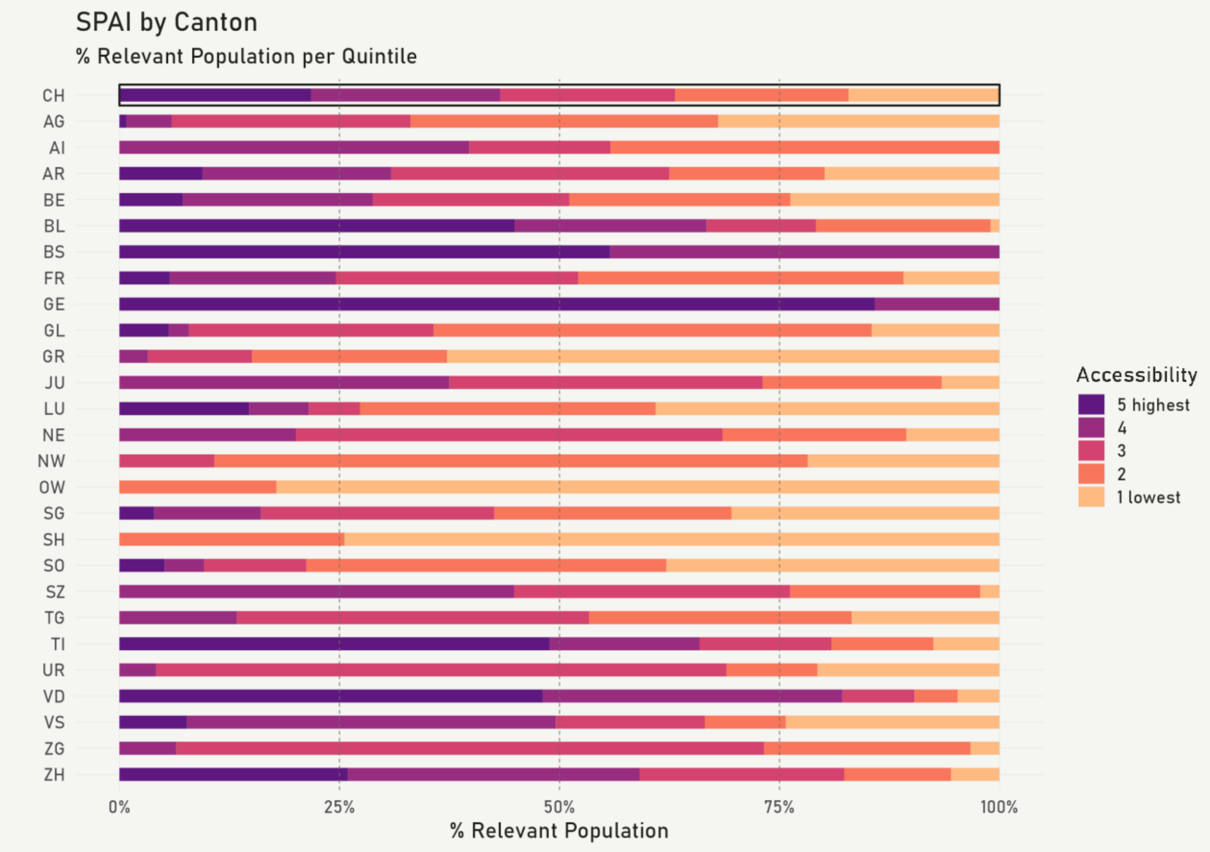

Fig 16: Accessibility to pediatric practices per canton and quintile, where the X axis represents % of relevant population per canton. Reading Aid: In the canton of Zurich, approx. 26% of the relevant population (resident + overnight stays) live in areas with the highest (top 20%) SPAI values.

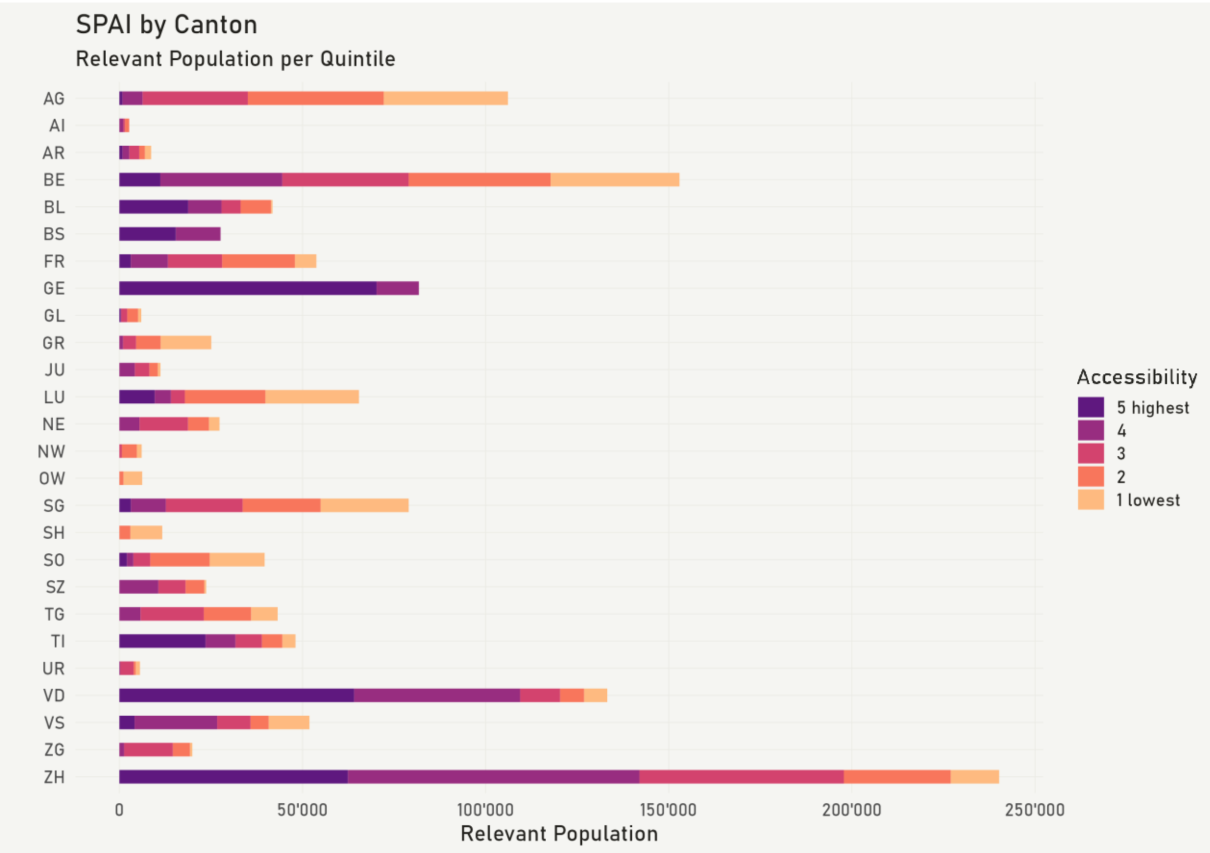

Fig 17: Accessibility to pediatric practices per canton and quintile, where the X axis represents the absolute relevant population. Reading Aid: In the canton of Zurich (ZH), approx. 60,000 children (resident + overnight stays) live in areas that have the highest (top 20%) SPAI values.

Because spatial accessibility is ultimately measured for populations and not primarily for an area of land, the results are also presented in a form that complements such assessment. Fig 16 & Fig 17 show the SA to pediatric practices by percentage, with the absolute population within NPVM zones divided into quintiles. These quintiles are based on NPVM zones (same division as in Fig 15, with the bar length weighted by the population (percentage) per zone per quintile). The top row in Fig 16 shows again that the population is distributed relatively evenly between all NPVM zones as each quintile takes up roughly 20%. The Distribution of spatial accessibility varies from canton to canton relatively widely. Again the same tendencies as described above are also notable here.

Fig 18 shows the distribution of SPAI values according to rural/urban typology in box- and jitterplots. While areas classified as "intermediate" show a slightly higher SA than "rural" areas, the biggest differences are found in areas classified as "urban". The median is notably higher, as is the spread with some outliers reaching SPAI values 8 times larger than the median. Fig 19 further highlights the differences in SA by investigating differences in relevant catchment sizes. Populations in NPVM zones classified as "rural" as well "intermediate" have substantially larger relevant catchments sizes. While the relevant population of approx. 10% of the "urban" zones reach 6 or more pediatricians within reach of 10 minutes, no zones classified as "intermediate" or "rural" have relevant catchment sizes this small. Interestingly, more than 70% of "urban" zones have relevant catchment sizes smaller than 20 minutes and almost no zones reach the global maximum of 6 minutes. Compared to that approx. 5% of "rural" zones have relevant catchment sizes less than 20 minutes and ca. 7% of "rural" zones reach catchment sizes of 60%. For summary statistics regarding the rural/urban typology and key measures, see also Tab 7.

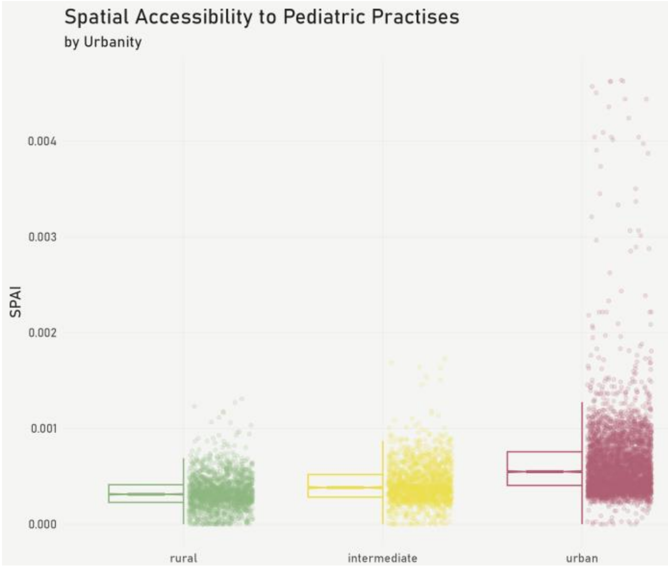

Fig 18: Spread of SPAI values by urbanity.

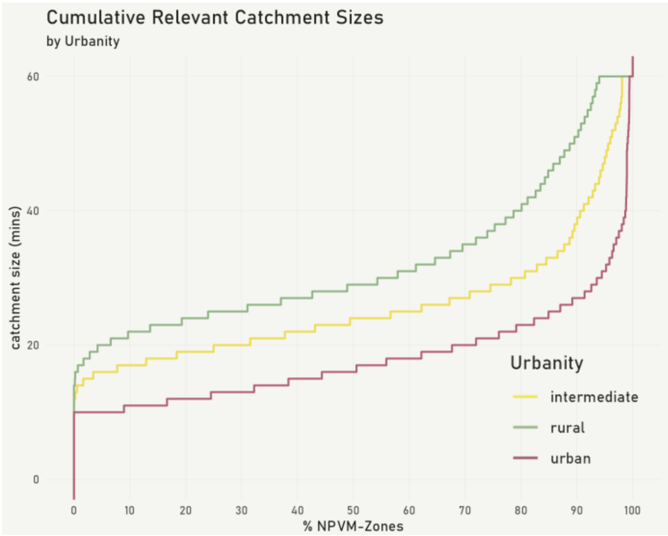

Fig 19: Cumulative catchment sizes by urbanity.

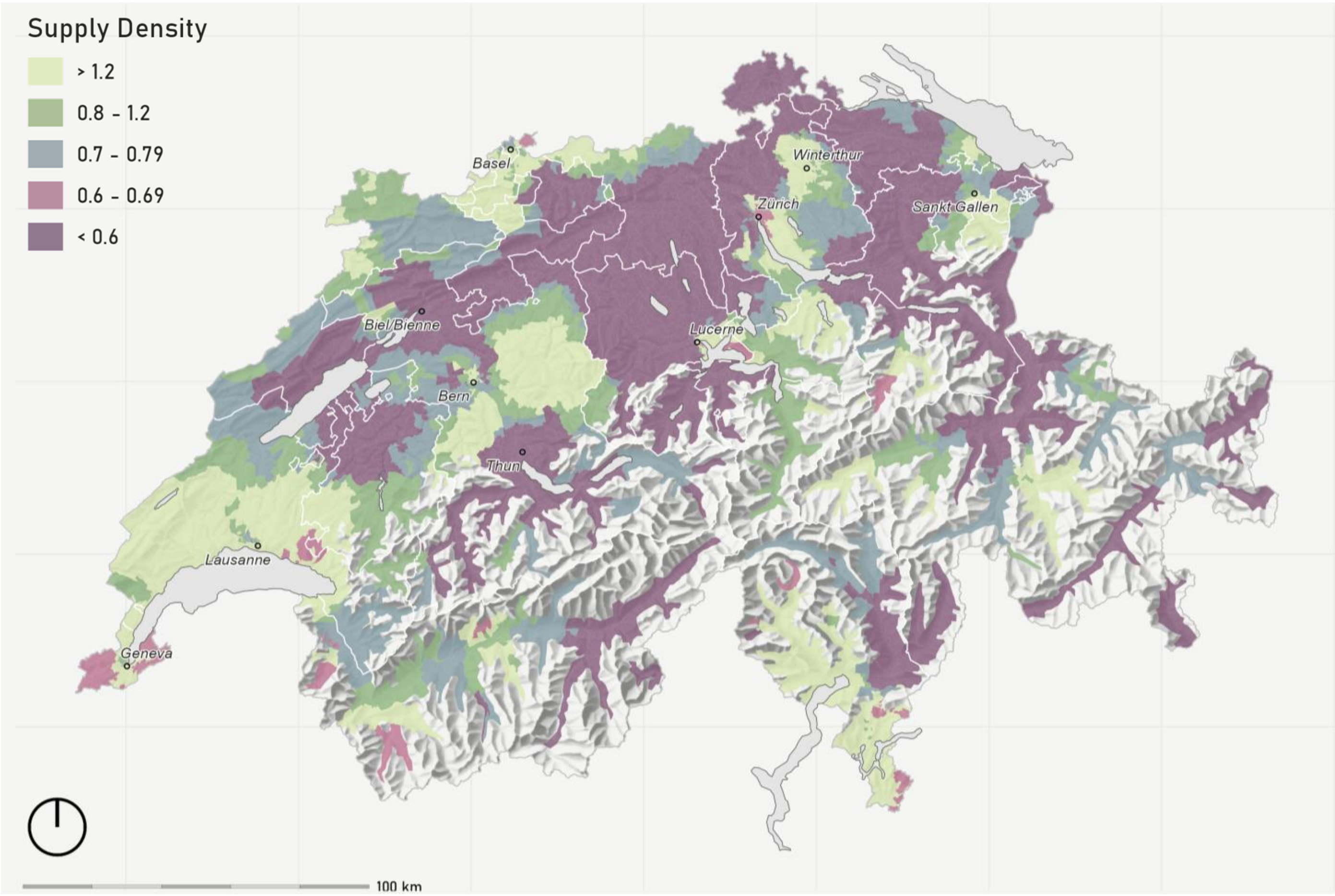

Fig 20: Supply density in FTE/1,000 population by NPVM zones in categories. (source: author)

In contrast to the SPAI, the Supply Density Index (SDI) can be directly read as fulltime equivalents (FTE's) per 1,000 demanding population. Fig 20 depicts the calculated SDI values per NPVM zone categorized in to 5 groups. The green category (0.8–1.2) represents the recommended supply density of 1 FTE per 1,000 with a bandwidth of ± 0.2 FTE's. Overall only about 12% of the relevant population lives in areas with the recommended supply density (see Fig 21), but a bit over 25% lives in areas with a supply density above the recommendation. The median SDI overall is 0.65 FTE's per 1,000 inhabitants, as reflected by the fact that over 40% of all the relevant population has an SDI under 0.6 (Fig 21).

Looking at the SDI spatial distribution (Fig 20) as well the distribution by canton in Fig 21 and Fig 22, disparities in supply density become apparent. Large areas of Switzerland, as well large parts of the population, fall into the extreme categories i.e. they exhibit either a very high or a very low SDI. Spatially, on a large scale, patterns similar to the mapped SPAI values emerge (Fig 14). Francophone parts of Switzerland tend to have high to very high SDI values, except for some areas of the cantons of Fribourg and Neuchâtel. Large parts of the Swiss Plateau feature SDI values below 0.6 FTE's per 1,000 population. Notable exceptions are areas around Bern, Lucerne, Zurich, Winterthur, and St. Gallen. Interestingly, large parts of the city of Zurich have a relatively low SDI (0.6–0.69), which can also be seen around Basel.

A noteworthy observation is that some areas within the highest SDI class directly border with areas that are within the lowest or second lowest SDI class. Examples of such occurrences are in Geneva, the border between the cantons of Bern and Lucerne, around Winterthur, and in the canton of Ticino (discussed further in the next section). Rather interestingly, some otherwise relatively remote alpine valleys feature high SDI values, especially in the canton of Graubünden, but also in the Bernese highlands, in the cantons of Ticino and Vaud.

As the calculation of the SDI does not consider the absolute distances between origin of demand and supply location, a connection to the SPAI map can be made by looking at the relevant catchment sizes (see Fig 23). Important here is that even though 5 supply sites can be reached within 20 minutes, the 6^{th} supply site could be as far away as 60 minutes or possibly more and hence result in a relevant catchment size of 60 minutes.

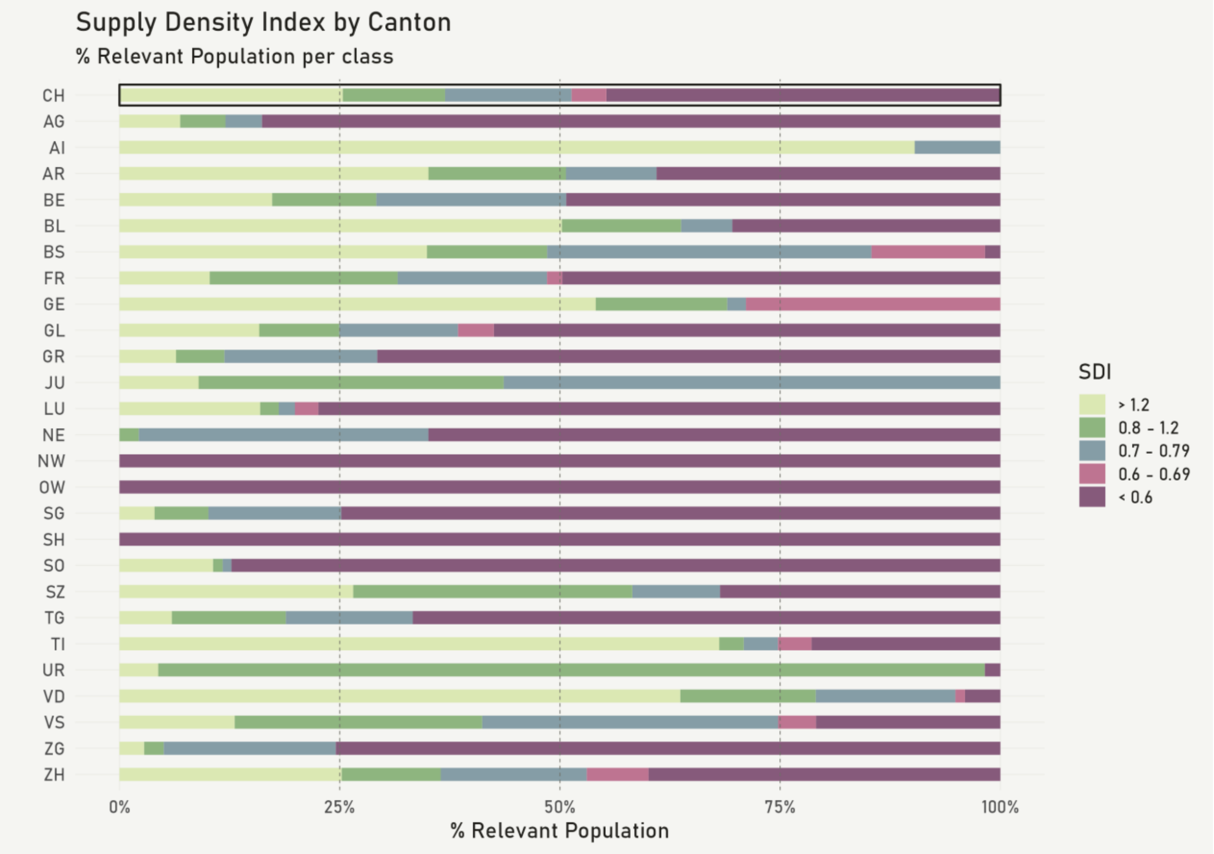

Fig 21: Supply densities in FTE/1,000 population per canton, the X axis represents the absolute relevant population.

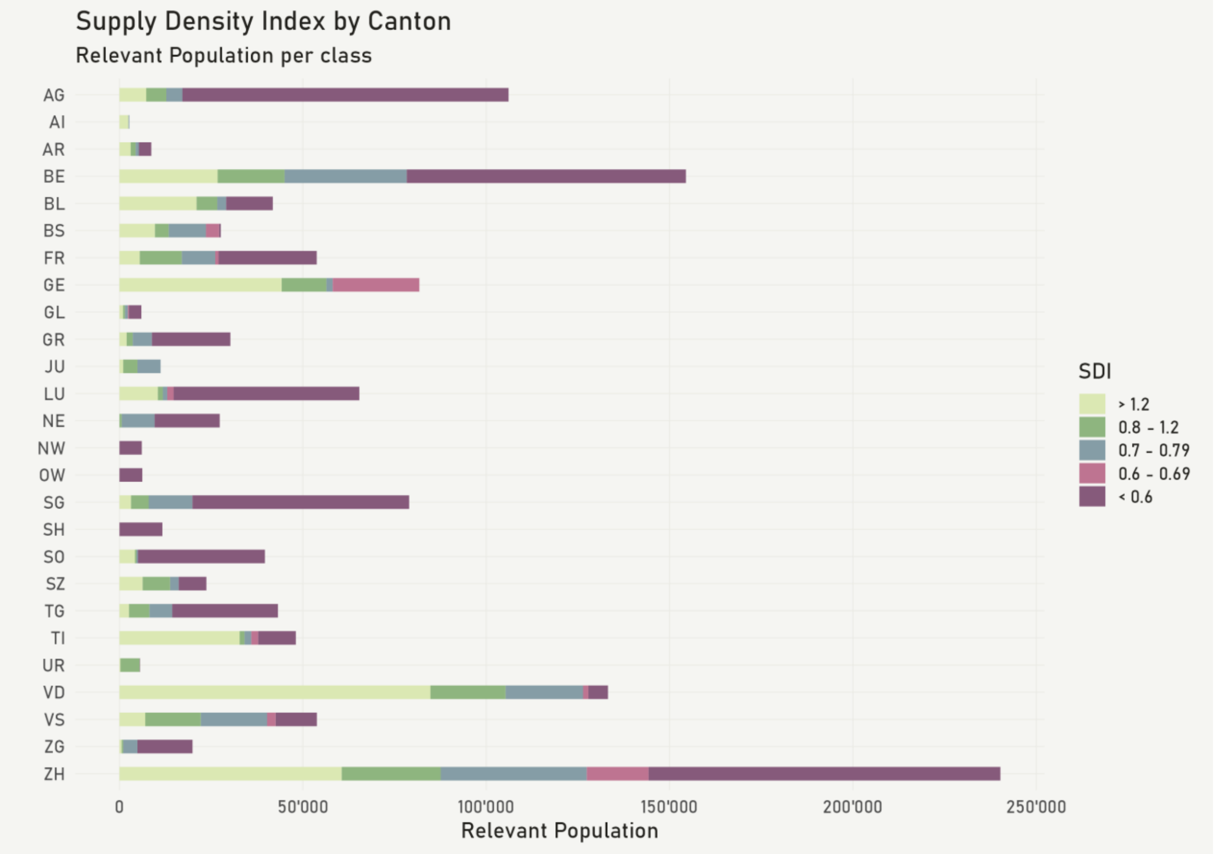

Fig 22: Supply densities in FTE/1,000 population per canton, the X axis represents the absolute relevant population.

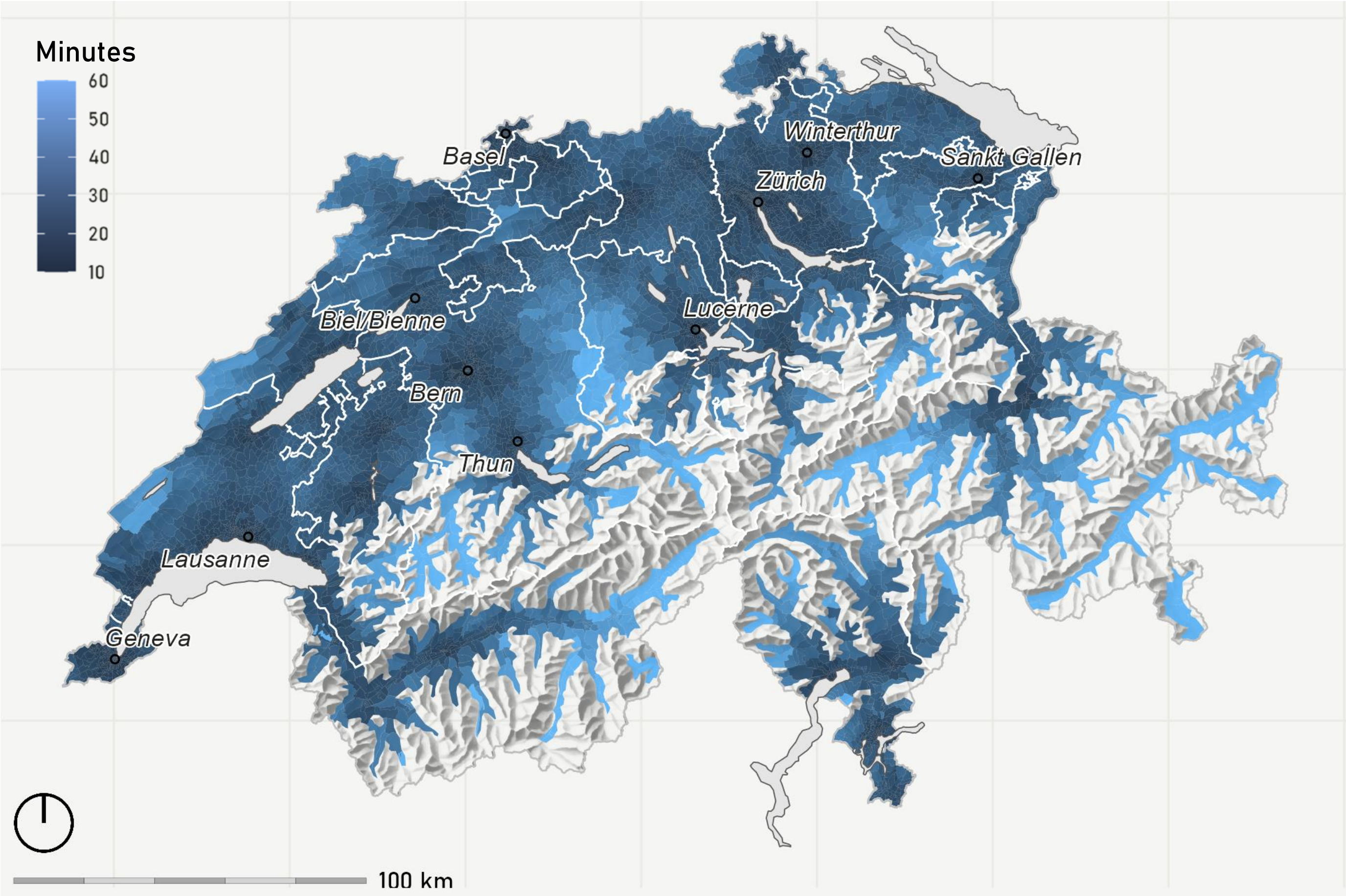

Fig 23: Relevant catchment sizes in minutes per NPVM zones. Catchment sizes are calculated based on the requirement of reaching a minimum of 6 supply locations or a maximum of 60 minutes.

3.2 Multimodal Accessibility

This section describes the results for the approach that considers not only transportation by car but also travel by public transport, including railways and busses. SPAI values are calculated on the premise that patients (incl. caretakers) always opt for the mode providing the fastest travel time between A and B.

The general distribution overall does not change drastically when public transportation is taken into account as an alternative travel mode (see Fig 24 and Fig 26). The density scatterplot in Fig 26 shows a 45° line, meaning that most zones' SA is not affected, while the rectangle marked in Fig 26 shows an outlier group. Their SPAI values are much lower in the model that considers public transport. This group of outliers is located in the inner most part of the city of Zurich, as shown in Fig 27. Even with an overall very similar measure in SA, on a local and in a few cases regional scale, SA can be notably influenced positively or negatively as shown in Fig 25. Most strikingly, areas around the cities of Bern, Lucerne, Zurich, Winterthur, and St. Gallen experience the most frequent changes in SA. Those areas feature a common pattern, in which the center of the cities have now at least a 10% lower SPAI value compared to when only individual transport is considered, while the surrounding (sub)urban areas experience an increase. This goes together with a reduction in the average size of the relevant catchments from 23.02 to 22.63 minutes. Specifically, zones classed as "urban" and "intermediate" experience a reduction (18 to 17.41 or 25.76 to 25.51 minutes, respectively). For "intermediate" zones as well, the median is reduced by 1 minute from 24 to 23 minutes (see also Fig 28). Fig 29 depicts the cumulative distribution of the relevant catchment sizes of both versions. With the option for public transport, more NPVM zones have relevant catchments below 20 minutes. Between 20 and 30 minutes this advantage starts to disappear and there is almost no difference anymore for larger catchment sizes.

Median *(Mean)*	SPAI	Catchment sizes (mins)
Overall	**0.0004529** ***(0.0005070)***	**21.00** ***(22.63)***
Rural	0.0003162 *(0.0003314)*	29.00 *(32.34)*
Intermediate	0.0003940 *(0.0004273)*	23.00 *(25.51)*
Urban	0.0005654 *(0.0006118)*	16.00 *(17.41)*

Tab 8: Summary statistics of MHV3FCSA method measuring SA to private pediatric practices with public transport as alternative travel mode, with median and mean given for overall area and per area typology.

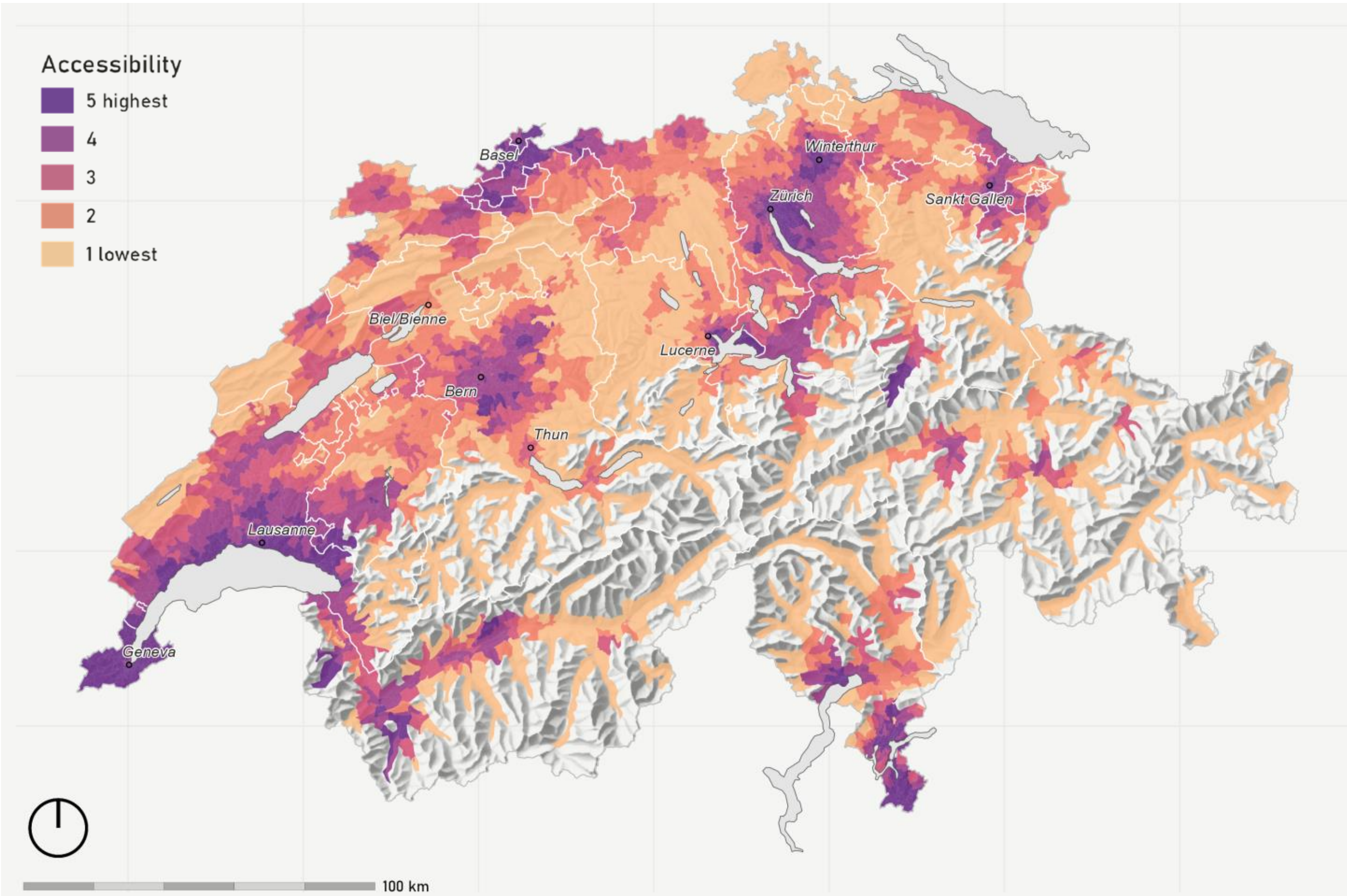

Fig 24: Spatial accessibility to pediatric practices by NPVM zones in quintiles, multi-mode approach including public transport.

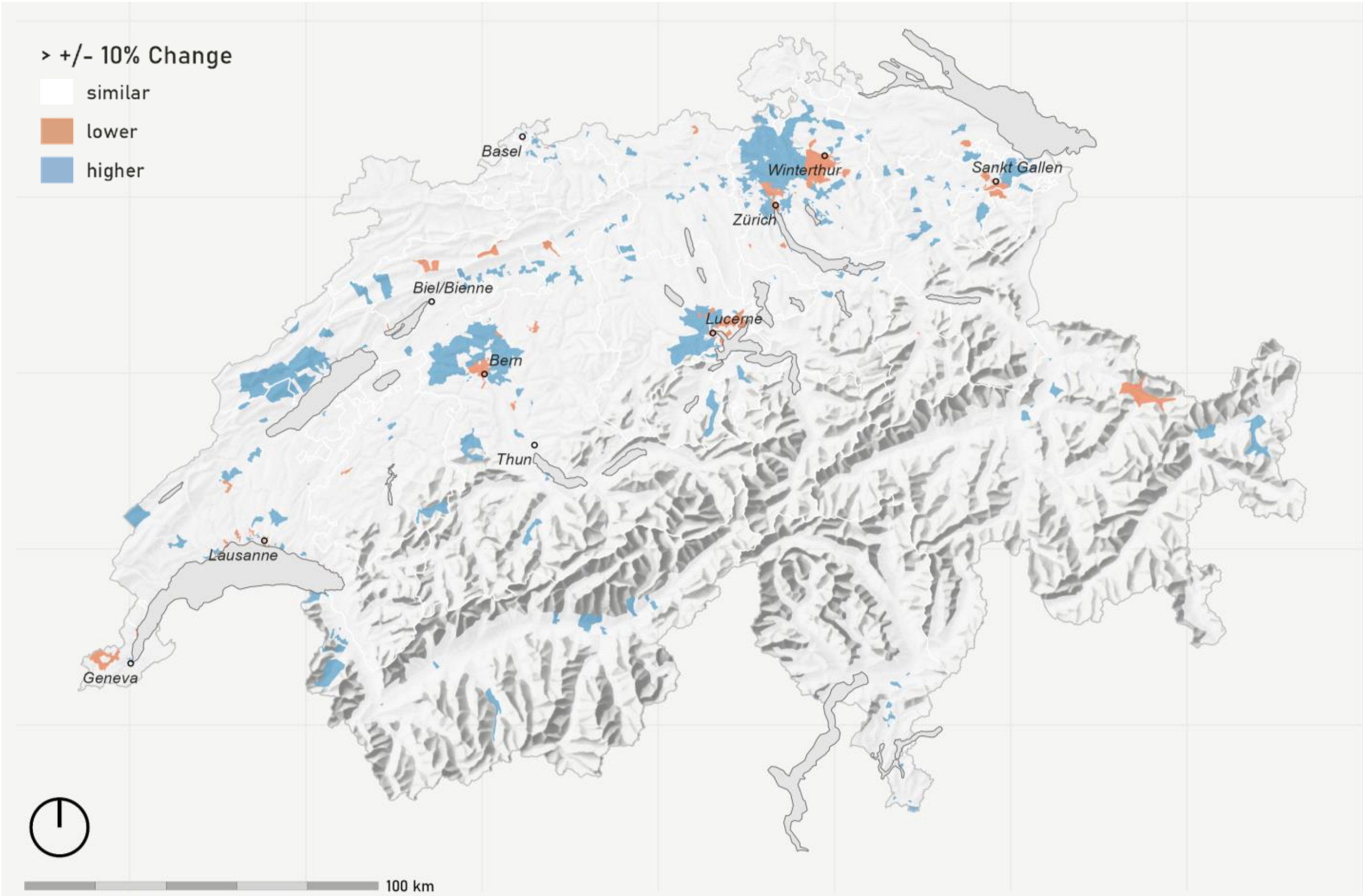

Fig 25: Significant differences on SPAI values when public transport is considered an alternative travel mode. Shown are NPVM zones with a relative SPAI value change of more than ± 10% compared to the model only considering travel times by individual transport means (car).

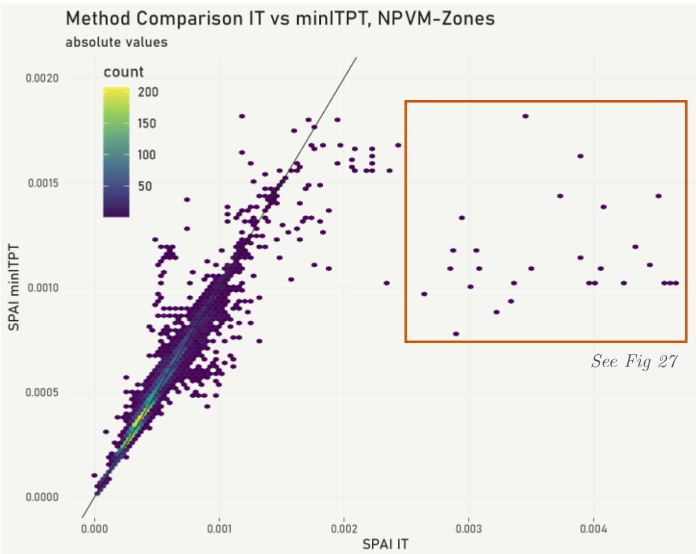

Fig 26: Density scatterplot of SPAI values using 2 different travel modes. On the horizontal axis, SPAI values for individual transport (IT) are depicted, and on the vertical axis, the SPAI values derived from the combined travel times of IT and public transport (minITPT) are displayed. Outliers are marked with a rectangle.

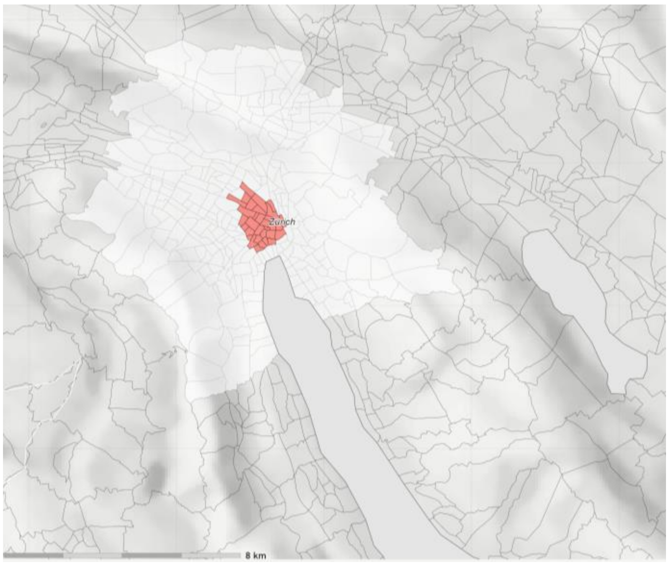

Fig 27: Highlighted in orange are the NPVM zones marked as outliers in Fig 26. *Shown in white is the area of the city of Zurich (municipality) for reference.*

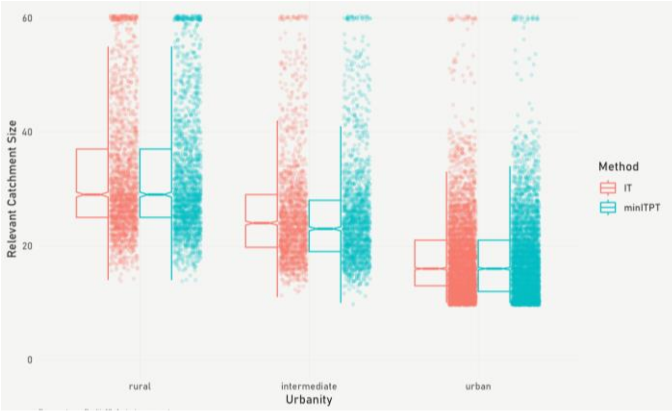

Fig 28: Box and jitterplot of the distribution of relevant catchment sizes by urbanity. Notches with no overlap indicate a significant difference in the medians of the box plots. IT = travel times by individual transport, minITPT = minimum travel time per connection when considering public transport (PT), whichever is fastest.

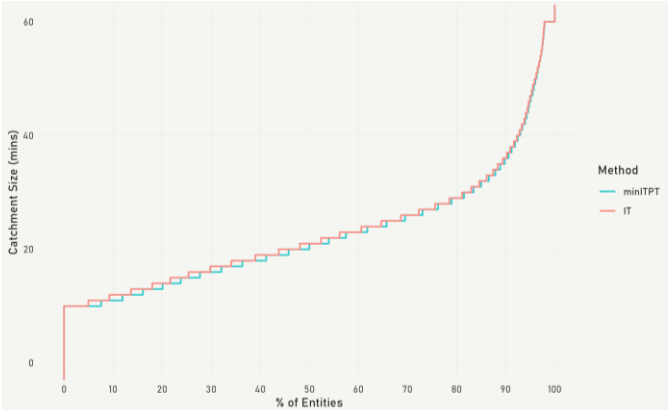

Fig 29: Comparison of cumulative catchment sizes by travel modes.

3.3 Comparative Analysis of OBSAN and NPVM Approaches

In this section, the results concerning the third research question will be presented. The aim here is to enable an assessment of whether the NPVM distance matrices can be considered a sensible alternative to the custom-generated distance matrices that have been utilized so far in previous and current applications of the MH(V)3SFCA method in Switzerland. To do so, the results presented in 3.1 are compared to the preliminary results of the study currently being conducted by von Rhein, Haldimann and Jörg (2023). Going forward, these results will be referred to as OBSAN results and the results presented above as NPVM results. Since the two methods use not only different time matrices but also different parameters, they are not exactly equivalent, which will be discussed further in section 4. First, the results of both models will be assessed visually using maps as well scatterplots, and secondly, a correlation analysis is presented. The maps of the OBSAN results can be found in Appendix D. Since the OBSAN results are calculated on the hectare basis, they are aggregated to a comparable spatial unit, which in this instance is the NPVM zone level (Fig D 1), as well the municipality level (Fig D 2).

3.3.1 Comparison of Maps and Scatterplots

Overall, both methods produce similar results, regardless the aggregation level. The SA classification in cities remains mostly unchanged. In large parts of the country, zones or municipalities remain within the same SA quintile. Some move up one quintile and a few jump two SA quintiles.[14] Differences on a larger scale can be found, particularly in rural areas of the cantons of Bern and Lucerne. According to the OBSAN results, SA is better in a wide part of this region. An overarching spatial pattern, especially pronounced on the NPVM zone level, can be made out in the distribution of SA classified by quintiles. The classes of the OBSAN seem to follow clearer contours than the results presented in 3.1, where SA distribution is more patchy. This is especially pronounced in the cantons of Vaud, Fribourg, and Bern.

Fig 30 shows a density scatterplot where the SPAI values of the OBSAN approach are plotted against NPVM SPAI values, with the NPVM zones as spatial units. There is a clear correlation between the two SPAI's. Because the majority of datapoints lie below the 45° degree line, the NPVM values are overall lower. However, two significant groups of outliers can be made out (marked with rectangles), and are then mapped in Fig 31. While the outliers originating from the OBSAN approach (marked in turquoise) are distributed over a large area, the NPVM outliers (marked in red) are all located within the same area in the city of Zurich. Interestingly, these outliers concern the same area as those analyzed in Fig 26 & Fig 27.

[14] An assessment solely based on the quintile classification is challenging, because if one NPVM zone or municipality ranks in another quintile, it means that another zone must also have changed a quintile, even without changing its SPAI value.

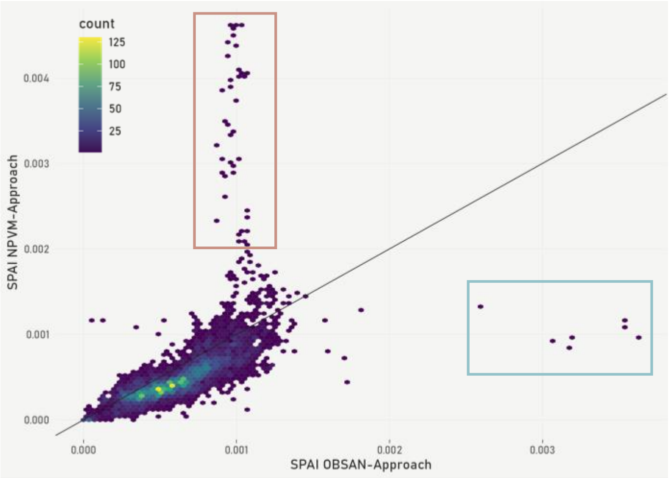

Fig 30: Density Scatterplot of OBSAN against NPVM SPAI values. Comparison on the NPVM zone level. Black line represents slope of 1. Outlier groups are marked in rectangles.

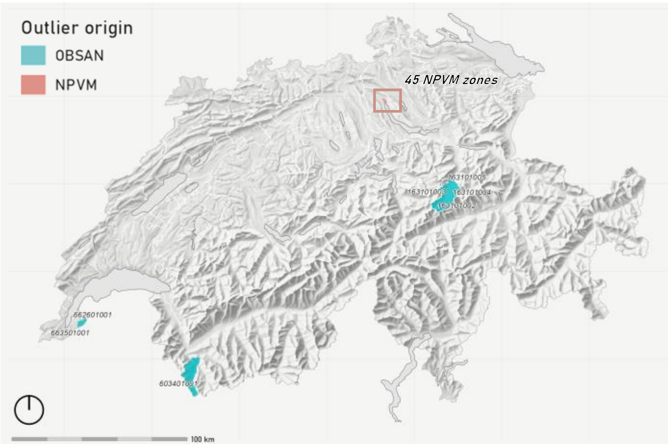

Fig 31: Outliers depending on methods mapped. Numbers are the ID's of the NPVM zones.

Upon comparison of results aggregated to the municipality level using the two methods (Fig 32), most outliers disappear. The two remaining OBSAN outliers are two municipalities in the canton of Geneva, as each zone area is equal to the municipality borders.

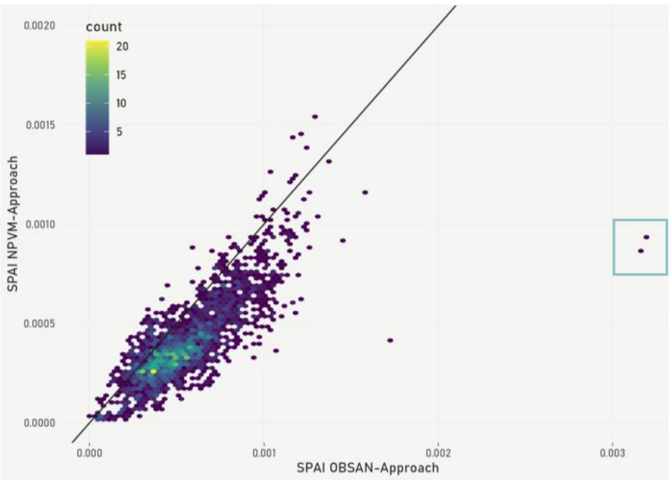

Fig 32: Density Scatterplot of OBSAN against NPVM SPAI values. Comparison on the municipality level. Black line represents slope of 1.

3.3.2 Correlation Analysis

As mentioned in before, normality condition is the prerequisite for an analysis using the Pearson correlation coefficient r, and an analysis for normality can be found in Appendix E. Even though the distribution looks visually normal, a left skewness appears due to the nature of the outliers. This means that for completion correlations are shown with and without the inclusion of outlier groups. Only the datapoints shown as outliers (above) are excluded.

	w/ outliers	w/o outliers
NPVM zone level	*n=7,964*	*n= 7,912*
Pearson's r	0.6686028 ***	0.821453 ***
Spearman's rho	0.8601056 ***	0.8581427 ***
Municipality level	*n=2,212*	*n=2,210*
Pearson's r	0.8119923 ***	0.8324093 ***
Spearman's rho	0.7957454 ***	0.7951993 ***

*Tab 9: Correlation coefficients with and without outliers for both aggregation levels. *** P value < 0.001.*

Overall, a relatively high correlation can be assessed between the two methods, regardless of the aggregation level (Tab 9), especially when we consider that the two methods operate with relatively different parameter settings. The exclusion of the outliers has an especially high effect at the NPVM-zone level, where more datapoints are also excluded (52 vs 2). Also of interest is the fact that for the higher aggregated comparison on the municipal level, the Spearman's rank correlation is lower than on the NPVM zone level.

4 Discussion

4.1 Spatial Disparities in Access to Pediatric Practices

4.1.1 Results

This thesis presented for the first time a nationwide assessment of disparities in spatial accessibility to pediatricians. Evidence presented suggests that the spatial accessibility in Switzerland is characterized by important disparities, and which are twofold in nature. Firstly, relatively high regional disparities can be found between regions. Especially the areas around Lake Geneva and including the cantons of Geneva, Vaud, as well francophone areas of Valais seem to have an advantage regarding SA. In German- as well Italian-speaking areas of Switzerland, high SA areas are bound by larger metropolitan areas (Bern, Basel, Zurich, Winterthur, St. Gallen, Lucerne, Lugano, and Locarno). However, in isolated cases, even fairly remote valleys show good SPAI values.

Another gradient in SA accessibility that has been identified is that areas classified as “urban” by the urban/rural typology classification 2012 have higher SPAI values than “rural” or “intermediate” areas. This does not come as a surprise because “rural” as well “intermediate” areas have much larger relevant catchment sizes, indicating further travel distances overall, something which is penalized by the MHV3SFCA method. But upon comparison with the population density of children aged under 15, it becomes apparent that the MHV3SFCA is not an overly complicated way of indicating areas with high or low population densities. Especially for large parts of the Swiss Plateau—such as the cantons of Fribourg, Solothurn, Lucerne, Aargau, and Thurgau—which are populated relatively densely over a larger area but whose SPAI values rank in the lowest or second lowest quintiles. The canton of Bern is a notable exemption, with relatively high ranking in both. The findings concerning the Swiss Plateau, correspond rather interestingly, to the assessments of SA to general practitioners (outpatient care) by Jörg, Lenz and Wetz (2019) and Jörg and Haldimann (2022). Previously, Grüebler (2021) had analyzed accessibility to pediatricians working in the outpatient care sector in the canton of Zurich utilizing the MH3SFCA method. Although only considering only pre-school aged children (0–4 years), the results are spatially relatively similar.

So far, the SPAI values calculated and presented on the NPVM-zone level were discussed. However, it is often the case that a statement based on aggregated jurisdictional regions is desired. These remain interpretable and have the advantage that they were not calculated based on any administrative boundaries. Hence, the accessibility indices of any spatial unit can generally be aggregated to any higher-level regional unit, depending on what is suitable for the specific research question (Love and Lindquist, 1995; Polzin, 2014). Following Jörg and Haldimann (2022), the SPAI values were aggregated to the municipal level.

A comparison between NPVM zones and municipalities reveals that the concentration of SA is significantly higher within urban areas, which may not be immediately evident when solely examining a map of municipalities. This is due to the fact that NPVM zones in cities are considerably smaller in size. This means that cities contain much more zones that are then aggregated to larger entities. When most of those zones rank in higher quintiles, those ranks are freed up for other entities to “move up” to better quintiles. This leads to an improved SA on the municipal level for a much larger area, which phenomenon is particularly pronounced when SPAI values are visualized using a rank based method, i.e. quintiles. Aggregation also means the loss of resolution and small variations in SA may disappear accordingly.

The SDI (supply density index), an alternative measure to the SPAI, is almost identical in its calculation except for the last step. The SDI does not consider absolute distances, but in turn retains a directly interpretable dimension. Like traditional provider-to-population ratios, it can be read as provider capacity (FTE) per 1,000 inhabitants. Its main advantages over the traditional measure are: 1) it is also a catchment based measure, is not based on predefined administrative spatial entities, and is therefore less prone to the modifiable areal unit problem (MAUP); and 2) the SDI still considers the economic behavior of patients with the Huff model.

Again, there are considerable disparities regarding supply density within Switzerland. Rather interestingly, only a relatively small proportion of the population as well as area is supplied with ± 1 FTE/1,000 inhabitants as recommend by the Swiss Society of Pediatrics (Zuercher, 2018). The SDI suggests a trend towards the extreme. While many populations (and areas) are supplied above the recommended ratio, evidence suggests that almost half of the study population faces a grave undersupply (<0.6 FTE’s/1,000). Jörg and Haldimann (2022) computed the SDI’s of primary care physicians, albeit by percentage municipality and not population. They found that 18% of the municipalities had an SDI of less than 0.6 FTE’s per 1,000 people. For 58% of the municipalities, the SDI ranges between 0.6 and 0.8 FTEs per 1,000 people, while only approx. 20% of the children have an SDI in this range. For 24% of municipalities, the SDI for primary care medicine is 0.8 or more. This compares to the 35% of the children within this SDI range.

Not too surprisingly, the mapped SDI and SPAI values correlate strongly overall. Large parts of the Swiss Plateau exhibit a poor supply density, with areas in the canton of Bern being a notable exception. Nonetheless, locally contrasting SDI and SPAI values can be made out. Examples of such deviations can be found in remote valleys that feature a low SPAI, but nonetheless a high SDI. This relation will be discussed in more depth in the following section 4.1.2. Furthermore, some populations might feature a similar SDI all the while having very different SPAI values. This can be attributed to the different distances between origin of demand and the relevant supply locations for those populations. This can be explained, at least partially, by examining the map showing the relevant catchment sizes.

With the recent hike of insurance premiums (BAG, 2023b) a renewed discussion about unwarranted variation i.e. oversupply ensued. Insurance premiums vary spatially quite drastically depending on the insurance region. Highly interesting is the fact that the high premium regions correlate visually well with regions that were found to have a high SPAI/SDI (for maps see Reich (2023). Of course insurance premiums are related to healthcare cost and hence correlates with child morbidity. Children in francophone regions were found to be significantly less active and to have a higher obesity rate even when accounted for socio-economic disparities (Bringolf-Isler *et al.*, 2015; Bürgi *et al.*, 2010). Although primary care is widely regarded as the most cost effective for healthcare provision and disease prevention (Marmot *et al.*, 2008), future research must investigate this connection more thoroughly.

Lastly the noted increase in pediatric workforce (Jenni and Sennhauser, 2016) especially from woman preferring to work parttime holds opportunities as well risks. Opportunities in so far that a coordinated allocation of this workforce might alleviate areas suffering from undersupply and low SA i.e. rural and remote communities. Parttime work might be beneficial as such areas might not warrant a fulltime pediatrician. On the other hand such efforts might be torpedoed by the fact that the upcoming pediatric workforce prefers to work in group practices, which won't find a market big enough to support them in remote areas.

4.1.2 Methodological Approach

This section discusses the general implementation of the MHV3SFCA method with the chosen approach and the resulting advantages and limitations. An extensive discussion regarding the utilization of the NPVM data (zone structure and travel time matrices) follows in section 4.3.

Base catchment size: Most FCA method applications utilize either discrete or continuous distances to operationalize the connections between demand and supply pairs. The implementation here makes use of a hybrid approach, something that was seldom used (Wang, 2014) in previous studies, but has distinctive advantages. Subal, Paal and Krisp (2021) criticize the use of discrete distance subzones based on the argument that within the subzone, all supplies are allocated the same distance selection weight and are thus considered equally accessible. However, this is exactly the indented effect of a base catchment as defined (10-minute radius). The reason for this decision is based on: 1) The economic idea that each trip is associated with some sort of fixed cost e.g. getting ready, leaving the house, getting the child in and out of the car, parking etc. This cost is likely to weigh more than the actual trip in the case of short distances. Moreover, the Swiss tend to prefer walking for very short distances instead of taking the car, due to the associated cost described above even if this might make the actual travel time a bit longer. This means that for very short trips, patients/caretakers are not thought to discriminate between supply locations based on how far away the pediatric practice is. 2) The travel time matrices used here have been calculated to model traffic between NPVM zone-centroids. Intrazonal traffic (origin and destination would be the same centroid) was not taken into consideration when establishing the model. Nonetheless, the NPVM data includes an estimation of intrazonal travel times, which is just the shortest travel time to the neighboring zones. This estimation is entirely unsuited for the application at hand, especially for remote mountainous regions. For this reason, intrazonal travel times were set also set to 10 minutes. Hence, the nearest possible connections, those within the same zone, between supply and demand locations are always included in the base catchment and the arguments made previously for very short travel times apply.

Relevant catchment size and required minimum supplies (Q): Key feature of the MHV3SFCA method is the integration of variable catchment sizes. The underlying idea is that patients only look as far until their need is met instead of utilizing a global catchment size. This need is set with the parameter Q. The previous application of the MHV3SFCA method (Jörg and Haldimann, 2022) set this need to a minimum of one supply location that must be reached ($Q = 1$). However, the utilization of discrete distance subzones has the effect that the demand of one population is rarely only attributed to one supply location (Jörg and Haldimann, 2023). They suggest using continuous distances instead, depending on the field of healthcare analyzed, and that higher Q*'s* of up to 10 should be considered. This study has conducted a sensitive analysis (see 6Appendix A) and determined an optimal Q of 6 supply sites. This is an opportune moment to contemplate whether it is appropriate to mandate a uniform Q for all regions and types of areas within a country. From the standpoint of policy advisors and makers, this might be seen as a favorable attribute of the methodology. For other applications, it might be favorable to operate with different *Q's*, depending on the area type, almost like the iFCA method of Bauer and Groneberg (2016). The iFCA requiring continuous data to do so has previously rendered its application in Switzerland unfeasible (Jörg and Haldimann, 2023). The iFCA still has the advantage of determining the parameter Q as well the distance weighting function for each population location individually. An application of the iFCA method could be used to verify the determined Q. Furthermore, future research might combine the strengths from both approaches. This would include the handling of absolute distances and constant demand from the MH(V)3SFCA method and the variable catchment size calculations from the iFCA method.

Demand misallocation and overestimation: The Huff model allocates a fraction of the demand within the catchment to each supply location, meaning that each supply "caught" faces a demand greater than 0. As Jörg, Lenz and Wetz (2019) demonstrated in a simulation study, there is a tendency for a misallocation of demand for a given population to relatively faraway supply sites, even more so if the latter have large capacities. This results in a bias in favor of smaller centers with relatively remote supply locations. This problem is especially relevant in applications of the MH3SFCA method that only operates with one global catchment size.

The solution to this problem was found through the inclusion of variable catchment sizes, as it only considers additional supply locations further away (expanding the relevant catchment size) if the minimum required practices are not yet reached (Jörg and Haldimann, 2022; Jörg and Haldimann, 2023). However, this solution somewhat appears again when Q is not set to 1. For example, in the most extreme case, a population reaches one supply site within the base catchment (10 minutes), but to meet the condition of $Q = 6$, the relevant catchment area has to expand right up to 60 minutes ($d_{max} = 60\,min$) as all other five supply locations are more are between 59 and 60 minutes away. On top of that, those locations feature large capacities.

The Huff model then allocates an unreasonable amount of demand towards those faraway supplies. Of course, this also depends on the chosen weighting function, but the bias stems from the Huff model. In reality, a scenario akin to the extreme case described could materialize in remote areas, such as alpine valleys. In this case the SDI is more prone to these effects than the SPAI, as the absolutes distances are not taken into account in its final calculation step. In fact such discrepancies between low SPAI's but high SDI's can be observed in the alpine valleys of the cantons of Vaud, Bern, Uri, and especially Grisons. The relatively large relevant catchment sizes of the mentioned regions in Fig 23 provide further evidence.

To partially mitigate this issue, a proposed enhancement for future endeavors is recommended. Instead of defining Q solely as the number of supply sites, it is advisable to consider the total of reached FTE's (Full-Time Equivalents) to determine whether demand is adequately met or if additional supplies are required, thus necessitating an expansion of the catchment size. This is underlined by the fact that total FTE's per zone vary from 0.1 to 9.5. with the current approach, all are counted equally with regards to Q (min. requirement for *practices* reached). A full solution although requires an optimization approach to model the complex interactions of demand competition (see Li, Serban and Swann, 2015 and Nobles, Serban and Swann, 2014). Such a model ideally takes the SDI and the recommended provider to population ratio into account which is used to estimate if people seek supplies further away or are already adequately supplied.

Global maximum catchment size (d_{max}): Bauer and Groneberg (2016) as well the previous explanations have shown that the choice of the (d_{max}) is potentially of great influence, especially for FCA methods that do not implement variable catchment sizes. Variable catchment sizes reduce the importance of the global catchment size limitation, insofar as it only acts as a runaway boundary for populations that do not reach the required Q. As demonstrated, only relatively few NPVM zones reach the maximum global catchment size and do not reach the required Q of 6. Setting 60 minutes as the global maximum is an approach based on the available literature. This leaves only very few populations without access at all, but does so purposefully. Studies that validate the current approach to the maximum catchment size are needed and could be a starting point for future research. A starting point might be studies akin to McGrail, Humphreys and Ward (2015) that empirically measure the maximum travel time tolerances and numbers of supplies considered by populations in different areas. Alternatively billing data might be employed to determine maximum travel times.

4.1.3 Data

Demanding Population: Based on the population of children aged 0–14 years per hectare, a need-adjusted demand was calculated using the model established by Jörg and Haldimann (2022) and has been discussed there. Nonetheless, the most relevant points shall be summarized here. This model also considers the additional demand from working commuters, something that is not relevant for the assessment of SA to pediatric practices. The impact of tourism is considered based on the number of overnight stays per region. This includes the overnight stays of tourists from Switzerland, whose needs are already accounted for in the resident population, thus slightly overestimating the total demand of the demand population. The need-adjusted data used in this thesis is also used by von Rhein, Haldimann and Jörg (2023). This allows for a better assessment of RQ III.

The resident population does not include the non-permanent resident population, consisting of two categories: foreign nationals with a short-term residence permit (Permits L & S) for a stay of fewer than twelve months, and secondly, individuals in the asylum process (Permits F or N) with a total length of stay of fewer than twelve months. In 2021, the proportion of the non-permanent resident population amounted to 0.8% (Jörg and Haldimann, 2022). Stemming from 2019, the population data is relatively recent and in general no big changes are expected to have occurred since. However, it is worth mentioning that large-scale displacements of people, such as the war in Ukraine, might have an impact. At the end of 2022 ca. 16,500 of the over 62,000 of Ukrainian refugees holding a Permit S were children under 14 years (SEM, 2023b). Abrupt influxes create additional demand locally which could have an impact on the SA, as refugees are also entitled to medical treatment (SEM, 2023a).

Supplying pediatric practices: This thesis derives its supply data from the same surveys that were also used in Jörg, Lenz and Wetz (2019) and Jörg and Haldimann (2022) and therefore feature the same limitations as those discussed in the respective studies. In summary, the incompleteness of the data sources poses a major limitation For instance, the MAS survey in 2019 had a response rate of 64%, which means that for over a third of the outpatient care providers in the MAS, no information is available. In terms of the number of healthcare providers, the FMH Physician Statistics are more comprehensive; however, the information regarding working hours in the FMH Physician Statistics is incomplete and sometimes outdated. For the analyses in the mentioned reports on primary care medicine, including primary pediatric care, data from both the MAS survey and the FMH Physician Statistics were combined. It is important to mention the reservations related to the working hours of healthcare providers. Due to the lack of information, a significant portion of the providers' capacities (FTE's) had to be estimated. Furthermore, Results regarding for the Engadin must be interpreted with caution due to the fact that pediatric healthcare provision is organized differently and suppliers are not included in the pediatric practice data. However, overall the supply of pediatric primary care available is underestimated, since only pediatricians working in outpatient private practices were taken into account. Pediatricians working in ambulant outpatient care in hospitals, for example in the Engadin but also elsewhere are not included in the supply data used here. This is due to the fact that in hospitals the delineation of working hours/capacities for in- and outpatient care is not simple. It is not excluded that other healthcare providers (e.g., specialists or physicians primarily engaged in inpatient care) may also provide a certain portion of outpatient primary care services (Jörg, Lenz and Wetz, 2019). As suggested by the same authors, billing data on the utilization of ambulant health services could be considered in order to better delineate between stationary and ambulant (primary) care. This would also make it possible to also take into account the capacities of hospitals for future SA assessments.

4.2 Multimodal Accessibility

4.2.1 Results

Overall, spatial accessibility was found to not be affected, positively or negatively, for large areas when public transport is taken into account as alternative travelmode. This is not unexpected, as for most possible connections between NPVM zones, travel by car is the faster option. However, some populations still achieve a notably higher SPAI, while others are affected negatively. Spatially, these areas seem to be in close proximity around the cities of Bern, Lucerne, Zurich, and Winterthur. What is likely happening here is that many supply sites are in the heart of the cities, which are often more difficult to access by car than by public transport. Hence, with the inclusion of public transport as a possible travel mode, people living in the suburbs now have a better chance of reaching these supplies, which increases their SPAI values. This is especially notable in zones classified as "intermediate" and which show a significant decrease in their relevant catchment sizes. Vice versa, populations living in inner cities that previously could enjoy their access to a large pediatric workforce with comparatively little outside demand face a deteriorating SA. An extreme case of this can be found in Zurich. The innermost part of Zurich, does not house many children but quite a few pediatric practices. In the car-only scenario, these populations have an extraordinary high SA. But this area is one of the most accessible by public transportation, as the main train station of Zurich is the largest public transport hub in Switzerland. Suburban areas around Zurich are extremely well connected with the city center by public transport. The results seem to be in line with previous studies, notably Apparicio *et al.* (2008; 2017), who also found the biggest differences in correlation between modes of transport in suburban areas.

The findings indicate that employing a multi-modal approach yields more accurate accessibility assessments, especially by more accurately modelling the mobility behavior of populations in areas of good public transport service and thereby furnishing policymakers with improved guidance for addressing health equity concerns.

4.2.2 Methodological Approach

Considerations for multimodality in FCA methods followed the criticisms brought forwards by Guagliardo (2004) & Wang (2012), which questioned the assumption that all residents at location i have equal access to healthcare. This is because not all patients have access to a car, which is usually assumed to be the furthest-reaching means of transportation. Following this, Mao and Nekorchuk (2013) calculate catchment sizes depending on travel mode and a fixed travel time limit (2SFCA). Then they assume for each population i a modal split and calculate a weighted SPAI value based on the reached facilities depending on transportation mode (see also Ni *et al.* (2019) for a survey-based variation). While this might for many locations be a suitable approach. The approach chosen here is more appropriate. Switzerland is a developed country and the decision to not own a car is usually deliberate. Of all Swiss households, 78% own a car, while 83% of all adults held a driving license in 2021 (BFS, 2023a). Even in areas classified as “urban”, the average household owns 1.02 cars, while in other areas the car density is even higher (BFS, 2017a). Furthermore, 53% of all residents (above 16) hold some sort of public transport fare reduction pass. These circumstances allow for the reasonable assumption that most people can freely decide between modes of transport, while those who can’t are likely to live in urban areas where public transport is best and in some cases even faster than traveling by car. With the logic behind the variable catchment sizes being that patients only travel as far as necessary, it is easy to justify that they do so in the fastest way possible and choose their mode of transportation accordingly.

Traffic congestion is a limitation that concerns both travel modes but in the end has implications for the multimodal model too. Traffic congestion is a factor rarely considered (also this work uses travel times that are calculated on uncongested roads) but may bear wide-reaching implications. Firstly congested roads would certainly reduce spatial accessibility to pediatric practices as travel times increase. Secondly and more importantly it would not affect all areas equally. This in turn means that more people are likely to consider other travel mode such as public transport or cycling. Future research could take this into account and identify areas that are strongly affected by traffic congestion.

4.3 Comparative Analysis of OBSAN and NPVM Approaches

4.3.1 Results

The comparison of the SPAI-values from the NPVM-approach against the OBSAN-approach shows a high spatial and numerical similarity between both approaches. This thesis benefits from the unique opportunity that von Rhein, Haldimann and Jörg (2023) are currently applying the MHV3SFCA method with the same demand and supply data as was used in this study. Their implementation follows the approach used previously by Jörg and Haldimann (2022) (OBSAN-approach). The preliminary, unpublished, results of von Rhein, Haldimann and Jörg (2023) were then compared to the results (NPVM-approach) presented in this study. However, it is important to keep in mind that the OBSAN-approach is not the “gold standard”—while both methods have distinctive approaches, they also entail distinctive advantages and disadvantages. These will form part of the discussion.

On the whole, both approaches’ results are similar in large areas of Switzerland with isolated areas showing larger differences. Relatively high Pearson as well Spearman correlations were calculated for both aggregation levels. Unsurprisingly impactful is the exclusion of outliers on the NPVM zone level (n=7,964). The exclusion of 52 outliers of which 45 stem from the NPVM method and 7 from the OBSAN method, increased correlation from 66% to over 82% (Pearson). This also does not come as a surprise when examining the scatterplot (Fig 30), since these have a high leverage. The Spearman rank correlation, being less sensitive to outliers, shows a high correlation of 86% in both cases.

4.3.2 Methodological Approach

That the NPVM-approach exhibits more outlier data points is something worth discussing, although not surprising. While the SPAI values for the NPVM-approach are calculated on the NPVM zone level and are therefore raw data, the SPAI values are merely aggregated to this spatial resolution. This allows for comparison, but means that individual outliers (hectare points) are likely to be smoothed out during the aggregation. Why the outliers from this comparison concern the exact same area as the outliers found between the IT vs minITPT methods is something that requires more investigation. Aggregating the data to the municipal level provides this benefit also to the NPVM method, where all outliers from the MPVM method disappear and only two remain from the OBSAN method. This exemplifies the risk that comes with using larger spatial units for the analysis of SA. A wrong or infeasible demand relationship between population i and supply j on the NPVM-zone level is more severe than on the hectare level, for two reasons: 1) a zone contains in many cases a more demanding population, whose (mis)allocation affects a given demand-supply-ratio R_j much more than if the same occurs on the hectare level; and 2) such effects are much more likely to show themselves due to the lower spatial aggregation discussed above. Obviously, such effects depend on chosen minimum required supplies reached Q. This leads to the discussion of how demand is spread out across different supply sites in the two different approaches. Although requiring only $Q = 1$, the OBSAN-approach operationalizes distance subzones, which leads populations in most cases to have more than just one supply location from which they are demanding. The NPVM-approach, in contrast, spreads the demand across multiple supply locations by setting a higher Q of 6. Using continuous distances and a Q of 1 would lead to relatively unstable and unreliable results, as the following example illustrates. A population (NPVM zone) has its nearest supply location *a* 11 minutes away from the zone centroid. The next closest supply site *b* is at 12 minutes. Now, assuming $Q = 1$, the entire population of said zone is only sent to *a*. Depending on the population size of the zone, this strongly affects R_j. Rationally, it is illogical to assume that not only, at least a part, of that population would demand from location *b*. The OBSAN-approach corrects this in that both supply sites are included in the subzone that stretches from 10–20 minutes. The NPVM-approach on the other hand, by setting a higher Q, which has both theoretical as well practical advantages. Theoretical because the distribution mimics a more realistic behavior of customers/patients insofar as other nearby options are considered *explicitly* and not just because they are in the same distance subzone. Furthermore, this addresses the issue brought up by Subal, Paal and Krisp (2021) and partially discussed earlier. Within each subzone, all supplies are considered equally accessible and receive the same distance weight (likelihood for demand). This is, as argued, not a problem for supplies very close to demand origin, however with increasing distances and especially larger subzones (30–60 minutes), it raises a valid point of critique. Due to the availability of continuous distances, the NPVM-approach assigns distance weights individually outside of the base catchment. Secondly, it offers practical advantages for the reason that when using $Q = 1$ with the OBSAN-approach, Jörg and Haldimann (2022) report that rural areas have a tendency to extreme values. In communities with a supply location (primary care physicians in this instance), accessibility is often significantly above average. Simultaneously, many neighboring communities lack outpatient primary care services, and the respective populations must sometimes travel long distances, especially since many of these communities are located in alpine regions with relatively large distances to neighboring communities. In the NPVM-approach, these disparities are less severe due to the higher required Q.

This is an opportune moment to contemplate whether it is appropriate to mandate a uniform Q for all regions and types of areas within a country. From the standpoint of policy advisors and makers, this might be seen as a favorable attribute of the methodology. For other applications, it might be favorable to operate with different Q*'s*, depending on the area type, almost like the iFCA method of Bauer and Groneberg (2016). This opens up two opportunities for future research. First, whether the found Q is ideal for all area types and second, whether an application of the iFCA method with the NPVM data could prove fruitful in Switzerland. The results then could be compared to the OBSAN- resp. NPVM-approaches

Last but not least, the suitability of the NPVM-zone structure and travel times must be considered. Due their design for a similar purpose (traffic modelling) the zones are homogenous in population size and delineated in a sensible way something which is of importance for SA-analysis see Riva *et al.* (2008). Apparicio *et al.* (2008; 2017) have shown that choosing the spatial unit of reference for calculating distances can affect aggregation error and thus overall accuracy. What is especially crucial is how the spatial unit (here, the NPVM zone) is connected to the road/rail network. Not surprisingly, the most accurate results are achieved when the centroid of the spatial unit is adjusted (weighted) for the population distribution within it. The distance between the NPVM zones were calculated using such weighted centroids. However, herein lies an important detail: those centroids are calculated using a synthetic population by hectares. This means that not only residents (encompassing all ages) are factored in, but also workers who are there only during the day. Since Swiss zoning laws mostly distinguish between residential and working areas, the true centroids for the population from 0–14 years might differ in some cases. On a small scale also, the age structure of different neighborhoods within the zone might have an influence. The same limitation exists also on the supply side and arguably even more pronounced. A pediatric practice can be located anywhere within the NPVM zone and thus connection times might vary here too. For smaller zones this is of course a smaller problem, whereas rural areas with larger zones would be affected more. An exact assessment of the extent of this limitation has yet to be undertaken.

A substantial benefit from using the NPVM data is that the entire area of is covered by the zone structure this allows for a streamlined application as its simple to join the population data and to look up the travel time from one zone to another. As reviewed before this is something that is harder and susceptible to errors in the OBSAN-approach.

5 Conclusions

To conclude this master's thesis, I will summarize the key findings, reflect on their implications, and shed light on potential avenues for future exploration.

Following anecdotal remarks in newspapers as well official communiques of pediatricians indicating shortages in primary pediatric care in certain areas, this thesis for the first systematically assessed spatial accessibility to residential primary care pediatricians. The analysis is based on the application of a state of the art Floating Catchment Area Method (MHV3SFCA). FCA methods, first introduced two decades ago, have consistently demonstrated their high effectiveness as a tool for measuring spatial healthcare accessibility. Their notable strength lies in their capacity to account for regional dependencies that extend beyond administrative boundaries. The research results provide valuable insights into the effectiveness of public health interventions, enabling policy makers to make informed decisions and tailor policies to improve overall community well-being. Adequate healthcare provision has positive long term health effects and reduces disease burden and costs down the line.

The analysis reveals large differences in potential spatial accessibility to pediatric practices for children aged 0–14 years with extensive areas of Switzerland being affected by low spatial accessibility (SA), while areas with high SA are mainly concentrated in and around metropolitan areas. Francophone areas around Lake Geneva exhibit disproportionately high SA while large parts of the German-speaking Swiss Plateau face a poor SA, especially in the light of population-density. The results align with the findings of previous research conducted in the Canton of Zurich. Interestingly, the spatial distribution of SA to pediatric practices also correlates well with the SA to general practitioners as analyzed in previous applications of the MHV3SFCA method. Furthermore, incorporating the supply densities index (SDI) this work shows that not only large disparities in SA exist but also in the supply densities. While ca. 35% of children aged 0–14 years face at least adequate supply, roughly half face potential severe undersupply. Significant limitations pertain to the data quality concerning the workload of the primary care pediatric workforce, as well as the precise delineation of this workforce.

The robustness of accessibility is enhanced by accounting for not only the commonly assumed mode of transportation by car but also by introducing a novel approach to integrate public transportation as an alternative mean of transportation. Instead of assigning a certain percentage of the population to use public transportation the approach assumes that public transport is used whenever a given supply is reached faster. By doing so, suburban areas around large cities especially benefit from better connectivity to city centers where many practices are located. In return, dwellers of those cities face a decreased SA due to the additional demand from outside. This overall can provide an approach that will likely model reality better than the uni-modal method alone. Further research is needed, especially in regards to the influence of travel times and modes, including different levels of traffic congestion, as most current approaches only calculate car travel times on uncongested networks.

Two crucial aspects of any FCA method application are the spatial unit of analysis and the operationalization of the distances between those units. Previous applications of the MH(V)3SFCA method, the OBSAN-approach, used a hectare raster grid (100m x 100m) and custom travel times calculation in subzones for each application. This thesis introduced a novel approach using a preexisting spatial structure as well as the correspondent travel time data from the National Passenger Transportation Model (NPVM). The newly developed NPVM-approach poses a cost saving viable alternative to the OBSAN-approach while offering distinctive advantages. Main benefit of the NPVM-approach is the integration of reliable, verified continuous distances, which allow for a better temporal resolution and more realistic implementation of variable catchment sizes while remaining a high spatial accuracy. A comparative analysis between the SPAI values of the two approaches has shown a correlation of 0.86 ($p<0.001$). The utilization of the NPVM data allows future research also in other fields to easily establish an assessment of spatial accessibility. Furthermore, the integration of continuous distances in the MHV3SFCA method opens up the possibilities for future methodological improvements especially in the regard of variable catchment size operationalization.

6 References

Aartsen, M.J. *et al.* (2019) 'Advantaged socioeconomic conditions in childhood are associated with higher cognitive functioning but stronger cognitive decline in older age', *Proceedings of the National Academy of Sciences of the United States of America*, 116(12), pp. 5478–5486. doi: 10.1073/pnas.1807679116

Aday, L.A. and Andersen, R. (1974) 'A Framework for the Study of Access to Medical Care', *Health Services Research*, 9(3), pp. 208–220.

Altman, D.G. and Bland, J.M. (1995) 'Statistics notes: the normal distribution', *BMJ (Clinical Research Ed.)*, 310(6975), p. 298. doi: 10.1136/bmj.310.6975.298

Andersen, R. and Aday, L.A. (1978) 'Access to Medical Care in the U.S: Realized and Potential', *Medical care*, 16(7), pp. 533–546.

Andersen, R. and Newman, J.F. (1973) 'Societal and individual determinants of medical care utilization in the United States', *The Milbank Memorial Fund Quarterly. Health and Society*, 51(1), pp. 95–124.

Andersen, R.M. (1968) *A behavioral model of families' use of health services*. Chicago: Center for Health Administration Studies, University of Chicago.

Andersen, R.M. (1995) 'Revisiting the Behavioral Model and Access to Medical Care: Does it Matter?' *Journal of health and social behavior*, 36(1), pp. 1–10. doi: 10.2307/2137284

Apparicio, P. *et al.* (2008) 'Comparing alternative approaches to measuring the geographical accessibility of urban health services: Distance types and aggregation-error issues', *International Journal of Health Geographics*, 7. doi: 10.1186/1476-072X-7-7

Apparicio, P. *et al.* (2017) 'The approaches to measuring the potential spatial access to urban health services revisited: distance types and aggregation-error issues', *International Journal of Health Geographics*, 16:32, pp. 1–24. doi: 10.1186/s12942-017-0105-9

ARE (2017) *NPVM 2017: Zonenstruktur und Verkehrsnetze: Schlussbericht.* Available at: https://www.are.admin.ch/are/de/home/mobilitaet/grundlagen-und-daten/verkehrsmodellierung/npvm.html (Accessed: 15 August 2023).

ARE (2020a) *Nationales Personenverkehrsmodell NPVM 2017: Schlussbericht.* Available at: https://www.are.admin.ch/are/de/home/mobilitaet/grundlagen-und-daten/verkehrsmodellierung/npvm.html (Accessed: 15 August 2023).

ARE (2020b) *Nationales Verkehrsmodell: Einführung.* Available at: https://www.are.admin.ch/are/de/home/mobilitaet/grundlagen-und-daten/verkehrsmodellierung/npvm/einfuhrung.html (Accessed: 19 August 2023).

Avenir Suisse (2016) *Noch 2294 Gemeinden in der Schweiz: Warum Fusionsförderung durch die Kantone sinnvoll ist.* Available at: https://www.avenir-suisse.ch/noch-2294-gemeinden-in-der-schweiz/ (Accessed: 19 August 2023).

BAG (2023a) *Krankenversicherung: Grenzgängerinnen und Grenzgänger in der Schweiz,* 6 July. Available at: https://www.bag.admin.ch/bag/de/home/versicherungen/krankenversicherung/krankenversicherung-versicherte-mit-wohnsitz-im-ausland/versicherungspflicht/grenzgaengerinnen-ch.html (Accessed: 19 August 2023).

BAG (2023b) *Stark steigende Kosten führen zu deutlich höheren Prämien im Jahr 2024* [Press release]. 26 September. Available at: https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-90514.html (Accessed: 28 September 2023).

Barbaro, J. and Dissanayake, C. (2009) 'Autism spectrum disorders in infancy and toddlerhood: a review of the evidence on early signs, early identification tools, and early diagnosis', *Journal of Developmental and Behavioral Pediatrics : JDBP*, 30(5), pp. 447–459. doi: 10.1097/DBP.0b013e3181ba0f9f

Bauer, J. and Groneberg, D.A. (2016) 'Measuring Spatial Accessibility of Health Care Providers - Introduction of a Variable Distance Decay Function within the Floating Catchment Area (FCA) Method', *PloS One*, 11(7). doi: 10.1371/journal.pone.0159148

Bennett, F.C. and Guralnick, M.J. (1991) 'Effectiveness of developmental intervention in the first five years of life', *Pediatric Clinics of North America*, 38(6), pp. 1513–1528. doi: 10.1016/S0031-3955(16)38234-7

BFS (2017a) *Fahrzeugbesitz der Haushalte, 2015 - Schweiz: Mikrozensus Mobilität und Verkehr (MZMV)*. Available at: https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/personenverkehr/verkehrsverhalten/tageszeit-unterwegszeit.html (Accessed: 10 September 2023).

BFS (2017b) *Raumgliederung der Schweiz: Gemeindetypologie und Stadt/Land-Typologie 2012*. (BFS-Nummer: 1702-1200). Neuchâtel. Available at: https://dam-api.bfs.admin.ch/hub/api/dam/assets/2543323/master.

BFS (2017c) *Mikrozensus Mobilität und Verkehr: Tagesdistanz, Tagesunterwegszeit und Anzahl Etappen nach Verkehrsmittelklasse und Zweck - Schweiz* (BFS-Nummer: su-d-11.04.03-MZ-2015-A3_CH). Available at: https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/personenverkehr/verkehrsverhalten/tageszeit-unterwegszeit.assetdetail.2004983.html (Accessed: 25 March 2023).

BFS (2020a) *Die Beölkerung der Schweiz 2019*. Neuchâtel (BFS-Nummer: 348-1900).

BFS (2020b) *Statistik der Bevölkerung und Haushalte (STATPOP), Geodaten 2019: GEOSTAT-Datenbeschreibung*. Neuchâtel. Available at: https://dam-api.bfs.admin.ch/hub/api/dam/assets/14716365/master (Accessed: 13 January 2023).

BFS (2023a) *Besitz von Fahrzeugen, Führerausweisen und ÖV-Abos: Mikrozensus Mobilität und Verkehr (MZMV)*. Available at: https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/personenverkehr/verkehrsverhalten/besitz-fahrzeuge-fahrausweise.html (Accessed: 10 September 2023).

BFS (2023b) *Mobilitätsverhalten der Bevölkerung: Tägliche Distanz und Unterwegszeit*. Available at: https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/personenverkehr/verkehrsverhalten/tageszeit-unterwegszeit.html (Accessed: 7 July 2023).

BFS (2023c) *Statistischer Atlas der Schweiz: Räumliche Gliederungen der Schweiz / Räumliche Typologien / Stadt/Land-Typologie 2012 / Stand 2023 Stadt/Land-Typologie 2012* (Karten-ID: 26733). Available at: https://www.atlas.bfs.admin.ch/maps/13/de/17223_12361_3191_227/26733.html (Accessed: 3 August 2023).

Bland, M. (2015) *An introduction to medical statistics*. 4th edn.: Oxford university press.

Boardman, J.D. *et al.* (2002) 'Low birth weight, social factors, and developmental outcomes among children in the United States', *Demography*, 39(2), pp. 353–368. doi: 10.1353/dem.2002.0015

Bringolf-Isler, B. *et al.* (2015) 'Regional differences of physical activity and sedentary behaviour in Swiss children are not explained by socio-demographics or the built environment', *International Journal of Public Health*, 60(3), pp. 291–300. doi: 10.1007/s00038-014-0645-8

Britannica (2023) *Switzerland*. Available at: https://www.britannica.com/facts/Switzerland (Accessed: 19 August 2023).

Bürgi, F. *et al.* (2010) 'Socio-cultural determinants of adiposity and physical activity in preschool children: a cross-sectional study', *BMC Public Health*, 10(733). doi: 10.1186/1471-2458-10-733

Campbell, M.J., Machin, D. and Walters, S.J. (2007) *Medical statistics: A Textbook for the Health Sciences*. 4th edn. Chichester: John Wiley & Sons.

Cervigni, F. *et al.* (2008) 'Spatial accessibility to pediatric services', *Journal of Community Health*, 33(6), pp. 444–448. doi: 10.1007/s10900-008-9112-x

Dai, D. (2010) 'Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit', *Health & Place*, 16(5), pp. 1038–1052. doi: 10.1016/j.healthplace.2010.06.012

Dai, D. and Wang, F. (2011) 'Geographic disparities in accessibility to food stores in southwest Mississippi', *Environment and planning. B, Planning & design*, 38(4), pp. 659–677. doi: 10.1068/b36149

Delamater, P.L. (2013) 'Spatial accessibility in suboptimally configured health care systems: a modified two-step floating catchment area (M2SFCA) metric', *Health & Place*, 24, pp. 30–43. doi: 10.1016/j.healthplace.2013.07.012

Dodge, Y. (2008) *The concise encyclopedia of statistics: Gini Index*. (Springer reference). New York: Springer.

EBP (2017) *NPVM 2017: Zonenstruktur und Verkehrsnetze*. Available at: https://www.ebp.ch/de/projekte/npvm-2017-zonenstruktur-und-verkehrsnetze (Accessed: 15 August 2023).

Field, K.S. and Briggs, D.J. (2001) 'Socio-economic and locational determinants of accessibility and utilization of primary health-care', *Health & Social Care in the Community*, 9(5), pp. 294–308. doi: 10.1046/j.0966-0410.2001.00303.x.

FMH (2022) *Berufstätige Ärztinnen und Ärzte nach Sektoren 2019,* 21 March. Available at: https://aerztestatistik.fmh.ch/.

FMH Verbindung der Schweizer Ärztinnen und Ärzte (2023) *FMH-Ärztestatistik*. Bern. Available at: https://aerztestatistik.fmh.ch/.

'FOPE II. The future of pediatric education II. Organizing pediatric education to meet the needs of infants, children, adolescents, and young adults in the 21st century. A collaborative project of the pediatric community. Task Force on the Future of Pediatric Education' (2000), *Pediatrics*, 105(1 Pt 2), pp. 157–212.

Fransen, K. *et al.* (2015) 'A commuter-based two-step floating catchment area method for measuring spatial accessibility of daycare centers', *Health & Place*, 32, pp. 65–73. doi: 10.1016/j.healthplace.2015.01.002

Fryer, G.E. *et al.* (1999) 'Multi-method assessment of access to primary medical care in rural Colorado', *The Journal of Rural Health : Official Journal of the American Rural Health Association and the National Rural Health Care Association*, 15(1), pp. 113–121. doi: 10.1111/j.1748-0361.1999.tb00605.x

Ghasemi, A. and Zahediasl, S. (2012) 'Normality tests for statistical analysis: a guide for non-statisticians', *International Journal of Endocrinology and Metabolism*, 10(2), pp. 486–489. doi: 10.5812/ijem.3505

Grüebler, E. (2021) *Geospatial Analysis of Access to Healthcare: Child Development Needs and Available Care in the Canton of Zurich*. Master's Thesis. Zürich.

Grüebler, E., Unterfinger, M. and Jörg, R. (2021) *R Package: Floating Catchment Area (FCA) Methods to Calculate Spatial Accessibility* (Version 0.1.0). Available at: https://egrueebler.github.io/fca/ (Accessed: 13 October 2022).

Guagliardo, M.F. (2004) 'Spatial accessibility of primary care: concepts, methods and challenges', *International Journal of Health Geographics*, 3(3). doi: 10.1186/1476-072X-3-3

Guyer, B. *et al.* (2009) 'Early childhood health promotion and its life course health consequences', *Academic Pediatrics*, 9(3), 142-149.e1-71. doi: 10.1016/j.acap.2008.12.007

Haas, S.A., Glymour, M.M. and Berkman, L.F. (2011) 'Childhood health and labor market inequality over the life course', *Journal of Health and Social Behavior*, 52(3), pp. 298–313. doi: 10.1177/0022146511410431

Haynes, A.G., Wertli, M.M. and Aujesky, D. (2020) 'Automated delineation of hospital service areas as a new tool for health care planning', *Health Services Research*, 55(3), pp. 469–475. doi: 10.1111/1475-6773.13275

Hehli, S. and Minder, T. (2022) 'Kinderärzte sind völlig überlastet – und im Winter könnte es noch schlimmer kommen', *Neue Zürcher Zeitung,* 6 October. Available at: https://www.nzz.ch/schweiz/kinderaerzte-warnen-vor-einem-versorgungsengpass-im-winter-ld.1706099 (Accessed: 28 October 2022).

Hehli, S. and Tribelhorn, M. (2022) 'Viele Eltern haben grosse Angst, ihr Kind zu frustrieren. Sie führen es nicht', *Neue Zürcher Zeitung,* 25 November. Available at: https://www.nzz.ch/schweiz/kinderarzt-ueber-modekrankheiten-und-alarmistische-telefonanrufe-ld.1713231 (Accessed: 28 November 2022).

Hewko, J., Smoyer-Tomic, K.E. and Hodgson, M.J. (2002) 'Measuring Neighbourhood Spatial Accessibility to Urban Amenities: Does Aggregation Error Matter?' *Environment and Planning A: Economy and Space*, 34(7), pp. 1185–1206. doi: 10.1068/a34171

Higgs, G. *et al.* (2017) 'Modelling spatial access to General Practitioner surgeries: Does public transport availability matter?' *Journal of Transport & Health*, 6(6), pp. 143–154. doi: 10.1016/j.jth.2017.05.361

Hoffmann, G.F. *et al.* (eds.) (2015) *Pädiatrie: Grundlagen und Praxis*. Berlin, Heidelberg: Springer (Springer Reference Medizin).

Hostettler, S. and Kraft, E. (2015) 'Frauen- und Ausländeranteil nehmen kontinuierlich zu: FMH-Ärztestatistik 2014', *Schweizerische Ärtzezeitung*, 96(13), pp. 462–469. doi: 10.4414/saez.2015.03528

Hostettler, S. and Kraft, E. (2023) *Geringe Hausarztdichte und grosse Auslandabhängigkeit: FMH-Ärztestatistik 2022*. 104th edn. Schweizerische Ärztezeitung. Available at: https://www.fmh.ch/files/pdf29/1162604427-de-fmh-aerztestatistik-5.pdf (Accessed: 17 July 2023).

Hudec, J. (2018) *Paradox in der Pädiatrie: Es mangelt an Kinderärzten, obwohl es immer mehr von ihnen gibt.* Zürich. Available at: https://www.nzz.ch/zuerich/kinderarzt-krauthammer-hoert-mit-88-jahren-auf-seine-nachfolger-kaempfen-mit-problemen-ld.1426648 (Accessed: 28 November 2022).

Huff, D.L. (1963) 'A Probabilistic Analysis of Shopping Center Trade Areas', *Land Economics*, 39(1), p. 81. doi: 10.2307/3144521

Huff, D.L. (1964) 'Defining and Estimating a Trading Area', *Journal of Marketing*, 28(3), pp. 34–38. doi: 10.1177/002224296402800307

Jenni, O. (2022) 'Meilen- und Grenzsteine der Entwicklung', *Monatsschrift Kinderheilkunde*, 170(7), pp. 651–662. doi: 10.1007/s00112-022-01547-z

Jenni, O.G. and Sennhauser, F.H. (2016) 'Child Health Care in Switzerland', *The Journal of Pediatrics*, 177, S203–212. doi: 10.1016/j.jpeds.2016.04.056

Jörg, R. and Haldimann, L. (2022) *Regionale Unterschiede um Zugang zur medizinischen Versorgung: Methodik zur Analyse der Versorgungsdichte und Anwendung am Beispiel der Hausartzmedizin (Obsan Bericht 07/2022).* Neuchâtel.

Jörg, R. and Haldimann, L. (2023) 'MHV3SFCA: A new measure to capture spatial accessibility of health care systems. Manuscript submitted for publication.', *Health & Place*, (79). doi: 10.1016/j.healthplace.2023.102974

Jörg, R., Lenz, N. and Wetz, M. (2019) *Ein Modell zur Analyse der Versorgungsdichte: Herleitung eines Index zur räumlichen Zugänglichkeit mithilfe von GIS und Fallstudie zur ambulanten Grundversorgung in der Schweiz (Obsan Bericht 01/2019).* Neuchâtel.

Joseph, A.E. and Bantock, P.R. (1982) 'Measuring potential physical accessibility to general practitioners in rural areas: a method and case study', *Social Science & Medicine (1982)*, 16(1), pp. 85–90. doi: 10.1016/0277-9536(82)90428-2

Joseph, A.E. and Phillips, D.R. (1984) *Accessibility and utilization: geographical perspectives on health care delivery.* New York: Harper & Row.

Kaiser, B. and Krähenbühl, M. (2020) *Kriterien und methodische Grundlagen für die Fest- legung der Höchstzahlen für Ärztinnen und Ärzte..*

Kalkbrenner, A.E. *et al.* (2011) 'Geographic access to health services and diagnosis with an autism spectrum disorder', *Annals of Epidemiology*, 21(4), pp. 304–310. doi: 10.1016/j.annepidem.2010.11.010.

Khan, A.A. (1992) 'An integrated approach to measuring potential spatial access to health care services', *Socio-Economic Planning Sciences*, 26(4), pp. 275–287. doi: 10.1016/0038-0121(92)90004-O

Khan, A.A. and Bhardwaj, S.M. (1994) 'Access to health care. A conceptual framework and its relevance to health care planning', *Evaluation & the Health Professions*, 17(1), pp. 60–76. doi: 10.1177/016327879401700104

Kwan, M.-P. (1998) 'Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-based Framework', *Geographical Analysis*, 30(3), pp. 191–216. doi: 10.1111/j.1538-4632.1998.tb00396.x

Laufer, M. *et al.* (2014) 'Pediatrician workforce planning: The Israeli experience and projections of pediatric manpower 1995–2025', *Journal of Hospital Administration*, 3(4), pp. 140–148. doi: 10.5430/jha.v3n4p140

Lenz, N. *et al.* (2020) 'Räumliche Zugänglichkeit zu tiermedizinischer Versorgung – eine GIS-basierte Analyse', *Schweizer Archiv fur Tierheilkunde*, 162(6), pp. 377–386. doi: 10.17236/sat00263

Lorenz, M.O. (1905) 'Methods of Measuring the Concentration of Wealth', *Publications of the American Statistical Association*, 9(70), pp. 209–219. doi: 10.2307/2276207

Love, D. and Lindquist, P. (1995) 'The geographical accessibility of hospitals to the aged: a geographic information systems analysis within Illinois', *Health Services Research*, 29(6), pp. 629–651.

Luo, J. (2014) 'Integrating the Huff Model and Floating Catchment Area Methods to Analyze Spatial Access to Healthcare Services', *Transactions in GIS*, 18(3), pp. 436–448. doi: 10.1111/tgis.12096

Luo, J. (2016) 'Analyzing Potential Spatial Access to Primary Care Services with an Enhanced Floating Catchment Area Method', *Cartographica: The International Journal for Geographic Information and Geovisualization*, 51(1), pp. 12–24. doi: 10.3138/cart.51.1.3230

Luo, W. and Qi, Y. (2009) 'An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians', *Health & Place*, 15(4), pp. 1100–1107. doi: 10.1016/j.healthplace.2009.06.002

Luo, W. and Wang, F. (2003) 'Measures of Spatial Accessibility to Healthcare in a GIS Environment: Synthesis and a Case Study in Chicago Region', *Environment and Planning. B, Planning & Design*, 30(6), pp. 865–884. doi: 10.1068/b29120

Luo, W. and Whippo, T. (2012) 'Variable catchment sizes for the two-step floating catchment area (2SFCA) method', *Health & Place*, 18(4), pp. 789–795. doi: 10.1016/j.healthplace.2012.04.002

Mao, L. and Nekorchuk, D. (2013) 'Measuring spatial accessibility to healthcare for populations with multiple transportation modes', *Health & Place*, 24(6), pp. 115–122. doi: 10.1016/j.healthplace.2013.08.008

Marmot, M. *et al.* (2008) 'Closing the gap in a generation: health equity through action on the social determinants of health', *Lancet (London, England)*, 372(9650), pp. 1661–1669. doi: 10.1016/S0140-6736(08)61690-6

McCrory, C. *et al.* (2015) 'The lasting legacy of childhood adversity for disease risk in later life', *Health Psychology : Official Journal of the Division of Health Psychology, American Psychological Association*, 34(7), pp. 687–696. doi: 10.1037/hea0000147

McGrail, M.R. and Humphreys, J.S. (2009) 'Measuring spatial accessibility to primary care in rural areas: Improving the effectiveness of the two-step floating catchment area method', *Applied Geography*, 29(4), pp. 533–541. doi: 10.1016/j.apgeog.2008.12.003

McGrail, M.R. and Humphreys, J.S. (2014) 'Measuring spatial accessibility to primary health care services: Utilising dynamic catchment sizes', *Applied Geography*, 54(1), pp. 182–188. doi: 10.1016/j.apgeog.2014.08.005

McGrail, M.R., Humphreys, J.S. and Ward, B. (2015) 'Accessing doctors at times of need-measuring the distance tolerance of rural residents for health-related travel', *BMC Health Services Research*, 15, p. 212. doi: 10.1186/s12913-015-0880-6

McIntyre, D., Thiede, M. and Birch, S. (2009) 'Access as a policy-relevant concept in low- and middle-income countries', *Health Economics, Policy, and Law*, 4(Pt 2), pp. 179–193. doi: 10.1017/S1744133109004836

Murphy, M.A. and Ruble, L.A. (2012) 'A Comparative Study of Rurality and Urbanicity on Access to and Satisfaction with Services for Children with Autism Spectrum Disorders', *Rural Special Education Quarterly*, 31(3), pp. 3–11. doi: 10.1177/875687051203100302

Ngui, A.N. and Apparicio, P. (2011) 'Optimizing the two-step floating catchment area method for measuring spatial accessibility to medical clinics in Montreal', *BMC Health Services Research*, 11. doi: 10.1186/1472-6963-11-166

Ni, J. *et al.* (2015) 'An Enhanced Variable Two-Step Floating Catchment Area Method for Measuring Spatial Accessibility to Residential Care Facilities in Nanjing', *International Journal of Environmental Research and Public Health*, 12(11), pp. 14490–14504. doi: 10.3390/ijerph121114490

Ni, J. *et al.* (2019) 'Multi-Mode Two-Step Floating Catchment Area (2SFCA) Method to Measure the Potential Spatial Accessibility of Healthcare Services', *ISPRS International Journal of Geo-Information*, 8(5). doi: 10.3390/ijgi8050236

Niethammer, D. (2009) 'Definition und Perspektiven des Faches', in Speer, C.P. and Gahr, M. (eds.) *Pädiatrie.* Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 3–5.

Nobles, M., Serban, N. and Swann, J. (2014) 'Spatial accessibility of pediatric primary healthcare: Measurement and inference', *The Annals of Applied Statistics*, 8(4), pp. 1922–1946. doi: 10.1214/14-AOAS728

Obsan (2023) *Swiss Health Care Atlas.* Neuchatel. Available at: https://www.versorgungsatlas.ch/en (Accessed: 3 August 2023).

pädiatrie schweiz (2022) *Kinderärzt:innen warnen vor bevorstehendem Versorgungsengpass: Medienmitteilung* [Press release]. 27 September. Available at: https://www.paediatrieschweiz.ch/news/bevorstehenden-versorgungsengpass/ (Accessed: 27 July 2023).

Parenteau, M.-P. and Sawada, M.C. (2011) 'The modifiable areal unit problem (MAUP) in the relationship between exposure to NO2 and respiratory health', *International journal of health geographics*, 10(1). doi: 10.1186/1476-072X-10-58

Penchansky, R. (1976) 'Access to Medical Care: Book Review', *Medical care*, 14(7), p. 642.

Penchansky, R. (1977) *The concept of access: a definition.* Hyattsville: National Health Planning Information Center.

Penchansky, R. and Thomas, J.W. (1981) 'The concept of access: definition and relationship to consumer satisfaction', *Medical Care*, 19(2), pp. 127–140. doi: 10.1097/00005650-198102000-00001

Peng, Z.-R. (1997) 'The Jobs–Housing Balance and Urban Commuting', *Urban Studies*, 34(8), pp. 1215–1235.

Plüss, M. (2022) 'Kindernotfällen droht der Kollaps', *NZZ am Sonntag,* 24 September. Available at: https://magazin.nzz.ch/nzz-am-sonntag/schweiz/schweizer-spitaeler-kindernotfaellen-droht-der-kollaps-ld.1704321?reduced=true (Accessed: 27 July 2023).

Polzin, P. (2014) *Integration of the assessments of access to health care and of competition between providers into a new method to identify target geographic markets*. Dissertation. Porto. Available at: http://hdl.handle.net/10216/79105 (Accessed: 30 July 2023).

Polzin, P., Borges, J. and Coelho, A. (2014) 'An Extended Kernel Density Two-Step Floating Catchment Area Method to Analyze Access to Health Care', *Environment and planning. B, Planning & design*, 41(4), pp. 717–735. doi: 10.1068/b120050p

Radke, J. and Mu, L. (2000) 'Spatial Decompositions, Modeling and Mapping Service Regions to Predict Access to Social Programs', *Annals of GIS*, 6(2), pp. 105–112. doi: 10.1080/10824000009480538

Reich, P. (2023) 'Sparpotenzial vorhanden? Das ist 2024 die tiefste Krankenkassen-Prämie in deiner Gemeinde: Daten BAG & BFS', *watson.ch,* 28 September. Available at: https://www.watson.ch/schweiz/leben/998987899-das-ist-2024-die-tiefste-krankenkassen-praemie-in-deiner-gemeinde (Accessed: 28 September 2023).

Riva, M. *et al.* (2008) 'Establishing the soundness of administrative spatial units for operationalising the active living potential of residential environments: an exemplar for designing optimal zones', *International Journal of Health Geographics*, 7(43). doi: 10.1186/1476-072X-7-43

SEM (2023a) *Fragen und Antworten für Geflüchtete aus der Ukraine: Medizinische Fragen,* 8 September. Available at: https://www.sem.admin.ch/sem/de/home/sem/aktuell/ukraine-krieg.html (Accessed: 10 September 2023).

SEM (2023b) *Kommentierte Asylstatistik 2022*. Bern-Wabern. Available at: https://www.sem.admin.ch/dam/sem/de/data/publiservice/statistik/asylstatistik/2022/stat-jahr-2022-kommentar.pdf.download.pdf/stat-jahr-2022-kommentar-d.pdf (Accessed: 17 August 2023).

Shipman, S.A. *et al.* (2011) 'Geographic maldistribution of primary care for children', *Pediatrics*, 127(1), pp. 19–27. doi: 10.1542/peds.2010-0150

Shipman, S.A., Lurie, J.D. and Goodman, D.C. (2004) 'The general pediatrician: projecting future workforce supply and requirements', *Pediatrics*, 113(3), pp. 435–442. doi: 10.1542/peds.113.3.435

Smith, M. (1986) *Physician's Specialties and Medical Trade Areas: An Application of Central Place Theory (Conference Paper). Papers and Proceedings of Applied Geography Conferences*. West Point NY.

Spital Oberengadin (2023) *Praxis für Kinder- und Jugendmedizin Engadin*. Available at: https://www.spital-oberengadin.ch/medizinische-leistungen/frau-mutter-kind/paediatrie-und-neonatologie/praxis-fuer-kinder-und-jugendmedizin-engadin (Accessed: 20 August 2023).

Stafford, M. *et al.* (2015) 'Childhood Environment and Mental Wellbeing at Age 60-64 Years: Prospective Evidence from the MRC National Survey of Health and Development', *PloS One*, 10(6). doi: 10.1371/journal.pone.0126683

Sturny, I. (2020) 'The Swiss Health Care System', in *2020 International Profiles of Health Care Systems*, pp. 191–200 (Accessed: 17 July 2023).

Subal, J., Paal, P. and Krisp, J.M. (2021) 'Quantifying spatial accessibility of general practitioners by applying a modified huff three-step floating catchment area (MH3SFCA) method', *International Journal of Health Geographics*, 20(1). doi: 10.1186/s12942-021-00263-3

Tao, Z. *et al.* (2018) 'Spatial accessibility to healthcare services in Shenzhen, China: improving the multimodal two-step floating catchment area method by estimating travel time via online map APIs', *BMC Health Services Research*, 18(1). doi: 10.1186/s12913-018-3132-8

Tao, Z., Cheng, Y. and Liu, J. (2020) 'Hierarchical two-step floating catchment area (2SFCA) method: measuring the spatial accessibility to hierarchical healthcare facilities in Shenzhen, China', *International Journal for Equity in Health*, 19(1). doi: 10.1186/s12939-020-01280-7

Transforming our world: the 2030 Agenda for Sustainable Development 2015, UN SDG's.

United States Census Bureau (no date) *Glossary*. Available at: https://www.census.gov/programs-surveys/geography/about/glossary.html (Accessed: 15 August 2023).

Universal Declaration of Human Rights 1948, UN UDHR (Paris).

VM-UVEK (2019) *Verkehrsmodellierung im UVEK; Daten Zustand 2017* (Accessed: 2 January 2023).

Vo, A., Plachkinova, M. and Bhaskar, R. (2015) *Assessing Healthcare Accessibility Algorithms: A Comprehensive Investigation of Two-Step Floating Catchment Methodologies Family (Conference Paper). Americas Conference on Information Systems.* Puerto Rico.

Voigtländer, S. and Deiters, T. (2015) 'Mindeststandards für die räumliche Erreichbarkeit hausärztlicher Versorgung: Ein systematischer Review', *Gesundheitswesen (Bundesverband der Arzte des Offentlichen Gesundheitsdienstes (Germany))*, 77(12), pp. 949–957. doi: 10.1055/s-0035-1548805

von Rhein, M., Haldimann, L. and Jörg, R. (2023) *Access to Pediatric Care in Switzerland: Regional Differences and Future Outlook [Manuscript in preparation].*.

Vries, J.J. de, Nijkamp, P. and Rietveld, P. (2009) 'Exponential or Power Distance-Decay for Commuting? An Alternative Specification', *Environment and Planning A: Economy and Space*, 41(2), pp. 461–480. doi: 10.1068/a39369

Wan, N., Zou, B. and Sternberg, T. (2012) 'A three-step floating catchment area method for analyzing spatial access to health services', *International Journal of Geographical Information Science*, 26(6), pp. 1073–1089. doi: 10.1080/13658816.2011.624987

Wang, F. (2012) 'Measurement, Optimization, and Impact of Health Care Accessibility: A Methodological Review', *Annals of the Association of American Geographers. Association of American Geographers*, 102(5), pp. 1104–1112. doi: 10.1080/00045608.2012.657146

Wang, F. (2014) *Quantitative Methods and Socio-Economic Applications in GIS*. 2nd edn. Boca Raton: CRC Press.

Wang, L. (2007) 'Immigration, ethnicity, and accessibility to culturally diverse family physicians', *Health & Place*, 13(3), pp. 656–671. doi: 10.1016/j.healthplace.2006.10.001

Weber, P. and Jenni, O. (2012) 'Screening in child health: studies of the efficacy and relevance of preventive care practices', *Deutsches Arzteblatt International*, 109(24), pp. 431–435. doi: 10.3238/arztebl.2012.0431

Wehrle, F.M. *et al.* (2020) 'The Importance of Childhood for Adult Health and Development-Study Protocol of the Zurich Longitudinal Studies', *Frontiers in Human Neuroscience*, 14(612453). doi: 10.3389/fnhum.2020.612453

Weibull, J.W. (1976) 'An axiomatic approach to the measurement of accessibility', *Regional Science and Urban Economics*, 6(4), pp. 357–379. doi: 10.1016/0166-0462(76)90031-4

Weinhold, I. *et al.* (2022) 'Assessing patients' acceptable and realised distances to determine accessibility standards for the size of catchment areas in outpatient care', *Health Policy (Amsterdam, Netherlands)*, 126(11), pp. 1180–1186. doi: 10.1016/j.healthpol.2022.08.011

Wennberg, J. and Gittelsohn (1973) 'Small area variations in health care delivery', *Science (New York, N.Y.)*, 182(4117), pp. 1102–1108. doi: 10.1126/science.182.4117.1102

Wennberg, J.E. (2014) 'Forty years of unwarranted variation--and still counting', *Health Policy (Amsterdam, Netherlands)*, 114(1), pp. 1–2. doi: 10.1016/j.healthpol.2013.11.010

Zuercher, C. (2018) 'La pénurie de pédiatres touche de plein fouet les régions périphériques', *Le Matin Dimanche,* 30 September, pp. 10–11.

Appendix A. The Optimal Q

To understand the influence of Q (minimum required reached suppliers) different analysis were performed with a selection of Q's (1-10, 12, 15, 20, 30, 40, 50).

A.1 Populations Supplied Inadequately

This analysis follows the intuition that people tent do lock for further options if the first q options are not sufficient to fulfill their needs. Therefore, the question is the following: What is the percentage of those (people or NPVM zones) who have a nearby service available ($d_{min} = 0$), yet still exhibit poor accessibility i.e. SPAI in the lowest or two second lowest quintiles (quintile 1 as well quintile 1 & 2). Unsurprisingly, the measures by population of by zones exhibit very similar behavior, due to the design idea behind the NPVM zone delineation. A stabilization of the percentages inadequately supplied can be seen from $Q \geq 6$. This can be read as meaning that a small percentage of the population and zones can increase their spatial accessibility from taking further supplies into consideration (higher Q). After six roughly or more supplies, this percentage does not change anymore, especially for those with the lowest SPAI's.

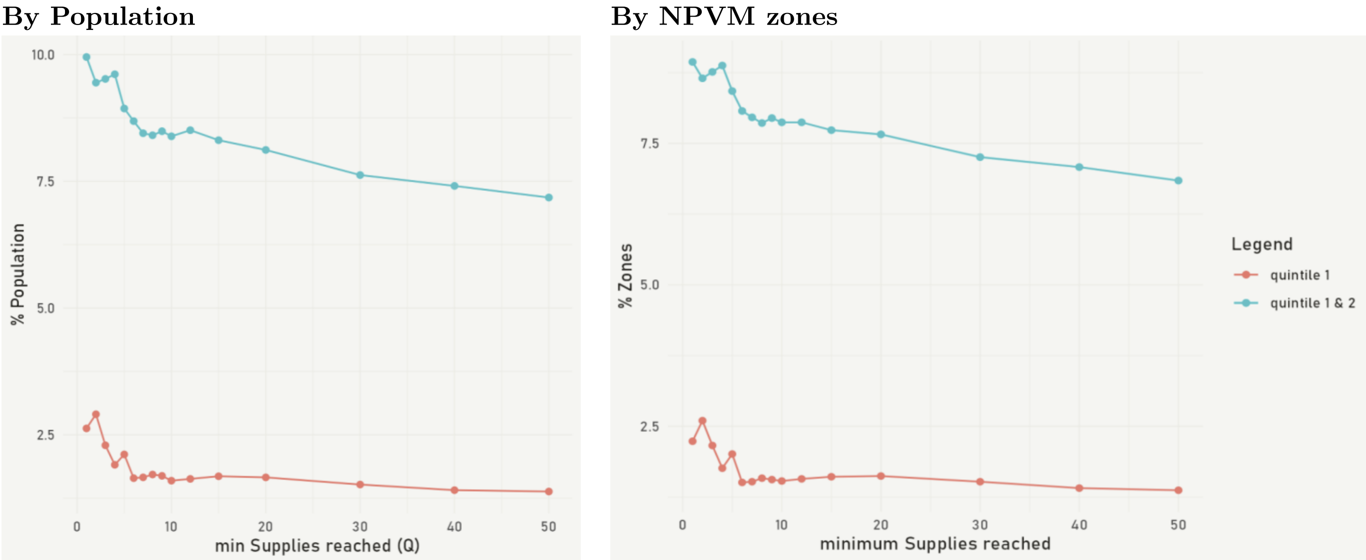

Fig A 1: Population/zones that show a low SPAI despite having a supply location within close range, depending on Q.

Very similar to the analysis above, the figure below shows which NPVM zones face a very low spatial accessibility (lowest SPAI quintile) when *Q=1*, but which increase their SPAI to at least the second lowest quintile when *Q=6*.

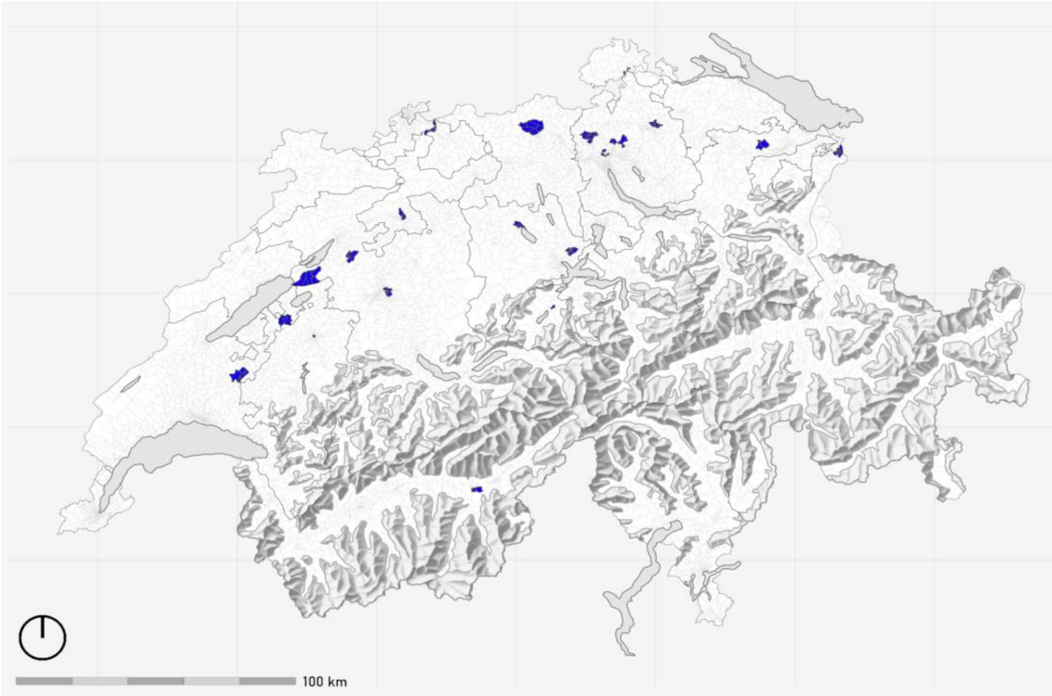

Fig A 2: NPVM-Zones that show improved spatial accessibility with higher Q. Therefore: i=quintile 1 | Q=1 and i≠quintile 1 | Q=6

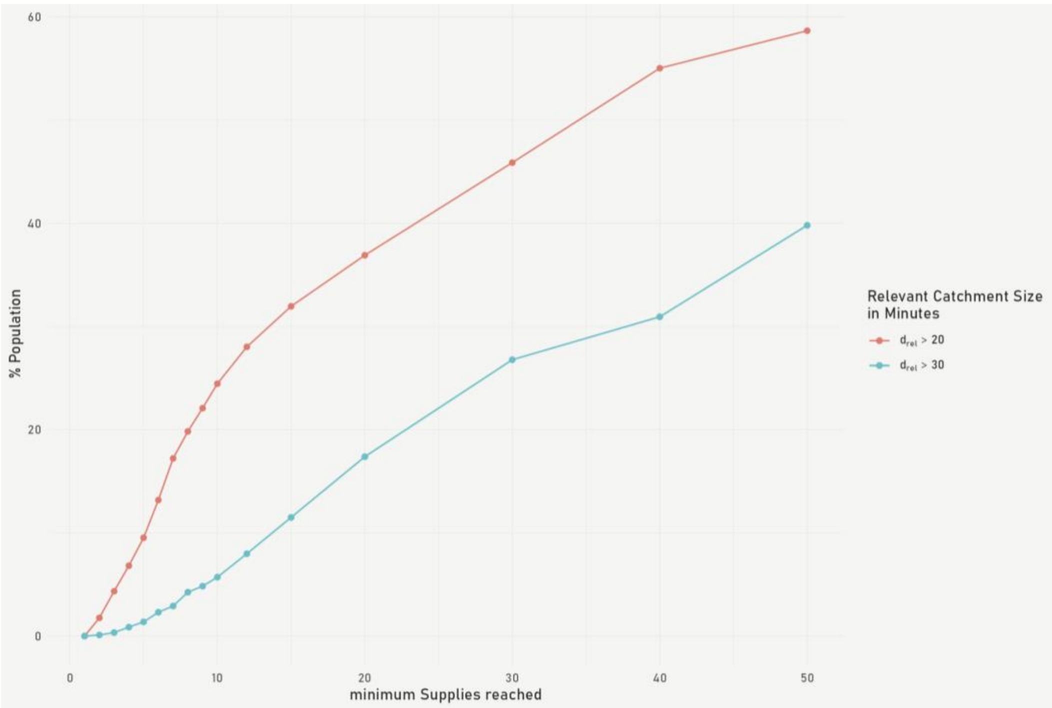

Fig A 3: Percentage of populations that have a close supply ($d_{min} = 10$) but travel (unrealistically) far ($d_{rel} > 20$ or $d_{rel} > 30$) to reach the required Q.

$$\text{Calculation: } \frac{\sum_{i \in \{d_{min}=10\ \&\ d_{max}>20\}} Pop_i}{\sum Pop_i} \times 100, \frac{\sum_{i \in \{d_{min}=10\ \&\ d_{max}>30\}} Pop_i}{\sum Pop_i} \times 100$$

Increasing *Q*, and thus expanding the relevant catchment sizes (sending people further) can also lead to unrealistic behavior and should be kept in mind. Put in other words, it must be ensured that people are not sent out too far as seen in Fig A 3. It is not possible to determine a clear *Q* that changes behavior significantly. Only a slight change in slope steepness can be made out around *Q = 6* for those where their relevant catchment is bigger than 20 minutes, despite having a close supply.

A.2 Supplies Facing Optimal Demand.

As discussed elsewhere a provider to demand ratio of 1 FTE/1,000 relevant inhabitants is seen as an indicator for an adequate healthcare provision. For this the results from step 2 in the MHV3SFCA-calculation can be used. Step 2 provides the supply-ratios R_j. Fig A 4 shows that for approx. $Q \geq 6$ a stable percentage of supplies that face optimal demand is reached. Moreover, the percentage of supply locations that see a high demand (green line) reaches a local minimum around $Q = 6$. Furthermore, supplies that see relatively low demand (red line), i.e. that would likely have free capacities, decline noticeably.

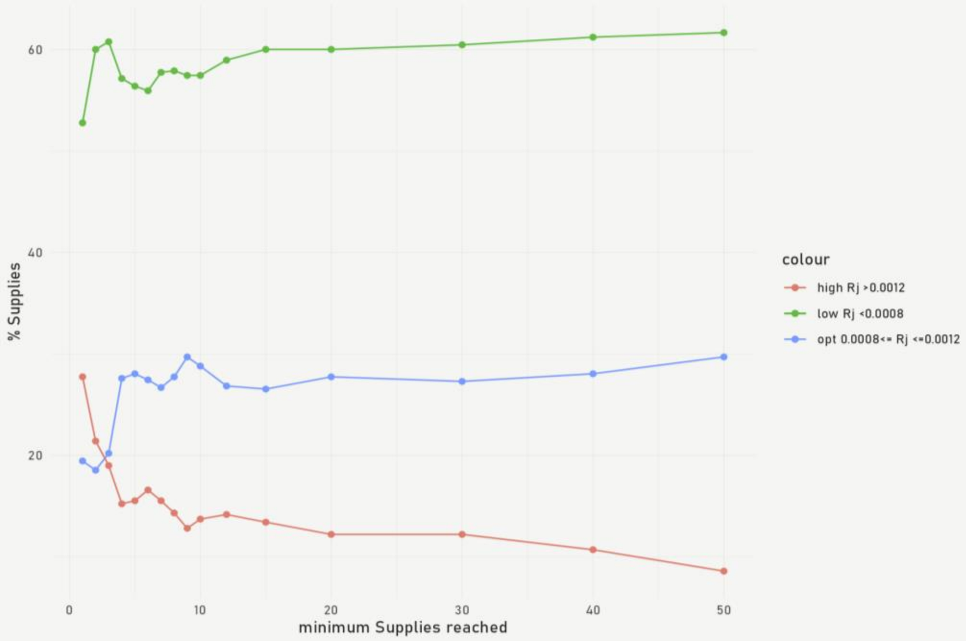

Fig A 4: Percentage of supplies with low, high and optimal supply ratios R_j.

Reading aid: $R_j = 0.0012 \approx \frac{1\ FTE}{833\ inhabitants}$, $R_j = 0.0008 \approx \frac{1\ FTE}{1250\ inhabitants}$,

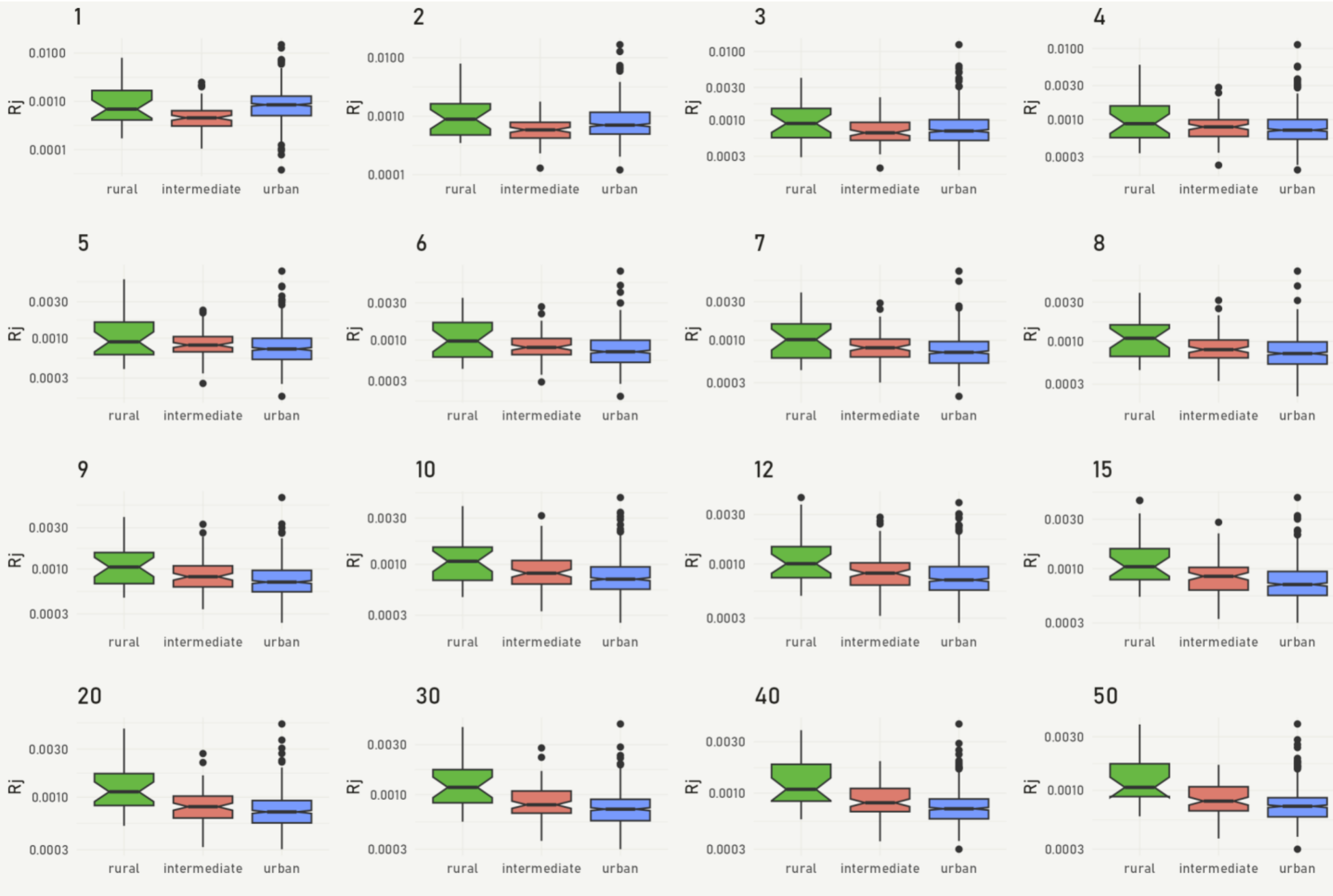

Fig A 5: Supply-ratios R_j depending on urbanity (urban-rural-classification 2012) and required Q. Q's are found on upper left corner of each subplot.

With increasing Q and therefore relevant catchment sizes, rural supply sites start to face less demand pressure, which is instead directed towards urban supplies (green boxplot moves up, blue boxplot moves down). This means that rural populations can no longer reach the required Q "locally" and expand their catchment to cities where they suddenly face many more options. It is difficult to make out a definitive turning point, but around $Q = 6$, is at approximately 1FTE/1,000 inhabitants for rural suppliers, yet without having an overly strong influence on urban suppliers.

A.3 Intrazonal Demand

It would also be interesting to know how often intrazonal relationships alone are relevant (meaning that distances according to NPVM distance matrices do not play a role at all, as they are an approximation anyway and later set to 10 minutes). This naturally depends on the chosen intrazonal travel times, base catchment size, the selected distance increments in catchment calculation, and the minimum number of practices that need to be reachable (Q). The following analysis is performed to determine the influence of Q on the extent of intrazonal demand. It is important to note that pediatricians in these zones do not solely cater to intrazonal demand. In total, there are 663 traffic zones with at least one practice. With $Q = 1$, out of these, in 178 zones, the population of these zones exclusively inquire within their own zone (exclusive intrazonal demand). Due to the data privacy agreement, these zones are not shown. The distribution of said zones is uniform across the entire study area and no regions show any anomaly. In this case (*intrazonal travel time = 10 minutes, 1st distance increment = 10 minutes,* $Q = 1$), within the first 10-minute step, there is no additional reachable service for 178 zones. This corresponds to 2.24% of the zones or 2.55% of the demanding population. However, for 485 zones with their own offering, there is at least one more accessible service within 10 minutes. With $Q = 2$ or higher, there is no exclusively intrazonal demand.

Appendix B. R Code

B.1 R Packages Used

```
library(sf)
library(tidyverse)
library(ggplot2)
library(rgdal)
library(raster)
library(fca)
library(reshape2)
library(viridis)
library(ggspatial)u
library(RColorBrewer)
library(classInt)
library(ggsn)
library(matrixStats)
library(ggpubr)
library(ggrepel)
library(scales)
library(ggpol)
library(gghalves)
library(gridExtra)
library(extrafont)
```

B.2 Data processing

```
########################################
### MANIPULATION OF INTRAZONAL TRAVEL TIMES
NPVM_mtrx <- readRDS("Daten/Processed/NPVM/NPVM_mtrx.rds")
intrazonaltt <- diag(NPVM_mtrx)

intrazonaltt <- enframe(intrazonaltt, name = "ID", value = "traveltime")
class(intrazonaltt$ID) = "double"

# sets all intrazonal travel times to a maximum of 10
manip_iztt <- intrazonaltt%>%
  mutate(manipulated = case_when(traveltime >=10 ~ 10,
                                 TRUE ~ traveltime))

# Replacing the intrazonal travel times in NPVM matrix
replace_vec = manip_iztt$manipulated
NPVM_mtrx_mod <- NPVM_mtrx
diag(NPVM_mtrx_mod) = replace_vec

########################################
### CLASSIFICATION OF TRAVELTIMES

# FUNCTION MTRX.CLASSIFIER
# mtrx = matrix, with continuous travel times
# classes = vector, containing classes for classification
# Note, values higher than highest classification step are left unchanged, this has to
# be coordinated with the use of d.rel.vec for FCA calculation
mtrx.classifier <- function(mtrx,
                            classes) {
  mtrx[mtrx <= classes[1]] <- classes[1]
  for (c in 1:(length(classes)-1)){
    mtrx[mtrx > classes[c] & mtrx <= classes[c+1]] <- classes[c+1]
  }
  return(mtrx)
}

NPVM_mtrx_mod_c <- mtrx.classifier(NPVM_mtrx_mod, c(10))
```

```
########################################
### Initializing Demand Supply distance matrix

## expand.grid() has element 1 (pop indices/ids) varying fastest
M <- as.matrix(expand.grid(POPsumID$ID, SUPsumID$ID))
## next step is unnecessary if `id` elements are already character ...
storage.mode(M) <- "character"

PopSupDist_mtrx <- matrix(NPVM_mtrx[M],
                          byrow = TRUE,
                          nrow = nrow(SUPsumID),
                          dimnames= list(SUPsumID$ID, POPsumID$ID))
```

B.3 MH3SVFCA-functions

```
### Function Relevant Catchment Size
# returns vector with relevant catchment sizes for all populations
# relevant catchment is defined by reaching either Q amount of practices or reaching th
e set d_max

# D = distance matrix
# d_max = max catchment size ("max search radius")
# Q = min amount practices in catchment required
# basesize = core size catchment size before widening of search distance. Reflects the
idea that very short travel times don't matter, default = 10
# increment = step by which relevant catchment size is increased (mins or metric distan
ce, depending on matrix used), default = 1

d.rel <- function(D, d_max ,Q ,basesize = 10, increment = 1) {
  # vector with relevant catchment sizes for all populations
  relcatch <- c()
  for (col in 1:ncol(D)){
    drel = basesize
    #counts how many suppliers have been catched with current traveltime
    catched = 0
    while(catched < Q && drel <= d_max) {
      catched = length(subset(D[,col],D[,col] <= drel))
      drel = drel + increment
    }
    relcatch <- append(relcatch, drel-increment)
  }
  return(relcatch)
}

### instead of linear increase search radius (increment) a vector is supplied defining
"search steps"
# incrementvec = vector containing the steps for the increasing of the search radius

d.rel.vec <- function(D, d_max ,Q ,basesize = 0, incrementvec ) {
  # check
  # for logic to work, sum of increments must add up to the maximum search radius
  if(!(basesize + sum(incrementvec) == d_max))
    {stop("inval: search radi must add up to d_max")}
  #append 1 to vector for logic in while loop, for the case that no supply is caught
  incrementvec <- append(incrementvec, 1)
  # vector with relevant catchment sizes for all populations
  relcatch <- c()
  for (col in 1:ncol(D)){
    drel = basesize
    #counts how many suppliers have been caught with current travel time
    catched = 0
    aux= 0
```

```
    while(catched < Q && drel <= d_max) {
      catched = length(subset(D[,col],D[,col] <= drel))
      aux = aux +1
      drel = drel + incrementvec[aux]
    }
    relcatch <- append(relcatch, drel-incrementvec[aux]) # -1 to deduct last (unnecessa
ry iteration) of while loop that has been artificially added
  }
  return(relcatch)
}

########################################
### Function for creating binary Matrix to check whether a supply site is within releva
nt catchment of a population
# Arguments:
# D = Distance matrix
# catchments = List with relevant catchment size for each population / output of functi
on d.rel or d.rel.vec
# return = Matrix with binary values for each Population-Supply combination

sup.catched <- function(D, catchments){
  sup_catched <- t(apply(D, 1, function(x) ifelse(x <= catchments, 1, 0)))
  return(sup_catched)
}

########################################
### MHV3SFCA | FCA Function, SPAI and SDI Calculation
# Adapted function from FCA package

# Modified-Huff-VARIABLE-Three-Step Floating Catchment Area method
# p numeric vector, number of population at origin locations
# s numeric vector, capacity of services at supply locations
# W numeric matrix, weighted distance or time matrix
# B numeric matrix, binary values indicating if supply location is within relevant catc
hment of population
# step numeric, number of the steps of the method to perform
# return data.frame, depending on selected step

spai_mhv3sfca <- function(p, s, W, B, step = 3) {
  #if (!step %in% seq_len(3)) stop("Invalid `step` value")
  step1 <- sweep(s * W * B, 2, colSums(s * W* B), FUN = "/")
  step1[is.nan(step1)] = 0
  if (step == 1) {
    return(data.frame(step1))
  }
  step2 <- s / colSums(p * t(step1))
  step2[is.infinite(step2)] = 0
  if (step == 2) {
    return(data.frame(step2))
  }
  # calculating supply density index (SDI), this is the same as step3 but leaving out t
he weights W, and adding a factor to get results per 1000 inhabitants
  step2.5 <- colSums(step1 * step2 * 1000)
  if (step ==2.5){
    return(data.frame(step2.5))
  }
  # calculating SPAI
  step3 <- colSums(step1 * W * step2)
  return(data.frame(step3))
}
```

B.4 MHV3SFCA-calculations

```
### Setting PARAMS

# Maximum search distance
d_max = 60

# minimum number of supplies
Q = 5

# Base catchment size
basecatch = 10

#######################################
## Population and Supply Vectors

#p <- setNames(statpop19$B19MWTOT, as.character(statpop19$pop_index))
p <- setNames(POPsumID$TOTChldID ,as.character(POPsumID$ID))
# [1:1000]

s <- setNames(SUPsumID$TotFTEsupID, as.character(SUPsumID$ID))
# s[1:100]

#######################################
## Normalizing Distance matrix

# Hardcoding distance classes, but for the weighting matrices the average distance with
in distance classes is taken
meanDist_mtrx <- PopSupDist_mtrx

meanDist_mtrx[meanDist_mtrx <= 10] <- 5

WghtdDist_mtrx <- dist_normalize(meanDist_mtrx, d_max, "gaussian")

#######################################
## Catchment calculations

# relevant catchments for populations
rel_catchments <- d.rel(PopSupDist_mtrx, d_max, Q, basecatch, increment = 1)

# Indicator matrix
B <- sup.catched(PopSupDist_mtrx, rel_catchments)

######################################
## calculating SPAI

SPAI_Result <- spai_mhv3sfca(p, s, WghtdDist_mtrx, B, step = 3)

## calculating SDI

SDI_Result <- spai_mhv3sfca(p, s, WghtdDist_mtrx, B, step = 2.5)
```

B.5 Spatial Aggregation

```
### Aggregating hectare results from OBSAN to NPVM-Zones

#Intersecting SPAI with NPVM-Zones
SPAI_Obsan_zns <- st_intersection(SPAI_obsan_sptl, trafficzns)

## TESTING FOR OUT OF BOUND CASES
#dealing with Population points that are out of bounds and get not assigned a traffic z
one (lying outside of borders,
#likely due to offsetting Raster rootpoint)
```

```
# anti_join requires only A to have a geometry thus dropping it here
SPAI_Obsan_znsWOG <- st_drop_geometry(SPAI_Obsan_zns)

#All rows in a that do not have a match in b
outofbounds <- dplyr::anti_join(SPAI_obsan_sptl, SPAI_Obsan_znsWOG, by = "DEM_ID")
# these  have to be joined with the nearest traffic zone
POPretrieved <- st_join(outofbounds, trafficzns, join = st_nearest_feature)

# Append retrieved to all others as new rows
SPAI_Obsan_zns <- dplyr::bind_rows(SPAI_Obsan_zns, POPretrieved)

# Simplifing data, summarize all populations within traffic zone
SPAI_wtmean_znID <- SPAI_Obsan_zns%>%
  group_by(ID)%>%
  mutate(wtSPAI = weighted.mean(spai_MHV3SFCA, ebl_orig))%>%
  summarise(wtSPAI = first(wtSPAI))%>% # no problem because all values are the same wit
hin ID
  st_drop_geometry()

# calculate mean of SPAI of zones where demand was zero and thus couldn't be calculated
by the weighed method
SPAI_mean_znID_nan <- SPAI_Obsan_zns%>%
  group_by(ID)%>%
  mutate(wtSPAI = weighted.mean(spai_MHV3SFCA, ebl_orig))%>%
  filter(is.na(wtSPAI))%>%
  group_by(ID)%>%
  mutate(meanSPAI = mean(spai_MHV3SFCA))%>%
  summarise(meanSPAI = first(meanSPAI))%>%
  rename(wtSPAI = meanSPAI)%>% # rename for next step
  st_drop_geometry()

# complete data with retrieved SPAI values
SPAI_wtmean_znID_nr <- SPAI_wtmean_znID%>%
  filter(!is.na(wtSPAI))%>%
  bind_rows(SPAI_mean_znID_nan)

#######################################
# calculating relevant catchment sizes per zone
Catchment_Radius <- SPAI_Obsan_zns%>%
  group_by(ID)%>%
  mutate(wtRadius = weighted.mean(max_effective_radius, ebl_orig))%>%
  summarise(wtRadius = first(wtRadius))%>% # no problem because all values are the same
within ID
  st_drop_geometry()

# calculate mean of SPAI of zones where demand was zero and thus couldn't be calculated
by the weighed method
Radius_mean_znID_nan <- SPAI_Obsan_zns%>%
  group_by(ID)%>%
  mutate(wtRadius = weighted.mean(max_effective_radius, ebl_orig))%>%
  filter(is.na(wtRadius))%>%
  group_by(ID)%>%
  mutate(meanRadius = mean(max_effective_radius))%>%
  summarise(meanRadius = first(meanRadius))%>%
  rename(wtRadius = meanRadius)%>% # rename for next step
  st_drop_geometry()

# complete Data with retrieved SPAI values
Catchment_Radius_wtmean <- Catchment_Radius%>%
  filter(!is.na(wtRadius))%>%
  bind_rows(Radius_mean_znID_nan)


#######################################
```

```
SPAI_JH_base<- trafficzns%>%
  inner_join(POPsumID, by= "ID")%>%
  inner_join(SPAI_wtmean_znID_nr, by= "ID")%>%
  inner_join(Catchment_Radius_wtmean, by= "ID")%>%
  rename(SPAI = wtSPAI)%>%
  rename(relevant_catchment = wtRadius)%>%
  st_as_sf()%>%
  mutate(quintile = factor(findInterval(SPAI,
                                        c(-Inf,
                                          quantile(SPAI,
                                                   probs=c(0.2, 0.4, 0.6, 0.8),
                                                   na.rm = TRUE),
                                          Inf)),
                           labels=c("1", "2", "3", "4", "5")))

########################################
### Aggregator function from NPVM-zones to municipalities
# this function aggregates SPAIs from zones to municipalities

# spaidata = class sf, results on NPVM level, must have columns: ID, SPAI
# population = dataframe 2 vars, NPVM ID and population, CAUTION this is what the weigh
ting is done with
# npvmcentroids = class sf, NPVM-Zone centroids delivered
# municipalities = class sf, geometries of municipalities CAUTION aggregation dependent
on year due to mergers

GMD.aggregator <- function(spaidata,
                           population,
                           npvmcentroids,
                           municipalities){
  # joining Population within zones
  step1 <- spaidata%>%
    inner_join(population, by="ID")%>%
    st_drop_geometry()%>%
    inner_join(npvmcentroids, by = "ID")%>%
    st_as_sf()

  # i want to know in which gemeinde the zones are today
  # due to constantly merging municipalities a spatial join is best option
  # for that the NPVM-Zone centroids are used
  step2 <- st_join(step1, municipalities, left= TRUE)%>%
    st_drop_geometry()

  # Simplifying data, summarize all populations within traffic zone
  step3 <- step2%>%
    group_by(bfs_nummer)%>%
    mutate(wtSPAI_GMD = weighted.mean(SPAI, TOTChldID))%>%
    summarise(SPAI = first(wtSPAI_GMD))%>%  # no problem because all values are the sam
e
    mutate(quintile = factor(findInterval(SPAI,
                                          c(-Inf,
                                            quantile(SPAI,
                                                     probs=c(0.2, 0.4, 0.6, 0.8),
                                                     na.rm = TRUE),
                                            Inf)),
                             labels=c("1", "2", "3", "4", "5")))      # Recategorize SPA
I's into quintiles
  step3.1 <- step2%>%
    group_by(bfs_nummer)%>%
    mutate(wtRelevant_catchment_GMD =weighted.mean(relevant_catchment, TOTChldID))%>%
    summarise(wtRelevant_catchment = first(wtRelevant_catchment_GMD))

  step3.2 <- step2%>%
    group_by(bfs_nummer)%>%
```

```
    mutate(wtSumaccess_GMD =weighted.mean(Sumaccess, TOTChldID))%>%
    summarise(wtSumaccess = first(wtSumaccess_GMD))

  # join step3 to municipality geometries for plotting
  Result <- municipalities%>%
    left_join(step3, by ="bfs_nummer")%>%
    left_join(step3.1, by ="bfs_nummer")%>%
    left_join(step3.2, by ="bfs_nummer")

  return(Result)
}
```

B.6 Maps for SPAI and SDI

```
########################################
### Map Theme
theme.map <- function(...) {
  theme_minimal() +
    theme(
      text = element_text(family = "Bahnschrift", color = "#22211d"),
      axis.line = element_blank(),
      axis.text.x = element_blank(),
      axis.text.y = element_blank(),
      axis.ticks = element_blank(),
      axis.title.x = element_blank(),
      axis.title.y = element_blank(),
      # panel.grid.minor = element_line(color = "#ebebe5", size = 0.2),
      panel.grid.major = element_line(color = "#ebebe5", size = 0.2),
      panel.grid.minor = element_blank(),
      plot.background = element_rect(fill = "#f5f5f2", color = NA),
      panel.background = element_rect(fill = "#f5f5f2", color = NA),
      legend.background = element_rect(fill = "#f5f5f2", color = NA),
      panel.border = element_blank(),
      ...
    )
}

########################################
### Wrapper function for ggplot to plot map of SPAI

# spaidata = class sf, results categorized in quintiles CAUTION: CRS must be the same o
ver all spatial object
# relief = Raster hillshade CAUTION: CRS must be the same over all spatial object
# lakes = class sf,  CAUTION: CRS must be the same over all spatial object
# kantone = class sf,  CAUTION: CRS must be the same over all spatial object
# export = logical indicating if export is wanted,
# exportpath = string, location
# exportfile = string, name
# exportdevice = string, "eps", "ps", "tex" (pictex), "pdf", "jpeg", "tiff", "png", "bm
p", "svg" or "wmf" (windows only).

map.wrapper.CH <- function(title = "title",
                           subtitle ="subtitle",
                           credits = "credits",
                           legendtitle = "Accessibility",
                           modelparams = "",
                           spaidata,
                           lwd = 0.05,
                           relief,
                           kantone = NULL,
                           lakes,
                           cities = citiesKT,
```

```
                            export = FALSE,
                            exportpath = NULL,
                            exportfile = subtitle,
                            exportdevice = c( "png","eps", "ps", "tex", "pdf", "jpeg", "
tiff", "png", "bmp", "svg", "wmf")){
  plot <- ggplot() +
    # first: draw the relief
    geom_raster(
      data = relief,
      inherit.aes = FALSE,
      aes(x = x,
          y = y,
          alpha = value)
    )+
    # use the "alpha hack" (as the "fill" aesthetic is already taken)
    scale_alpha(name = "",
                range = c(0.6, 0),
                guide = F # suppress legend
    )+
    # Add the polygon layer
    geom_sf(data = spaidata,
            aes(fill = quintile),
            lwd= lwd,
            color = "white",
            alpha = 0.8
    )+
    geom_sf(data = kantone,
            fill = "transparent",
            lwd = 0.3,
            color = "white"
    )+
    geom_sf(data = Switzerland,
            fill = "transparent",
            lwd = 0.3,
            color = "grey"
    )+
    # Add lakes
    geom_sf(data= lakes
    )+
    geom_sf(data =cities,
            pch= 1,
            size =1
    )+
    geom_text_repel(
      mapping = aes(geometry = geometry,
                    label=city),
      bg.color = "white",
      bg.r = 0.1,
      data = cities,
      stat = "sf_coordinates",
      family = "Bahnschrift",
      color= "#22211d",
      size = 3,
      fontface="italic",
      parse = FALSE,
      nudge_x = 0,
      nudge_y = 0,
      na.rm = FALSE,
      show.legend = FALSE,
      inherit.aes = TRUE,
      fun.geometry = NULL
    )+
    scale_fill_manual(
      values = rev(magma(8, alpha = 1)[2:7]),
```

```
      breaks = waiver(),
      labels=c("1 lowest", "2", "3",'4','5 highest'),
      name = legendtitle,
      drop = FALSE,
      na.translate = FALSE,
      guide = guide_legend(
        direction = "horizontal",
        keyheight = unit(4, units = "mm"),
        keywidth = unit(5/length(labels), units = "mm"),
        title.position = 'top',
        title.hjust = 0.5,
        label.position = "right",
        label.hjust = 0,
        ncol = 1,
        byrow = T,
        reverse = T,
        )
      )+
    # Set the color scale and legend
    annotation_scale(location = "bl",
                     width_hint = 0.4,
                     line_width = 0.1,
                     bar_cols = c("darkgrey", "lightgrey"),
                     pad_y = unit(0.05, "cm"),
                     pad_x = unit(0.15, "cm"),
                     height = unit(0.15, "cm"),
                     text_family = "Bahnschrift"
    )+
    north(location ="bottomleft",
          scale = 0.08,
          symbol = 13,
          x.min = 2464000,
          x.max = 2866429,
          y.min = 1061258,
          y.max = 1302922
    )+
    coord_sf(crs = 2056,
             datum = sf::st_crs(2056)
    )+
    theme.map()+
    theme(legend.position = "right",
          plot.title = element_text(size = 15
                                    ),
          plot.caption = element_text(size = 7,
                                      hjust = 0,
                                      vjust = -0.9,
                                      margin = margin(t = 0,
                                                      b = 0,
                                                      unit = "cm"),
                                      color = "#939184",
                                      debug = FALSE)
    )+
    labs(title = title,
         subtitle = subtitle,
         caption = paste(modelparams, "\n", credits,
                         sep="")
    )

  if(export == TRUE){
    ggsave(
      paste(exportfile, ".",exportdevice, sep =""),
      plot = plot,
      device = exportdevice,
      path = exportpath,
```

```
      scale = 1,
      width = 29.7,
      height = 21,
      units = "cm",
      dpi = 300,
      limitsize = TRUE,
      bg = NULL,)
    print("plot saved")
  }
  return(plot)
}

########################################
## Wrapper function for ggplot to map SDI
# Basically identical to map.wrapper.CH but with SDI instead of SPAI
map.wrapper.CH.sdi <- function(title = "title",
                               subtitle ="subtitle",
                               credits = "credits",
                               legendtitle = "SDI",
                               modelparams = "",
                               spaidata,
                               lwd = 0.05,
                               relief,
                               kantone = NULL,
                               lakes,
                               cities = citiesKT,
                               export = FALSE,
                               exportpath = NULL,
                               exportfile = subtitle,
                               exportdevice = c( "png","eps", "ps", "tex", "pdf", "jpeg
", "tiff", "png", "bmp", "svg", "wmf")){
  plot <- ggplot() +
    # first: draw the relief
    geom_raster(
      data = relief,
      inherit.aes = FALSE,
      aes(x = x,
          y = y,
          alpha = value)
    )+
    # use the "alpha hack" (as the "fill" aesthetic is already taken)
    scale_alpha(name = "",
                range = c(0.6, 0),
                guide = F # suppress legend
    )+
    # Add the polygon layer
    geom_sf(data = spaidata,
            aes(fill = SDI_clssd),
            lwd= lwd,
            color = "white",
            alpha = 0.8
    )+
    geom_sf(data = kantone,
            fill = "transparent",
            lwd = 0.3,
            color = "white"
    )+
    geom_sf(data = Switzerland,
            fill = "transparent",
            lwd = 0.3,
            color = "grey"
    )+
    # Add lakes
```

```
    geom_sf(data = lakes
    )+
    geom_sf(data = cities,
            pch= 1,
            size =1
    )+
    geom_text_repel(
      mapping = aes(geometry = geometry,
                    label=city),
      bg.color = "white",
      bg.r = 0.1,
      data = cities,
      stat = "sf_coordinates",
      family = "Bahnschrift",
      color= "#22211d",
      size = 3,
      fontface="italic",
      parse = FALSE,
      nudge_x = 0,
      nudge_y = 0,
      na.rm = FALSE,
      show.legend = FALSE,
      inherit.aes = TRUE,
      fun.geometry = NULL
    )+
    scale_fill_manual(
      values = c("#865A7B","#be7491", "#859da6","#8EB57F","#abc89f"),#rev(c("#FFE5A9","
#8EB57F","#859da6","#ae96bd","#be7491")),
      breaks = waiver(),
      labels=c("< 0.6", "0.6 - 0.69", "0.7 - 0.79", "0.8 - 1.2", "> 1.2"),
      name = legendtitle,
      drop = FALSE,
      na.translate = FALSE,
      guide = guide_legend(
        direction = "horizontal",
        keyheight = unit(4, units = "mm"),
        keywidth = unit(5/length(labels), units = "mm"),
        title.position = 'top',
        title.hjust = 0.5,
        label.position = "right",
        label.hjust = 0,
        ncol = 1,
        byrow = T,
        reverse = T,
      )
    )+
    # Set the color scale and legend
    annotation_scale(location = "bl",
                     width_hint = 0.4,
                     line_width = 0.1,
                     bar_cols = c("darkgrey", "lightgrey"),
                     pad_y = unit(0.05, "cm"),
                     pad_x = unit(0.15, "cm"),
                     height = unit(0.07, "cm"),
                     text_family = "Bahnschrift"
    )+
    north(location ="bottomleft",
          scale = 0.08,
          symbol = 13,
          x.min = 2464000,
          x.max = 2866429,
          y.min = 1061258,
          y.max = 1302922
    )+
```

```
    coord_sf(crs = 2056,
             datum = sf::st_crs(2056)
    )+
    theme.map()+
    theme(legend.position = "right",
          plot.title = element_text(size = 15
          ),
          plot.caption = element_text(size = 7,
                                      hjust = 0,
                                      vjust = -0.9,
                                      margin = margin(t = 0,
                                                      b = 0,
                                                      unit = "cm"),
                                      color = "#939184",
                                      debug = FALSE)
    )+
    labs(title = title,
         subtitle = subtitle,
         caption = paste(modelparams, "\n", credits,
                         sep="")
    )

  if(export == TRUE){
    ggsave(
      paste(exportfile, ".",exportdevice, sep =""),
      plot = plot,
      device = exportdevice,
      path = exportpath,
      scale = 1,
      width = 29.7,
      height = 21,
      units = "cm",
      dpi = 300,
      limitsize = TRUE,
      bg = NULL,)
    print("plot saved")
  }
  return(plot)

}
```

B.7 Plot cumulative catchment sizes & cumulative supplies reached

```
## THEME
theme.cumplots <- function(...) {
    theme_minimal() +
    theme(
      text = element_text(family = "Bahnschrift", color = "#22211d"),
      #panel.grid.major.x = element_line(color = "#707068", size = 0.8),
      panel.grid.major = element_line(color = "#ebebe5", size = 0.2),
      panel.grid.minor = element_blank(),
      plot.background = element_rect(fill = "#f5f5f2", color = NA),
      panel.background = element_rect(fill = "#f5f5f2", color = NA),
      legend.background = element_rect(fill = "#f5f5f2", color = NA),
      panel.border = element_blank(),
      legend.position = "right",
      plot.title = element_text(size = 15),
      plot.caption = element_text(size = 7,
                                  hjust = 0,
                                  vjust = -0.9,
                                  margin = margin(t = 0,
                                                  b = 0,
                                                  unit = "cm"),
                                  color = "#939184",
```

```
                                   debug = FALSE)
    )
}

########################################
## Function wrapper of ggplot functions to plot cumulative catchment sizes of two varia
nts ("alt" vs "base")

# spaidata = dataframe, containing two columns describing catchment sizes ("Relevant_ca
tchment_alt", Relevant_catchment_base") of the two variants
# modelparam = sting, specification parameters of the two model variants
# altname,basename = string, names for models in legend.
# export = logical indicating if export is wanted,
# exportpath = string, location
# exportfile = string, name
# exportdevice = string, "eps", "ps", "tex" (pictex), "pdf", "jpeg", "tiff", "png", "bm
p", "svg" or "wmf" (windows only).

plot.wrapper.cumCatch <- function(title = "title",
                                        subtitle ="subtitle",
                                        credits = "credits",
                                        legendtitle = "",
                                        spaidata,
                                        modelparams = "",
                                        basename = "base",
                                        altname = "alt",
                                        export = FALSE,
                                        exportpath = NULL,
                                        exportdevice = c( "png","eps", "ps", "tex", "pdf
", "jpeg", "tiff", "png", "bmp", "svg", "wmf")){
  colors <- c("alt" = "#F78F87", "base" = "#31CACD")
  plot <- ggplot(spaidata)+
    stat_ecdf(aes(Relevant_catchment_alt,
                  color="alt"),
              geom = "step",
              linewidth=0.7,
    )+
    stat_ecdf(aes(Relevant_catchment_base,
                  color="base"),
              geom = "step",
              linewidth=0.7,
    )+
    labs(x="catchment size (mins)",
         y="% of entities",
         color = "Legend",
         title = title,
         subtitle = subtitle,
         caption = paste(modelparams, "\n", credits,
                         sep=""))+
    xlim(0,60)+
    coord_flip()+
    scale_y_continuous(breaks=seq(0,1,0.1),
                       labels = seq(0,100,10),
    )+
    scale_color_manual(values = colors,
                       labels=c(altname,basename),
                       name = legendtitle)+
    theme.cumplots()
  if(export == TRUE){
    ggsave(
      paste(subtitle, ".",exportdevice, sep =""),
      plot = plot,
      device = exportdevice,
```

```
      path = exportpath,
      scale = 1,
      width = 29.7,
      height = 21,
      units = "cm",
      dpi = 300,
      limitsize = TRUE,
      bg = NULL,)
    print("plot saved")
  }
  return(plot)
}

#######################################
## Function wrapper of ggplot functions to plot cumulative pediatric practices reached
of two variants ("alt" vs "base")

# spaidata = dataframe, containing two columns describing reached supply locations per
entity ("Sumaccess_alt", Sumaccess_base") of the two variants
# modelparam = sting, specification parameters of the two model variants
# altname,basename = string, names for models in legend.
# export = logical indicating if export is wanted,
# exportpath = string, location
# exportfile = string, name
# exportdevice = string, "eps", "ps", "tex" (pictex), "pdf", "jpeg", "tiff", "png", "bm
p", "svg" or "wmf" (windows only).

plot.wrapper.cumsumSupaccess <- function(title = "title",
                                  subtitle ="subtitle",
                                  credits = "credits",
                                  legendtitle = "",
                                  spaidata,
                                  modelparams = "model description",
                                  basename = "base",
                                  altname = "alt",
                                  export = FALSE,
                                  exportpath = NULL,
                                  exportdevice = c( "png","eps", "ps", "tex", "pdf", "j
peg", "tiff", "png", "bmp", "svg", "wmf")){
  colors <- c("alt" = "#F78F87", "base" = "#31CACD")
  plot <- ggplot(spaidata)+
    stat_ecdf(aes(Sumaccess_alt,
                  color="alt"),
              geom = "step",
              linewidth=0.7,
    )+
    stat_ecdf(aes(Sumaccess_base,
                  color="base"),
              geom = "step",
              linewidth=0.7,
    )+
    labs(x="supplies reached",
         y="% of entities",
         color = "Legend",
         title = title,
         subtitle = subtitle,
         caption = paste(modelparams, "\n", credits,
                         sep=""))+
    #xlim()+
    coord_flip()+
    scale_y_continuous(breaks=seq(0,1,0.1),
                       labels = seq(0,100,10),
    )+
    scale_color_manual(values = colors,
```

```
                        labels=c(altname,basename),
                        name = legendtitle)+
    theme.cumplots()
  if(export == TRUE){
    ggsave(
      paste(subtitle, ".",exportdevice, sep =""),
      plot = plot,
      device = exportdevice,
      path = exportpath,
      scale = 1,
      width = 29.7,
      height = 21,
      units = "cm",
      dpi = 300,
      limitsize = TRUE,
      bg = NULL,)
    print("plot saved")
  }
  return(plot)
}
```

Appendix C. Overview of Switzerland

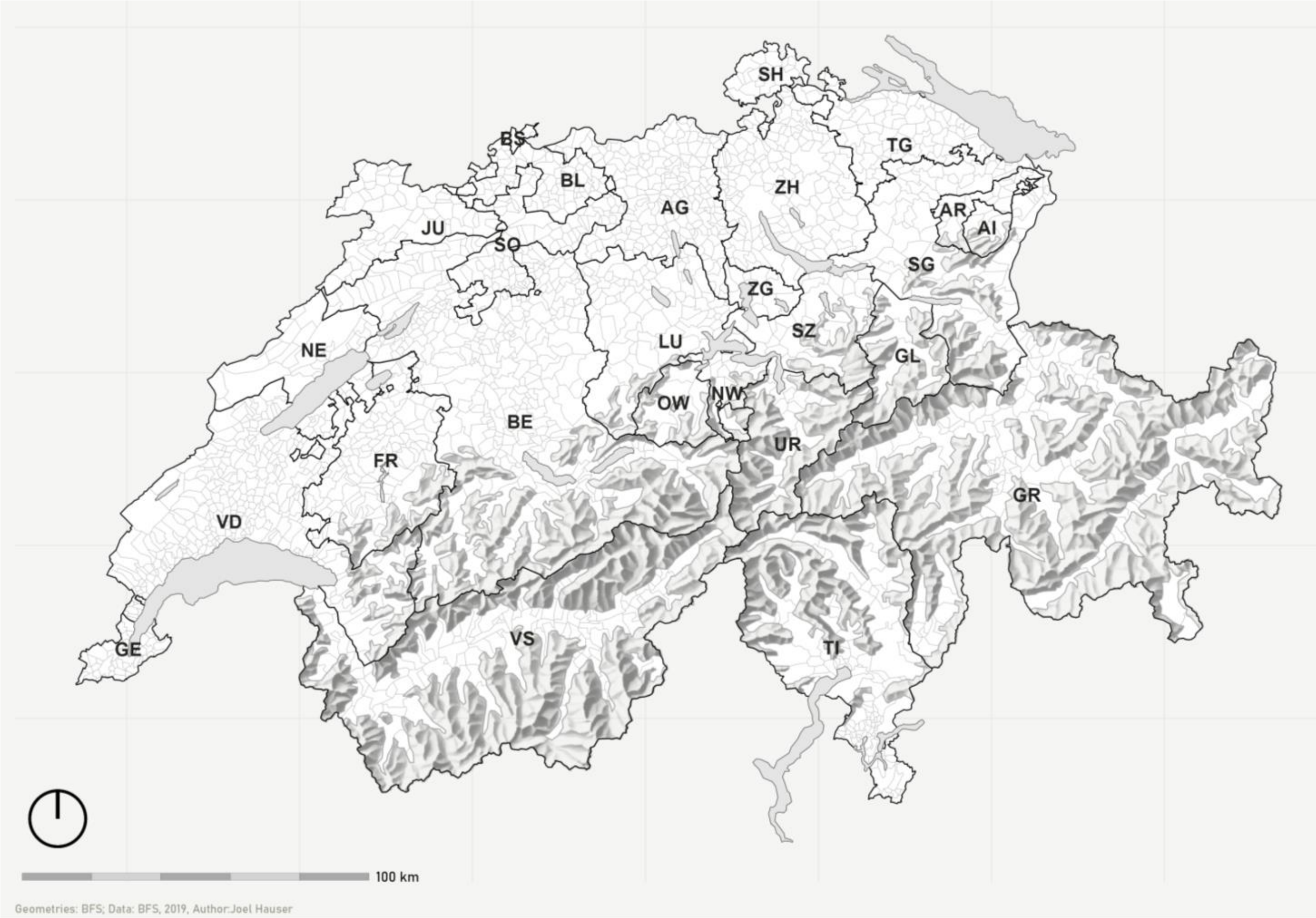

Fig A 6: Overview map of Switzerland with cantonal abbreviations. Cantonal borders are shown in black outlines. Municipalities are shown in grey outlines. Unproductive areas (uninhabited land) are subtracted from the municipalities.

Abbreviation	**Canton**	**Abbreviation**	**Canton**
AG	Aargau	NW	Nidwalden
AI	Appenzell Innerroden	OW	Obwalden
AR	Appenzell Ausserroden	SG	St. Gallen
BE	Bern	SH	Schaffhausen
BL	Basel Landschaft	SO	Solothurn
BS	Basel Stadt	SZ	Schwyz
FR	Fribourg	TG	Thurgau
GE	Geneva	TI	Ticino
GL	Glarus	UR	Uri
GR	Grisons	VD	Vaud
JU	Jura	VS	Valais
LU	Lucerne	ZG	Zug
NE	Neuchâtel	ZH	Zurich

Tab A 1: Table with cantonal abbreviations and full names (in English, where available)

Appendix D. Preliminary OBSAN Results

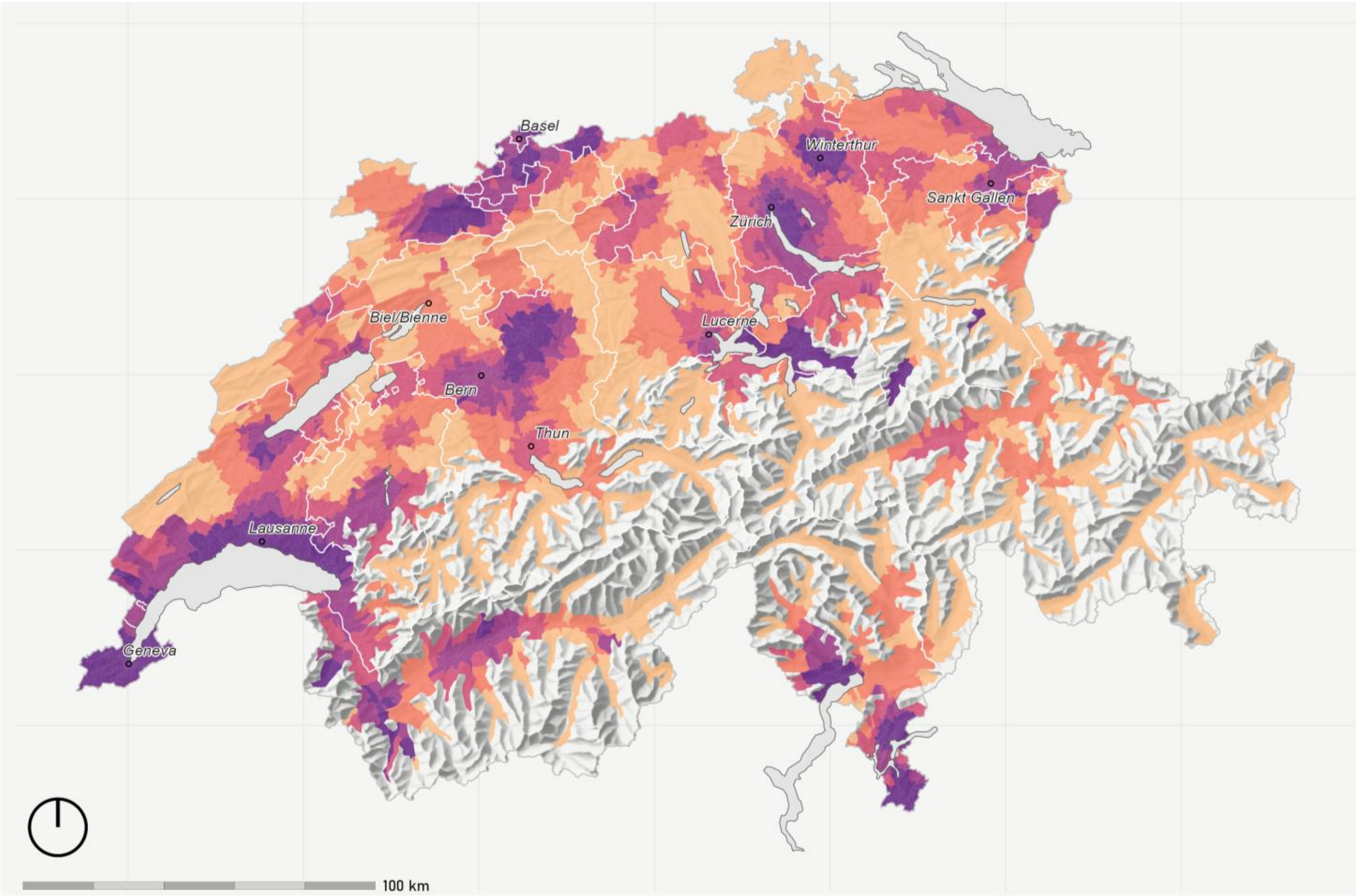

Fig D 1: Spatial accessibility by quintiles to pediatric practices as calculated by von Rhein, Haldimann and Jörg (2023) (OBSAN Results). Hectare results are aggregated to the spatial resolution of NPVM zones. Parameters used for the MHV3SFCA calculations: Distance subzones of 10, 20, 30, 60 minutes and minimum required supplies reached (Q) = 1.

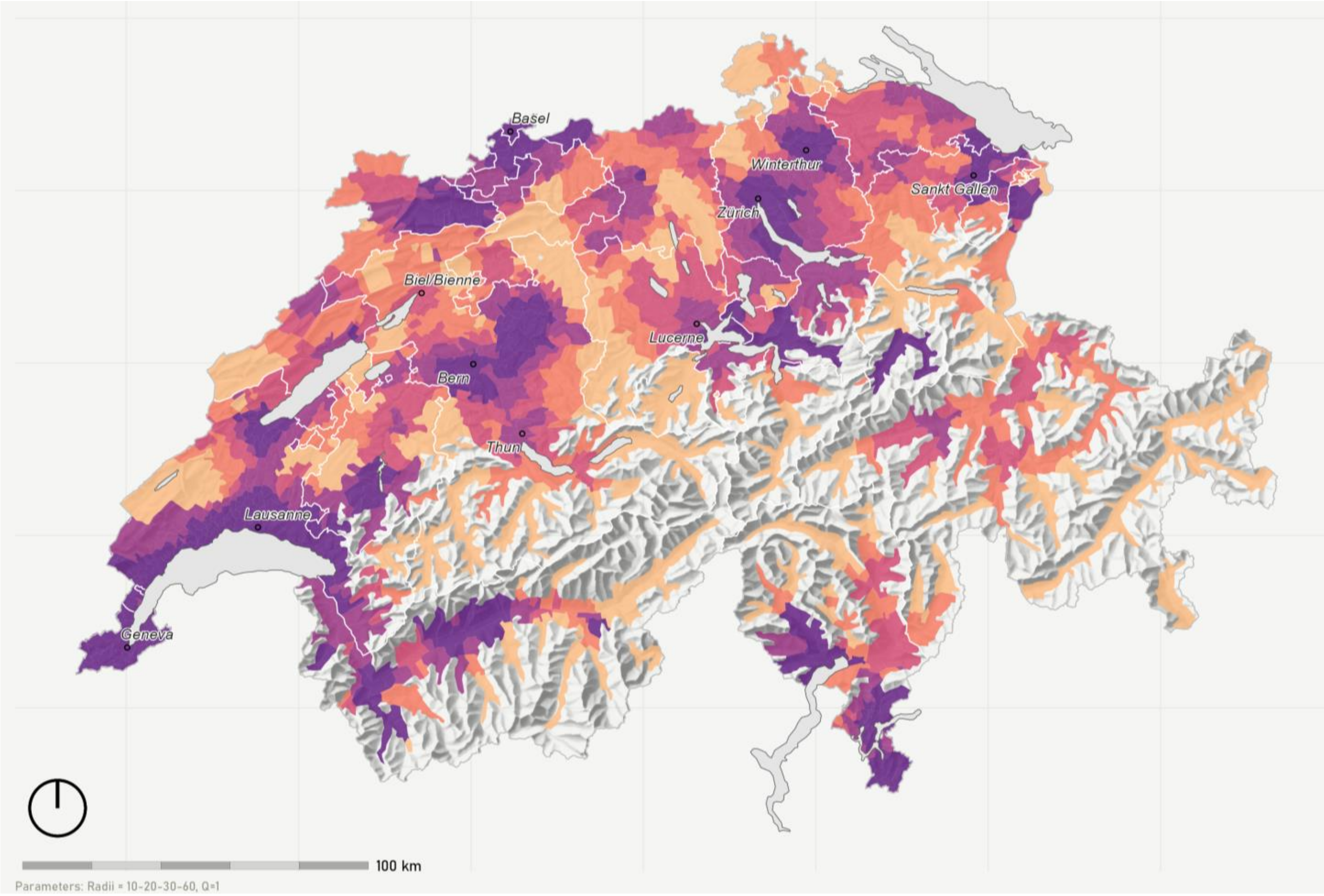

Fig D 2: Spatial accessibility by quintiles to pediatric practices as calculated by von Rhein et al. (2023) (OBSAN Results). Hectare results are aggregated to the spatial resolution of municipalities. Parameters used for the MHV3SFCA calculations: Distance subzones of 10, 20, 30, 60 minutes and minimum required supplies reached (Q) = 1.

Appendix E. Normality Assessment

The analysis of normality is only shown for the aggregation on the NPVM level as it is very similar on the municipality level.

The Kolmogorov-Smirnov test for the SPAI values from the OBSAN as well NPVM results suggest a rejection of the Null hypothesis with a significant p value of 0.00000000004438 respectively < 0.00000000000000022.

Fig E 1 allows for a visual assessment of normal distribution. Histograms and normal Q-Q plots show for both methods a left skewed distribution. This comes as no surprise, as both methods have a group of outliers (see Fig 30). Both distributions show a normal bell curve associated with normal distribution, but with a positive (left) skew.

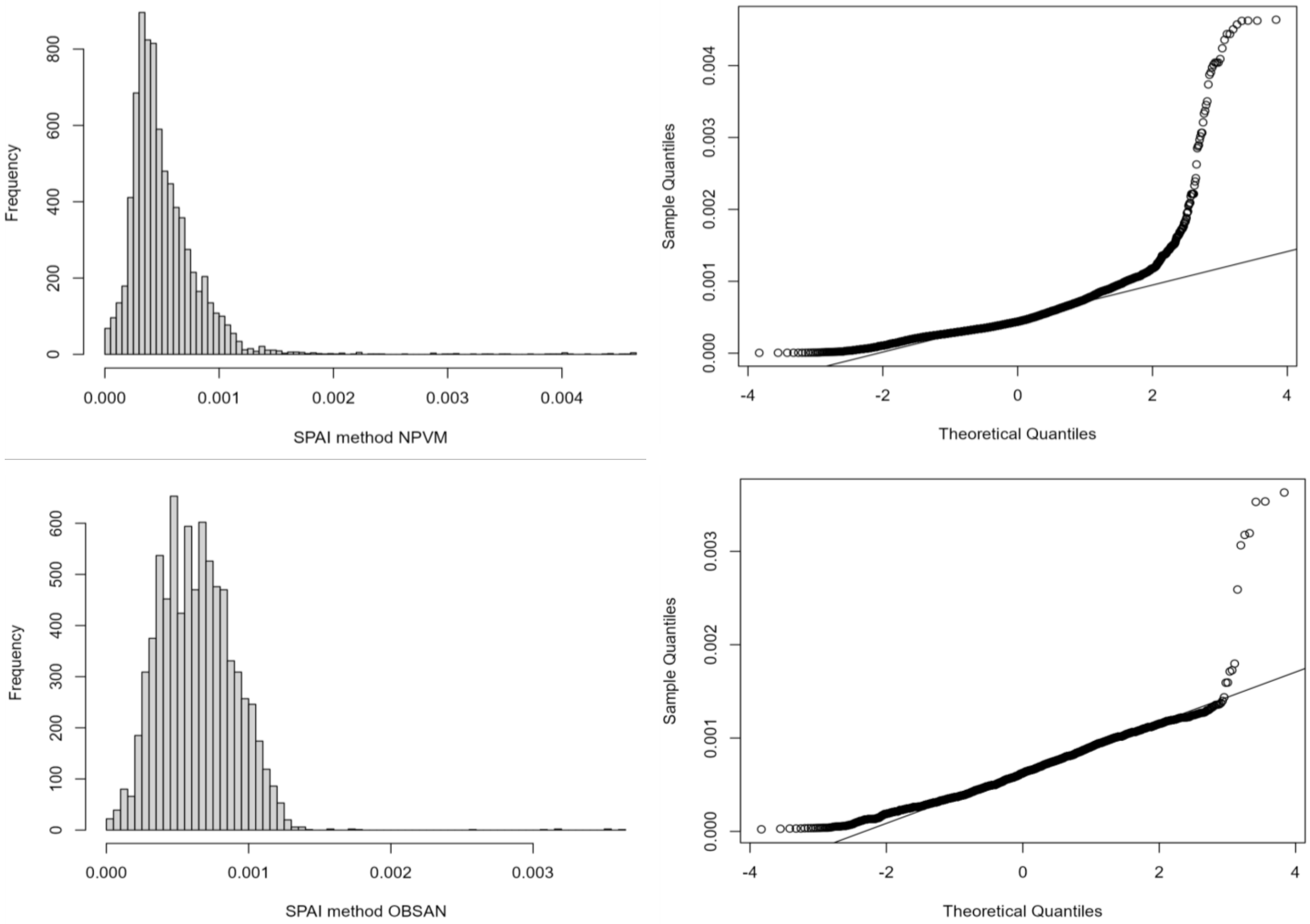

Fig E 1: Left: Histograms of SPAI values, top NPVM method, bottom OBSAN method. Right: the corresponding normal Q-Q plots.

Declaration of Authorship

Personal declaration:

I hereby declare that the submitted Thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the Thesis.

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