University of Zurich[UZH]

Geospatial Analysis of Access to Healthcare: Child Development Needs and Available Care in the Canton of Zurich

GEO 511 Master's Thesis

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Abstract

Developmental delay is one of the most frequent disorders in early childhood with 4-15% of all preschool children being diagnosed. Early identification of children with developmental delay is critical to ensure appropriate therapeutic interventions, to support the families, and finally to prevent chronic, life-long health, educational, and social consequences. Amongst researchers it is widely acknowledged that early intervention programs are both ethically mandatory and cost-effective for a society on a long-term basis. However, data shows that many cases are missed in early childhood. Although research has identified potential risk factors for under-utilization of early intervention, the spatial distribution of children in need, referring doctors, and therapy services has been neglected so far. Consequently, not much data evidence is available on the spatial variation in early intervention, and knowledge on potential impacts through spatial variation in referral to therapy and utilization is lacking. In this regard, this master's thesis sheds light on the missing information of the spatial component impacting early detection and early intervention in the canton of Zurich, Switzerland.

For this purpose, a comprehensive data set of all preschool aged children (age 0-4) admitted to the two Units of Special Needs Education (USNEs) in the canton of Zurich in 2017 (n=1971) was used and analyzed with the 3SFCA method. The applied method combines the supply and demand ratio with a distance decay by applying the Gaussian function. In addition, floating catchment areas were used instead of defined areas or fixed organizational units. The results are visualized in univariate and bivariate choropleth maps presenting the Spatial Accessibility Index SPAI values. The results show that the distribution of the spatial accessibility of early detection and early intervention present great disparities. A significant finding of this thesis was that zip codes are overrepresented where preschool aged children have less than one slot at a pediatrician or therapist accessible within 20 minutes travel time by car. Moreover, in certain areas regions it appears that the spatial accessibility has a direct impact on late referral or low utilization in therapy hours.

The major contribution of this thesis is a first overview on spatial patterns concerning the spatial accessibility of early detection and early intervention in the canton of Zurich.

Keywords health services; GIS; access to healthcare; developmental delay; early detection; early intervention; preschool aged children; spatial accessibility; FCA methods; 3SFCA method

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List of Acronyms

2SFCA Two-Step Floating Catchment Area

3SFCA Three-Step Floating Catchment Area

ADHD Attention-Deficit/Hyperactivity Disorder

AJB Amt für Jugend und Berufsberatung/Office of Youth and Vocational Guidance

ASD Autism Spectrum Disorder

BM Behavioral Model of Health Services Use

E2SFCA Enhanced Two-Step Floating Catchment Area

E3SFCA Enhanced Three-Step Floating Catchment Area

Esri US American software producer of geoinformation systems

FCA Floating Catchment Area

GIS Geographic Information System

Infostar Register of civil status

Kispi Universitäts-Kinderspital Zürich

KSW Kantonsspital Winterthur

MAS Medical Ambulatory Structure

MAUP Modifiable Area Unit Problem

MH3SFCA Modified-Huff-Model Three-Step Floating Catchment Area

Ordipro Information system of diplomats and international officials of the Federal Department of Foreign Affairs

SDGs Sustainable Development Goals

SNSF Swiss National Science Foundation

SPAI Spatial Accessibility Index

STATPOP Statistics of Population and Households of the Federal Statistical Office, Switzerland

USNE Unit of Special Needs Education (*Fachstelle Sonderpädagogik*)

ZEMIS Central migration information system of the State Secretariat for Migration, Switzerland

1. Introduction

The first years of life are crucial for a child's future development in various respects (Lohaus and Vierhaus, 2015). As children begin to interact with their environment, external factors not only shape their personal experiences and characteristics, but they also have an impact on their linguistic, cognitive, motor and social development (Weber and Jenni, 2012). Across all areas, nearly one in five children worldwide faces developmental delays or deviations to some degree (Stich et al., 2012, Jenni et al., 2013a, and O'Hare and Bremner, 2016). While a large number of the children affected have been able to catch up by the time they enter school mainly thanks to early therapy intervention, studies show that late therapeutic intervention or no intervention at all can have serious consequences for a child's physical, intellectual and emotional development into adulthood (Bennett and Guralnick, 1991, Law et al., 2004, Bonnier, 2008, Orton et al., 2009, Weber and Jenni, 2012, Benzies et al., 2013).

The importance of early detection and intervention as well as the crucial role of early child education in addressing developmental and behavioural difficulties or delays have also been recognised by the United Nations in their 2030 Sustainable Development Goals (SDGs).

Figure 1.1: 2030 Sustainable Development Goals, (Early Childhood Peace Consortium, 2021).

In addition to Goal 4 (*figure 1.1*), which explicitly addresses the issue that *"early stimulation increases duration of schooling, school performance and adult income"*, early child development is also part of other goals: Goal 1, for example, addresses the topic of increasing adult productivity and income and reducing inequities through early intervention, while Goal 3 highlights the importance of providing support in the area of health and well-being in order to protect people against stress and reduce the risks of chronic disease. Furthermore, Goal 17, promotes the strengthening of coordination across different sectors through early intervention, thereby uniting civil society and governmental partners and thus contributing to the achieving of common health, social and economic goals (Early Childhood Peace Consortium, 2021, *n.p.*). While these goals primarily address low- and middle-income countries, global trends indicate as well that special attention needs to be given to children with developmental delays.

The Global Burden of Diseases, Injuries, and Risk Factors Study 2016 (Global Health Data Exchange, 2021) shows that across 195 countries worldwide an average of 4-8% of all preschool children have been diagnosed with developmental delay (Olusanya et al., 2018). Between 1990 and 2016, the so-called global burden of developmental delays has not significantly improved, although child mortality halved in that period (Ibid.). Studies show that many cases are still not accounted for (McDonald et al., 2006, Kalkbrenner et al., 2011, Silove et al., 2013, Little et al., 2015, Ozonoff et al., 2018, Hicks et al., 2017). In addition, there are not enough therapy services for all affected children (Kalkbrenner et al., 2011, Murphy and Ruble, 2012, Drahota et al., 2020). The SDGs show that the global step forward is already taking place, but what does its implementation look like on a smaller scale?

Although global policy attention certainly has a beneficial influence on therapeutic measures available to children with developmental delay, there are national and even smaller-scale (e.g., socioeconomic, urban/rural or spatial) differences (Morgan et al., 2012, Marrus and Hall, 2017, Wang et al., 2019). In order to look at smaller-scale effects, it is necessary to identify the mechanisms and spatial impacts that children with developmental delay face in their respective area.

For Switzerland, no such analyses have been carried out so far. The comparison to worldwide numbers shows that every year thousands of children in Switzerland are affected who need adequate access to therapy (McDonald et al., 2006, Kalkbrenner et al., 2011, Silove et al., 2013, Little et al., 2015, Olusanya et al., 2018, Ozonoff et al., 2018, Hicks et al., 2017). In order to know whether the problem of under-identification of cases with developmental delay and under-supply of therapy is intensified in certain areas, a thorough spatial analysis of supply and demand is needed - a research gap that this master's thesis aims to fill.

This master's thesis focuses on the spatial variation of the functional relationship between between the healthcare needs of preschool children with developmental delay and the respective health services available to them in the canton of Zurich. The thesis is structured as follows: Chapter 1 presents an overview of the state of the art of previous and current research, identifies existing research gaps and addresses the specific research questions of this thesis. In chapter 2, the methodological approach is presented in more detail: The first part specifies the study area and data examined, while the second part outlines the methods used for the discussion of the research questions. The results of the spatial analyses on early detection and early intervention are then presented in chapter 3. In chapter 4, the results are discussed in relation to the specific research questions, followed by ideas for further research. In conclusion, the final chapter summarizes the main findings and points out the contributions of this thesis.

1.1. Basics of Child Development

In order to be able to discuss the different influences on child development adequately, it is necessary to have at least a basic understanding of some common concepts and terminology used in this context. By introducing more background information on terms such as developmental delay, early detection and early intervention, this section therefore lays the foundation for the more in-depth analyses in the following chapters.

Developmental Delay

A child's development is not a static or constant matter, but it is commonly measured via specific stages in relation to the child's age (Lohaus and Vierhaus, 2015). However, since there there usually exist significant differences within an age group, an orientation with regard to age is only meaningful as long as the variance between the age groups is greater than the variance within one age group; furthermore, clear distinctions between individual age groups diminish with increasing age (Ibid.). When looking at the development of children, so-called milestones which denote the first occurrence of certain developmental stages (e.g., sitting, crawling, walking) are more helpful for the evaluation (Jenni et al., 2013a). These milestones are not developmental tests in themselves and therefore do not lead to a diagnosis, but they can help estimating the linguistic, cognitive, motor and social development stage of a child (Ibid.). If a child's abilities in one or more areas of development (linguistic, cognitive, motor, and/or social) are below the norm for its age, this is referred to as a developmental delay (Lohaus and Vierhaus, 2015). This can be caused by neurological, metabolic or genetic disorders such as attention-deficit/hyperactivity disorder (ADHD), autism spectrum disorder (ASD) and/or physical disorders such as muscular hypotonia or cerebral palsy (Weber and Jenni, 2012, Jenni et al., 2013a, Lohaus and Vierhaus, 2015). In general, speech development delays occur more frequently than developmental delays in other areas with up to 15% of toddlers being diagnosed as *Late Talkers* (Jenni et al., 2013a, Lohaus and Vierhaus, 2015, O'Hare and Bremner, 2016) compared to the global total prevalence of other developmental delays of 4-8% (Olusanya et al., 2018). If the delay is compensated before the age of four, the child is referred to as a *Late Bloomer*; if not, the speech development delay is classified as a *disorder* (Lohaus and Vierhaus, 2015). With regard to the milestones, if a child does not speak 50 or more words by 24 months of age, it is considered at risk for developing a speech development disorder (Jenni et al., 2013a, Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e.V., 2021). Further, the age of 36 months serves as a clear threshold: If a speech developmental delay is not caught up by 36 months, a disorder can be diagnosed (Ibid.).

The developmental stage of a child is thus considered specifically in relation to its chronological age or to the milestones corresponding to its age respectively (Jenni et al., 2013a, Lohaus and Vierhaus, 2015). Quantitatively, this means that if the development is at least one standard deviation (SD) below the norm, a developmental delay is indicated (Jenni et al., 2013a). In the canton of Zurich, these age-dependent norm values for the various developmental areas are based on the results of the Zurich longitudinal studies (*Zürcher Longitudinalstudien*, Kinderspital Zürich, 2021). The variability regarding a child's development is large and the pace of the development is rather flexible at preschool age, which is why a clear distinction between developmental delay and disorder is usually not yet possible. For preschool aged children in particular, the term developmental delay is preferred over disorder or disability (Jenni et al., 2013a). While the causes of developmental delays can vary widely, the stage of development itself can be assessed well through standardized testing.

Early Detection

Standardized test procedures are used for the assessment of the child's developmental stage in all relevant areas (linguistic, cognitive, motor or social) (Jenni et al., 2013a). In addition to the information obtained from the tests, the assessment and confirmation by caregivers and, if applicable, by therapists are also taken into account (Ibid.). While in some cases developmental delays can be caught up at a young age, the effects of long-lasting developmental disorders are more profound (Lohaus and Vierhaus, 2015). Therefore, a developmental delay should be detected as early as possible, which in specialist terms is referred to as *early detection* (e.g., Weber and Jenni, 2012, Jenni et al., 2013a, Jenni and Sennhauser, 2016).

In order to prevent developmental disorders altogether or to be able to treat them early and appropriately, any child's development should be monitored from an early age (Weber and Jenni, 2012). This mostly happens within the framework of preventive medical checkups via paediatricians or general practitioners, ideally at 1, 2, 4, 6, 12, 18, and 24 months as well as at the age of four within the preschool age span (Weber and Jenni, 2012, Jenni et al., 2013a). These screenings can also be carried out by general practitioners, but there has been an increase in visits to paediatricians compared to general practitioners since 2007, which is probably due to a decreasing availability of general practitioners (Jenni and Sennhauser, 2016). This trend is even stronger in rural areas of Switzerland (Ibid.).

Weber and Jenni (2012) show in their study that the early detection of developmental delays in the areas of linguistic, cognitive, motor and social development is possible and allows for effective early intervention using different forms of therapy. Obviously, early detection is a prerequisite for early therapy intervention, with early intervention focusing on the particular kind of therapy to be utilized.

Early Intervention

There are different types of intervention for preschool children with developmental delays: Medical-therapeutic measures such as physiotherapy, occupational therapy and psychotherapy, additional family support offers such as maternal and paternal counseling, socio-pedagogical family support, family and educational counseling, and pedagogical-therapeutic measures such as speech therapy, special needs education including audio and low vision therapy (Jenni et al., 2013a). In Switzerland, medical-therapeutic measures are financed by the health or disability insurance based on a medical prescription, while pedagogical-therapeutic measures are assigned and financed by the respective canton (Ibid.). Even though these offers are often used in combination, the research carried out for this thesis specifically looks at the pedagogical-therapeutic measures. In the canton of Zurich, a standardized evaluation procedure has been developed for this kind of early intervention care (Bildungsdirektion Kanton Zürich, 2013).

Several studies have shown that early interventions through pedagogical-therapeutic measures for children with developmental delays in early childhood have a positive cost-benefit ratio and therefore generate high returns for society in the longer term (Bennett and Guralnick, 1991, Law et al., 2004, Bonnier, 2008, Orton et al., 2009, Weber and Jenni, 2012, Benzies et al., 2013). Early intervention may also reduce potential risk factors and create positive protective factors, which in turn positively impacts resilience in childhood, thereby counteracting developmental delays and preventing developmental disorders (Holtmann and Schmidt, 2004). The pedagogical-therapeutic interventions mainly based on two types of therapy: Speech therapy and special needs education, which also includes low-vision training and audio pedagogy (Jenni et al., 2013a).

Speech Therapy

Speech therapy is used for children with speech development delays and disorders and is primarily intended to support phonation, articulation, vocabulary and speech comprehension (Lohaus and Vierhaus, 2015). Speech developmental delays can affect speech production (*expressive speech disorders*) and/or speech comprehension (*receptive speech disorders*) in the following ways: Vocabulary may be limited, grammatical errors increased, too few words understood, terms confused, and/or grammatical structures of sentences may not be recognized (Ibid.). Often, however, the disturbance of speech comprehension is linked to further developmental delays, since the development of language production can only proceed undisturbed if language is also understood appropriately (Ibid.). For this reason, speech therapy should also consider cognitive abilities and organic causes for the delay or disorder (e.g. inadequate hearing). Furthermore, this intersection of different developmental areas is why many children need to receive therapy in more than one field (Ibid.).

In speech therapy, early intervention is known to significantly improve phonology, vocabulary, and syntax, and more intensive and prolonged interventions also help to achieve the best possible outputs (Weber and Jenni, 2012). However, if speech developmental delays are not treated, they can affect the overall development of children and lead to school problems and emotional behavior disorders (Lohaus and Vierhaus, 2015). However, early, intensive intervention is not only effective with regard to speech therapy, it also plays a crucial part in special needs education (Ibid.).

Special Needs Education

Special need education is mainly provided for children who suffer from cognitive delays and disorders or require additional support in school with reading, writing and mathematics (Lohaus and Vierhaus, 2015). Furthermore, special needs education for children at preschool age also provides preventive educational and family support (Stiftung Schweizer Zentrum für Heil- und Sonderpädagogik, 2021). The specific problems are first identified through a comprehensive diagnostics check in order to then systematically address them in therapy (Lohaus and Vierhaus, 2015). Thanks to special needs education, children are able to benefit from therapeutic measures that are tailored to their individual needs (Stiftung Schweizer Zentrum für Heil- und Sonderpädagogik, 2021).

Since special needs education allows to address and support specific weaknesses, it is a good way to compensate for a delay, ideally before school entrance age, or at least to acquire successful coping mechanisms (Ibid.). In the field of special needs education, the earlier therapy intervention takes place, the better, even though there is no clear threshold as in speech therapy (Lohaus and Vierhaus, 2015).

While there is plenty of scientific research highlighting the impact of developmental delays on a child's physical, social and intellectual abilities (Dawson, 2008, Morgan et al., 2012, Grant and Isakson, 2013, Little et al., 2015), it has also been shown that such delays can be treated effectively through early diagnosis and intervention (Center for Disease Control and Prevention, 2021). Amongst researchers it is widely acknowledged that early intervention programs are both ethically mandatory and cost-effective for a society on a long-term basis (Bennett and Guralnick, 1991, Law et al., 2004, Bonnier, 2008, Orton et al., 2009, Weber and Jenni, 2012, Benzies et al., 2013). However, research shows that many cases of developmental delays remain undetected in early childhood, although early detection and early intervention have proven to achieve the most effective, therapeutic treatment (Barbaro and Dissanayake, 2009, Kalkbrenner et al., 2011, Kasper et al., 2011, O'Hare and Bremner, 2016, Bishop-Fitzpatrick et al., 2018 Ozonoff et al., 2018, Olusanya et al., 2018).

Successful early detection and early intervention thus rely on a network of different professional groups and specialists as well as various other factors determining the situation of the children and their family (Jenni et al., 2013a). Since in the past the use of standardized tests has proven to be particularly effective in this context (e.g., Weber and Jenni, 2012, Jenni et al., 2013a, Jenni and Sennhauser, 2016), the relevant processes will be examined in more detail in the next section of this chapter considering the example of the study area: The canton of Zurich.

1.2. The System of Early Intervention Care in the Canton of Zurich

In Switzerland, early intervention measures are managed on cantonal level. While the basics of a standardized assessment procedure have been drawn up as a nationwide framework, each Swiss canton has had full legal and financial responsibility for the implementation of its early intervention measures since 2008 (Bildungsdirektion Kanton Zürich, 2013). Each canton covers the costs and also sets the scope of the respective therapy (Ibid.). Thus, therapy services are regulated and distributed within a canton, while doctor's visits can also take place across cantonal borders. For this reason, it is worth taking a closer look at the exact process of the assessment procedure and the relevant influencing factors in the canton of Zurich (*figure 1.2*).

In the canton of Zurich, there are two Units of Special Needs Education

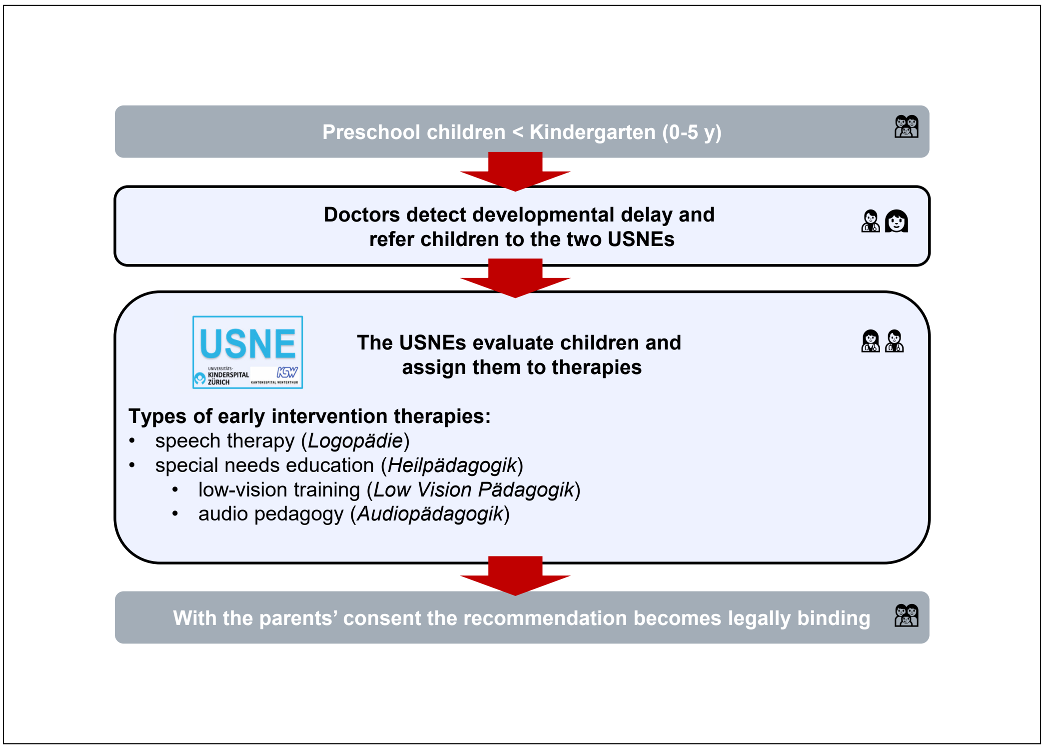

Figure 1.2: The process and stages involved in the standardized assessment procedure in the canton of Zurich (*based on Bildungsdirektion Kanton Zürich, 2013*).

(USNEs) at the Universitäts-Kinderspital Zürich (Kispi) and the Kantonsspital Winterthur (KSW). Both units evaluate preschool children with suspected developmental delay with regard to their individual need of therapy within the framework of the cantonal standardized assessment procedure (*Zürcher Abklärungsverfahren*) based on the current stage of the children's development and assign children to the following early intervention services: Speech therapy, special needs education including low-vision training and audio pedagogy. Furthermore, they allocate each child an individual amount of therapy hours over a defined period of time. The canton covers the costs for the assigned therapy hours and the transport to therapy is also subsidized (public transport ticket or 0.70 CHF per kilometer in a private car). Children are mainly referred to the USNEs by paediatricians and general practitioners. Therefore, the referring primary care provider plays a major role in the early detection of special needs (Bildungsdirektion Kanton Zürich, 2013, Müllner, 2020, Amt für Jugend und Berufsberatung ZH, 2021).

At first, the USNEs only makes a recommendation: With the parents' consent and signature, the recommendation then becomes legally binding. Since parents are oftentimes overwhelmed with the situation, the USNEs are commonly involved in the search for therapists. Therefore, the USNEs also have an overview of the available supply and capacity of therapists (Bildungsdirektion

Kanton Zürich, 2013).

From school age onward, speech therapy and special needs education are organized within the framework of the school districts in the canton of Zurich. From then on, assignments are clearly tied to an allocated therapist (Volksschulamt, Kanton Zürich, 2021). However, for preschool aged children the responsibility is on the canton, as the therapies have to take place in the child's canton of residence.

While the referring doctors are crucial for the early detection of developmental delays, therapists play an equally important part in the area of early intervention. In order to investigate the interplay of the involved entities and of further influences on developmental delays, researchers need access to comprehensive data relating to early detection assessments of preschool children as well as the spatial accessibility of referring doctors and therapists. In 2017, the canton of Zurich collected all data from the first official cantonal assessment at a USNE of preschool children with developmental delay for scientific purposes (NRP74, Project 15, 2021). The following section highlights some of the main findings of previous research based on this data (2020), Moser (2020) and Müllner (2020) and investigates how this information can be built upon in order to gain further insights on the spatial spatial distribution of relevant factors for early detection and early intervention.

1.3. Research Project "Preschool Children with Developmental Delay: The Standard of Care Evaluated"

This master's thesis is embedded in a larger Swiss National Science Foundation (SNSF) research project about preschool children with developmental delay in the canton of Zurich (NRP74, Project 15, 2021). Based on this research project, two medical master's theses and one dissertation were already completed in 2020. In the context of this master's thesis, the findings of the master's theses conducted by Müllner (2020) and Ferro (2020) and the dissertation of Moser (2020) are particularly relevant. Statistics of Müllner (2020) have shown, for example, that the share of referral entities for speech therapy cases is distributed as follows: 10% lay persons (e.g. family or people involved in children's care), 12% therapists and 78% doctors, who in turn are mainly paediatricians. There is also a large variety in a child's age at the time of the first assessment. Furthermore, the children's age at the time of their first assessment varies greatly from zero to 84 months. The median for the age at the first assessment for speech therapy cases is 37 months (Müllner, 2020), while the median for special needs education cases is 35 months (Ferro, 2020). In this regard, more detailed analyses have shown that specialists usually refer children significantly earlier than lay persons (Müllner, 2020). Statistics have also shown that children with additional medical diagnoses or prematurely born children are registered earlier, as they are usually seen by specialists at an early age (Ferro, 2020). Thus, it becomes evident that the referral entity has a major impact on early intervention measures in the canton of Zurich. However, while many aspects with regard to the individual referral entities have already been statistically evaluated, their spatial accessibility has not yet been investigated.

Another important element in the process towards early intervention is a target-oriented therapy and, as a prerequisite for this, the capacity of institutions. Moser's (2020) study revealed that long waiting times, especially with regard to finding a therapist, are a major weakness from the paediatricians' point of view.

As a common conclusion, the previous studies have already shown that there is an under-identification in terms of early detection of developmental delays and an under-supply of early therapy intervention services in the canton of Zurich (Ferro, 2020, Moser, 2020, and Müllner, 2020). However, the question as to what extent the spatial distributions of paediatricians and therapy institutions plays a role for the effectiveness of early detection and early intervention for children with developmental delay has not been addressed so far within this research project. In this regard, next sections of this chapter will review the relevant literature, which sheds light on the missing information on early detection and early intervention in the canton of Zurich.

In order to include the spatial component and analyze the relationship between supply and demand holistically, three aspects of research are particularly relevant. Firstly, spatial research on children with developmental delay provides an overview of the degree to which comparable analyses already exist (*section 1.4*). Secondly, the aspect of access to healthcare sheds light on the different influences including the effect of distance and time on travel costs (*section 1.5*). Thirdly, the fact that supply and demand can be calculated in different ways necessitates a closer look at this research area (*section 1.6*). The following section reviews the literature available on spatial research conducted with regard to children with developmental delay, which provides the foundation for the other research areas.

1.4. Spatial Research on Children with Developmental Delay

Previous research on children with developmental delay is very diverse and includes a wide variety of factors. Often, common statistical methods are used to analyze whether a particular cohort (e.g. with specific medical, socioeconomic or racial-ethnic conditions) has a significant disadvantage in early detection or early intervention compared to the rest of the children (e.g., Morgan et al., 2012, Marrus and Hall, 2017, Wang et al., 2019). The spatial component, however, has been included only marginally or not at all so far, even though it plays a decisive role with regard to many healthcare topics including access to health services for children with developmental delay. Therefore, this section focuses specifically on studies on children with developmental delay that include the spatial component. Studies that do not include the aspect of space at least in a qualitative manner are not considered.

While the most rudimentary way to incorporate the spatial aspect is to break down the results by different locations (e.g. on county, district or state level), in the last decades the use of Geographic Information System (GIS) applications in healthcare has become increasingly important. Through computer-based GIS, data from different sources can be linked based on spatial location. The variation ranges from the integration of different factors (e.g. social, economic, political, environmental) to network analyses and analyses of space-time patterns. In regard to research conducted with GIS applications concerning children with developmental delay, a wide variety of studies is mostly based on findings from the US. Furthermore, the studies from European affiliations often analyze US sites or low-income countries (*figure 1.3*).

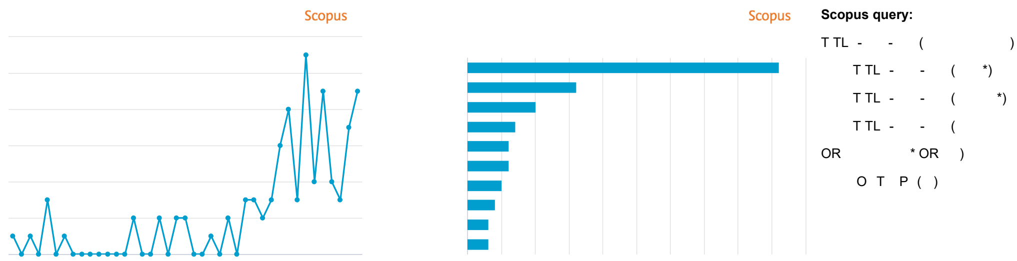

Figure 1.3: Scope of journal articles published related to geographical accessibility and children with developmental delay, 1980–2020.

Numerous studies show that the financial dimension plays a major role in access to health services (Porterfield and McBride, 2007, Patten et al., 2012, Pantaleoni, 2012). There are large differences in how different states fund pedagogical-therapeutic services, but even if the therapy itself is covered by a political entity (e.g. the state or county), various other financial factors remain (e.g. visits to the paediatrician, transport cost) that are indirectly related to early detection and early intervention (Porterfield and McBride, 2007). Therefore, the monetary aspect is relevant at different levels. For example, the type of health insurance, the means of transportation available (car, train, pedestrian) and, in this context, a family's financial resources are highly important with regard to obtaining access to a checkup for developmental delays at all (Porterfield and McBride, 2007, Patten et al., 2012, Pantaleoni, 2012). Many studies on access to health services for children with developmental delay therefore focus on socioeconomic factors (Grant and Isakson, 2013, Little et al., 2015, DeGuzman et al., 2018, Drahota et al., 2020). These studies analyze whether certain characteristics such as low income, insurance status, migration background, origin and other social stressors have an influence on referral and therapy intervention.

In addition to the socioeconomic status, the aspect of gradations of urbanity such as urban-rural typology is often addressed (Skinner and Slifkin, 2007, Murphy and Ruble, 2012, DeGuzman et al., 2017, Drahota et al., 2020). In this regard, various factors are examined for differences related to the urbanity of a region in bivariate and multivariate manner. In this context, the age of a child at diagnosis or first assessment as well as at the start or end of therapy plays a crucial role. Even though the age at the start of therapy is important for its effectiveness, it has so far been analyzed primarily in relation to urban versus rural areas (Mandell et al., 2005, Murphy and Ruble, 2012, Stahmer et al., 2019). However, Kalkbrenner et al. (2011) observed that in addition to urbanity a higher density of specialists and psychologists and an area's proximity to a medical school also led to a significantly earlier diagnosis at 3–16 months for children with autism spectrum disorder (ASD) compared to areas with a high density of primary care physicians (4–5 month later) (Kalkbrenner et al., 2011).

DeGuzman et al. (2017) analyzed the impact of different factors such as urbanity on a child's age at diagnosis with ASD by the help of a detailed rural–urban classification scheme including the location of paediatricians and insurance status. Thus, to explore the relationship between urbanity and early detection, different methods such as Pearson's chi-squared tests on different variables, Poisson and linear regression with dependent variables, descriptive clustering and qualitative methods have been applied (Mandell et al., 2005, Skinner and Slifkin, 2007, Kalkbrenner et al., 2011, Murphy and Ruble, 2012, DeGuzman et al., 2017, Stahmer et al., 2019, Drahota et al., 2020). The importance of a child's age at the time of intervention for the success of the respective therapy has been proven by a large number of studies conducted on this topic (Mandell et al., 2005, Kalkbrenner et al., 2011, Murphy and Ruble, 2012, Jenni et al., 2013a, Stahmer et al., 2019). However, there is a significant lack of studies that examine the relationship between missing or late detection of developmental delays and spatial accessibility of referrers.

A few recent studies on children with developmental delays are also taking further environmental influences such as air and water pollution as additional factors into account (Pantaleoni, 2012, Hicks et al., 2017, Ha et al., 2019). Thus, there are different approaches that either weigh different aspects against each other (e.g. using a regression model or Pearson's chi-square test) or analyze the specific distribution of a relevant factor (e.g. two sample t-tests or Wilcoxon rank-sum test) (Pantaleoni, 2012, Hicks et al., 2017, Ha et al., 2019).

The comparatively large number of US American studies on the influence of space on a child's access to therapeutic measures shows that the spatial aspect with regard to developmental delays has so far been given more attention in the US than in Europe. However, since the findings with regard to the US are characterized by the large organizational units within which the assessment procedures are processed and organized as well as by the greater distances between, they cannot serve as a comparison for all relevant mechanisms in Switzerland, or only with the necessary caution.

In Europe, a wide-ranging project to analyze different impacts on children's development has recently been launched by the EU Child Cohort Network established by the Horizon2020-funded LifeCycle Project. Nineteen pregnancy and childhood cohorts have been brought together, comprising more than 250'000 children and their parents (EU Child Cohort Network, 2021). The EU Childhood Cohort Network has an open character and has enabled collaborative, interdisciplinary research in particular since mid-2020. Among other things, the collaboration between prospective pregnancy/child cohort studies is also seen as a way to stratify and analyze different factors by geographical area (Jaddoe et al., 2020). As the data collection of the EU Child Cohort Network is still in its beginnings, the studies are limited and so far tend to focus on the effects of maternal pregnancy (e.g., Taylor et al., 2021 and Philips et al., 2020). However, this international collaboration again highlights the importance of early detection of developmental delays and the associated demand for effective early intervention.

Other European projects mainly focus on socioeconomic factors, only considering the spatial component either as a supporting or an additional aspect (Russell, 2007, Horstkotte and Zimmermann, 2008, Westman Andersson et al., 2017). However, the negative impact of higher distances between child and paediatrician on the regularity of doctor visits as shown by various US studies (Kalkbrenner et al., 2011, Murphy and Ruble, 2012) has also been outlined by Field et al. (2001) in their study on Northhampton, Great Britain. Studies show the use of telemedicine or audio conferencing in overcoming barriers due to spatial location (Gettings et al., 2015, Salinas et al., 2020). In general, these studies show that children from disadvantaged neighborhoods or regions have more limited access to health services than children from wealthier neighborhoods or areas. In turn, the lack of access to therapy due to the families' place of residence can be seen as a stressor and as a reinforcing effect for affected families.

Switzerland is not among the European countries involved in the EU Childhood Cohort Network research project (Jaddoe et al., 2020, *p. 711*), but the launch of the Swiss atlas of selected medical interventions (*Schweizer Atlas der Gesundheitsversorgung, Versorgungsatlas der Schweiz*) is a step towards integrating the spatial component into research on the availability of health services (Schweizer Atlas der Gesundheitsversorgung, 2021). The atlas currently maps around 30 of the most common inpatient treatments in Swiss acute hospitals, with specific data on paediatric medicine already available (Ibid.). Nevertheless, the question remains as to which methods can be used to incorporate this data profitably into research on developmental delays of Swiss children. Further, Stülb et al. (2019) analyzed predictors of behavioral problems of healthy preschool children. The data sample also included children with mild developmental delay. The study compared cohorts in Switzerland on a large scale (French-speaking and German speaking part) and, unlike similar studies in the US and Sweden, showed that the low-income population living in rural areas has a higher prevalence rate of behavioral problems compared to urban areas.

Other studies have shown that the identification of areas of under- or oversupply is also relevant in the context of early detection and early intervention (Kalkbrenner et al., 2011, Murphy and Ruble, 2012, Drahota et al., 2020). In order to quantify the relationship between demand and supply, it is necessary to define which distance to paediatricians and therapist is considered accessible. The next section therefore outlines the relevant factors concerning a child's access to healthcare.

1.5. Access to Healthcare

Access to health services does not only depend on distance from a person's place of residence to a respective service. Researchers have thus come up with different concepts in order to situate access to healthcare in a suitable framework (*table 1.1*). The most often cited approach in this context is the Behavioral Model of Health Services Use (BM) developed by Ronald Andersen (Andersen, 1968, Andersen and Newman, 1973, Aday and Andersen, 1974). Placing a strong focus on the political rather than the operational context, he addressed five components shaping access: Health policy, characteristics of the health delivery system, characteristics of the population at risk, utilization of health services, and consumer satisfaction (Aday and Andersen, 1974, *p. 212*).

A more detailed definition of access focusing on the interaction between healthcare demand and supply was introduced by Penchansky (1977), who rejected the common definition of "access as all factors that influence use" (Penchansky, 1977, *p. 31*). Penchansky and Thomas (1981) introduced one of the leading frameworks in recent research on accessibility measures following Donabedian (1972), who stated that access not only refers to the presence of health services, but also their utilization. According to the approach of Penchansky and Thomas (1981), access is a multidimensional concept with five different dimensions: *availability*, *accessibility*, *accommodation*, *affordability*, and *acceptability* (Penchansky and Thomas, 1981, *p. 128f*). This approach addresses previous limitation in order to obtain a multidimensional and thus more objective perspective on the relationship between healthcare needs and services. The dimensions describe a double-sided, detailed relationship between patient and health services, whereas only the dimensions availability and accessibility can be considered spatial. Availability addresses the density of the relation between supply and demand including the number and type of health services, whereas accessibility includes the spatial proximity taking transportation resources such as travel time, distance and cost into account. The further dimensions address more comprehensive factors such as organizational, financial and cultural barriers (Penchansky, 1977, Penchansky and Thomas, 1981, Penchansky and Thomas, 1984).

Dutton (1986) ties in with and reshapes these dimensions by considering patient characteristics and provider and system attributes as key influences on access. The spatial component is reduced to time barriers, which include not only travel times, but also office waiting times depending on the capacity of the health services, among other factors (Dutton and Diana, 1986). Further studies also place a special focus on the parameter of time (Margolis et al., 1995, Weber and Kwan, 2002, Haynes et al., 2003, Kelly et al., 2016, Weiss et al., 2018).

Among other studies which modify or extend the theory of Penchansky and Thomas (1981) is the one by Haddad and Mohendra (2002). They argue that the dimensions are not completely independent but rather interrelated (e.g. affordability influencing transport mode and time) and therefore affect the opportunity to use health services. Moreover, like some researchers after them, they also replaced the dimension *accommodation* with the dimension *adequacy* in their framework (Haddad and Mohindra, 2002, Haddad and Mohindra, 2005). Shengelia et al. (2003) refer to the same dimensions as Penchansky and Thomas (1981), however, instead of *accommodation* they talk about the dimension *quality of care*, while focusing on demand rather than supply in terms of revealed or realized access. Contrary to potential access revealed or realized access is achieved when barriers are overcome (Khan, 1992). Still, in this regard, terms such as utilization and coverage may be as relevant as measuring the actual use of health services. Peters et al. (2008) also place a particular focus on supply and demand by including the actual use of health services in their framework and considering it alongside other characteristics. Levesque et al. (2013) define five dimensions of access, whereas *availability* and *accommodation* are considered one dimension. *Accessibility* is renamed *approachability*, thereby emphasizing the spatial component, and *appropriateness* is added as a further dimension concentrating on the process of utilization, which includes concepts such as coordination, adequacy and technical/interpersonal quality. Levesque et al. (2013) also highlight a correlation between the characteristics of clients and the dimensions that influence their access: They address five corresponding abilities of populations on the demand side, which interact with the dimensions generating access. Saurman (2016) extends the framework of Penchansky and Thomas (1981) by the dimension *awareness* which addresses factors concering communication and information. These includes strategies and channels of communication, which improve or hinder the understanding of procedures and healthcare interventions. This additional dimension has been included or at least considered by most recent case studies in this area (Badu et al., 2018, Kang et al., 2019, Retrouvey et al., 2019). Furthermore, adequate information is another key factor in ensuring that health services are actually used.

In line with the original concept of Penchansky and Thomas (1981), this this master's thesis focuses on the components *accessibility* and *availability*. In research, all five dimensions are rarely addressed within a single study, as the measures used to validate the dimensions vary widely. While accessibility and availability can be assessed well with quantitative, statistical methods, softer criteria such as acceptability need a greater variation of data (e.g. qualitative variables). Given the limited scope of this thesis, the factor *awareness* could unfortunately not be taken into account, although it certainly plays a role regarding the access to health services for children with developmental delay. For example, consultants working in youth centers are also heavily involved in raising awareness regarding developmental delays and the importance of early intervention. However, this master's thesis pays special attention to revealed versus potential accessibility, since it juxtaposes data obtained from actual case studies with the total population of preschool children in Switzerland.

When talking about spatial accessibility, it is important to take into account different types of distance: For example, many studies still refer to straight-line distances, even though it is impossible that a trip by public or private transport to a healthcare service is traveled as a straight line. A more meaningful way of referring to the concept of distance is therefore by talking about travel time or a distance that takes the road or public transport network into account, and thus uses either shortest or quickest route for implementation (Kelly et al., 2016). The importance of actual travel time as distance has been underlined by a variety of studies in terms of access to healthcare (Dutton and Diana, 1986, Margolis et al., 1995, Weber and Kwan, 2002, Haynes et al., 2003, Kelly et al., 2016, Weiss et al., 2018). Recognizing the importance of time, special attention is paid to the temporal distance rather than the spatial distance in this thesis.

Access to healthcare is a multidimensional concept, which includes various factors. Since it would go beyond the scope of this thesis to analyze all the dimensions outlined above, the focus of the following chapters is placed on spatial accessibility - including both availability and accessibility -, which is analyzed and operationalized using the concept of temporal distance. It is also important to note that the multidimensional concept is not self-contained and that other dimensions such as awareness are also gaining in importance.

In addition to accessibility, the relationship between supply and demand also plays an important role with regard to the under and oversupply of therapeutic measures (Subal et al., 2021). The next section of this chapter provides further background information on the various approaches to spatial relations with regard to demand and supply.

Table 1.1: Definitions, dimensions and emphases of different concepts on access to health-care highlighting the relevant aspects for this research using bold font (based on Levesque et al., 2013, *p. 3*).

Authors	*Definition*	*Emphasis*	*Dimensions*
Andersen, 1968 Andersen and Newman, 1973 Aday and Andersen, 1974	Access as entry into the health care system	Political component to enable access	• Health policy • Characteristics of the health delivery system • Characteristics of the population at risk • **Utilization of health services** • Consumer satisfaction
Donabedian, 1972	Access as the use of service, not simply the presence of a facility	Delivery of health services	• Measurement of "health" • The distribution of "health" • **Amount and distribution of access** • Magnitude and distribution of costs • Consumers, providers and the organizations • The client-therapist relationship • Instrumentalities (rationality, predictability and control, coordination and continuity, continuing assessment, responsibility and accountability)
Penchansky, 1977 Penchansky and Thomas, 1981	Access as a multidimensional concept	Double-sided interaction between patients and health services	• **Availability** • **Accessibility** • Accommodation • Affordability • Acceptability
Dutton and Diana, 1986	Utilization as the product of patients characteristics plus provider and system attributes	Characteristics of patients and health services	• Financial • **Time** • Organizational factor
Haddad and Mohindra, 2002	The opportunity to consume health services	Interaction and influences of multiple factors	• **Availability** • Affordability • Acceptability • Adequacy
Shengelia et al., 2003	Access is composed of coverage and utilization	Demand perspective in terms of **revealed access**	• **Physical access** • **Resource availability** • Cultural acceptability • Financial affordability • Quality of care
Peters et al., 2008	Access as the notion of fit between users and services including the actual use of services	Interaction between patients and health services in terms of **revealed access**	• Quality • **Geographic accessibility** • Availability • Financial accessibility • Acceptability of services
Levesque et al., 2013	Access as an interplay of corresponding abilities of populations interacting with the dimension generating access	Correlation between the characteristics of clients and the dimensions that influence their access	Dimensions: • Approachability • Acceptability • **Availability and accommodation** • Affordability • Appropriateness Abilities: • Ability to perceive • Ability to seek • **Ability to reach** • Ability to pay • Ability to engage
Saurman, 2016	Access as a multidimensional concept taking double-sided awareness additionally into account	Adequate communication and information is a key factor for **revealed access**	• **Accessibility** • **Availability** • Acceptability • Affordability • Adequacy (Accommodation) • Awareness

1.6. Spatial Relations between Demand and Supply

Classic supply and demand ratios in healthcare usually refer to a specific organizational unit on municipal, cantonal or national level. Following this approach, the potential demand is represented by the number of locations of healthcare providers within a certain area (e.g. 2 medical practices per 1000 inhabitants), also known as a *container index* (Talen and Anselin, 1998). This approach is useful if for a given service a certain supply is assigned to the inhabitants within the respective unit (e.g. supplementary school services, which are organized by a specific school district) (Luo, 2014). However, if inhabitants of a certain area are free in their choice of service, there are other contributing factors such as capacity or or distance to consider (Ibid.). In addition, this approach does not take into account the inter-dependencies between different areas (Ibid.). As soon as an organizational unit has no supply, the people in need of a certain service will be assigned to a different unit nearby (Jörg et al., 2019). Accordingly, the service per population ratio overestimates the accessibility of the supply for the surrounding units, whereas the accessibility within a respective unit is underestimated, since other services are within good reach (Ibid.). In addition, analyses based on supply and demand ratios lead to inaccuracies outside of the study site, which are commonly referred to as edge effects (Wang, 2015).

In research, further problems that may arise due to the scale of the chosen organizational unit when using a rudimentary approach of supply and demand is usually referred to as the Modifiable Area Unit Problem (MAUP) (Openshaw, 1984). In this context, the boundaries of the organizational units have no meaningful relationship with the variables of interest (Openshaw, 1984, Fotheringham and Wong, 1991, Guagliardo, 2004, Higgs, 2009).

Another classic approach is based on the assumption that a person chooses the nearest service. On the one hand, this approach is to be treated with caution in that it assumes that each person only utilizes one supply of a kind. This may be the case for certain services such as a general practitioner or a paediatrician, but not for other services such as specialists or therapists. On the other hand, the assumption that a person chooses the nearest service also excludes all other services within a considerable distance (e.g. larger, more appealing services), which has proven to be an unrealistic assumption (Handy and Niemeier, 1997).

Hansen's (1959) approach provided an early solution for overcoming these limitations by applying a so-called population-over-distance analysis. In this regard, he refers to a gravity model, which assumes that the greater the the distance to a certain service provider, the less likely it is that this service will be utilized. For the weighting of the distance within the gravity model, he used an exponential function and evaluated different exponents for different services.

Hansen's (1959) study has thus laid an important foundation for an entire research field dealing with spatial accessibility of health services, specifically for the Floating Catchment Area (FCA) set of methods (*table 1.2*). Being also based on the fundamentals of economic gravity models, which state that trade flows are based on the economic size and the distance between two entities (Weibull, 1976, Cheng and Wall, 2005), the rudimentary *Two-Step-Floating-Catchment-Area* (2SFCA) method was introduced by Luo and Wang (2003), who combined the supply and demand ratio with a distance decay (gravity model). The original method has evolved in many ways since its initial formation and it has been applied to a myriad of issues related to the planning and analysis of health services (e.g. Vo et al., 2015, Bauer and Groneberg, 2016, Jia et al., 2017, Wang, 2018, Wang, 2020, Subal et al., 2021). The rudimentary 2SFCA method is based on two underlying assumptions: Firstly, the population is expected to use health services within the defined area (binary distance values of 1 and 0), and secondly, the proximity aspect is negligible within the defined area. As the name implies, FCA methods use floating catchment areas instead of defined areas or fixed organizational units. The size of the floating catchment areas can be adapted to the corresponding purpose or research topic as well as the required health services within an area (Luo and Wang, 2003). The original 2SFCA approach has undergone many enhancements and modifications since its initial publication, each with their own particular purpose as well as advantages and disadvantages. Not all methods will be discussed in detail in this chapter, but only those relevant for this specific research design. An overview of the relevant methods is provided in *table 1.2*. However, in principle, all methods follow the same basic idea:

(i) defining and operationalizing the relevant supply and demand;

(ii) quantifying the relationship between supply and demand (availability);

(iii) operationalizing 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 (Salze et al., 2011, Jörg et al., 2019, *p. 25*).

The original 2SFCA approach calculates a Spatial Accessibility Index (SPAI) in two steps: In a first step, the supply and demand ratio is calculated in a given radius. In a second step, the previously calculated supply and demand ratios for each population are summarized within the same radius. This results in a SPAI per demand population point (Luo and Wang, 2003). Accordingly, the 2SFCA method accounts for demand rivalry or consumption rivalry, respectively. The more people make use of a certain supply, the more of its capacity is shared (Jörg et al., 2019).

Table 1.2: Overview of the main FCA methods relevant for this study (based on Jörg et al., 2019, *p. 27*).

Authors	*Method*	*Special features*
Luo and Wang, 2003	**2SFCA** – Two-Step Floating Catchment Area Method	Original method; population-over-distance relationship within floating catchment areas in two steps
Luo and Qi, 2009	**E2SFCA** – Enhanced Two-Step Floating Catchment Area Method	Including different subzones within catchment area for weighting
Wan et al., 2012	**3SFCA** – Three-Step Floating Catchment Area Method	Addressing overestimation of demand through a selection weight based on distance
Luo, 2014 Luo, 2016	**E3SFCA** – Enhanced Three-Step Floating Catchment Area Method	Including Huff model (capacity and distance) for estimation of demand
Jörg et al., 2019	**MH3SFCA** – Modified-Huff-Model Three-Step Floating Catchment Area Method	Including the absolute distance to the supplies and assuming a constant demand of each population point

Many enhancements of the 2SFCA method mainly concern the operationalized distance decay. While in the rudimentary method the distances are based on binary values (0 and 1), improvement can be achieved by using a distance decay function. This was done for the first time in the *Enhanced Two-Step Floating Catchment Area* (E2SFCA) method. In the E2SFCA method, the catchment area is divided by distance into different subzones with a different weighting and the method thus represents spatial accessibility in a more realistic way (Luo and Qi, 2009).

Further enhancements prefix an additional calculation step and the calculation of the index is therefore based on three steps. For example, in the *Three-Step Floating Catchment Area* (3SFCA) method, a so-called selection weight is calculated in the first step, which expresses the probability of interaction between the entire supply within reach of a specific demand location. In this way, supply competition is taken into account. This means that the calculation considers alternative supply options that are available to the specific population. In the 3SFCA method, the selection weight depends on the distance between demand and a specific supply in relation to all other supplies within reach of that demand. Compared to the 2SFCA and the E2SFCA method, the 3SFCA method addresses the overestimation of demand. The distance function is thereby independent and can be implemented either on the basis of subzones or continuous distance decay (Wan et al., 2012).

Similarly, the *Enhanced Three-Step Floating Catchment Area* (E3SFCA) method aims to address overestimation of demand, but incorporates the Huff model for determining the selection weight. The Huff model is an interaction model that assumes that the size of a supply has a positive effect while the increasing distance has a negative effect on utilization (Huff, 1963). Thus, in addition to distance, the capacity of the services supplied is also included in the first step, which is the calculation of the selection weight (Luo, 2014, Luo, 2016). The *Modified-Huff-Model Three-Step Floating Catchment Area* (MH3SFCA) method uses the Huff model in step one and three in the same way as the E3SFCA method. The difference lies in the second calculation step, where the distance weight in the denominator is removed to take into account absolute and not only relative distances, since distance divided by distance only results in a relative ratio. Omitting the weight in the denominator, however, has a second effect: The demand of each population remains constant (demand is independent from the sum of distances to supplies) in contrast to the other FCA methods, where the demand of a population also increases in line with the number of services supplied (Jörg et al., 2019).

There are also extensions to the FCA methods that can in principle be integrated independently of the underlying base model. For example, the Integrated 2SFCA method (Bauer and Groneberg, 2016) focusing on different distance decay function, the Inverted 2SFCA method (Wang, 2018) focusing on the supplies instead of the demands in the sense of a crowdedness index or the Multi-Transportation-Mode 2SFCA method (Mao and Nekorchuk, 2013) focusing on different transport modes. As crucial as these methods may be for future studies in this field, they will not be explored further in the context of this master's thesis.

Joerg et al. (2019) evaluated different methods of the FCA set of methods for a nationwide case study in Switzerland on accessibility in ambulatory primary care. This study shows how the different methods can be applied to a Swiss context and also which distance thresholds are suitable, thereby providing an important foundation for this thesis. Similar comparisons are possible with the study of Lenz et al. (2020), in which the MH3SFCA method was applied to detecting the spatial accessibility of veterinary care in Switzerland.

The Huff model, which comprises the MH3SFCA method developed and applied in these two studies (Jörg et al., 2019, Lenz et al., 2020), was originally used for examining consumer behavior regarding the choice of shopping centers. The original investigation showed that the choice and thus the attractiveness of a shopping center always depends on its size (Huff, 1963). In a similar way, the capacity of the services supplied may therefore also be relevant to the probability of demand in many areas of healthcare services (Jörg et al., 2019). In primary care, for example, there is a wide range of alternative care options. Larger service facilities have a greater capacity, which in turn may lead to faster appointments and a greater choice of services. This means that the size of a location may well influence its attractiveness and, as a consequence, its popularity with people who can choose between different facilities (Luo, 2014, Luo, 2016, Jörg et al., 2019). In other areas, this assumption seems rather unrealistic. For example, self-employed therapists often adjust their capacity at least to some degree to meet demand or paediatricians are called upon based on recommendations. In these cases, the size of the corresponding supply has a significantly smaller effect on a client's choice than distance.

Another argument in favor of the 3SFCA method as opposed to the MH3SFCA is that it does not assume a constant demand, but rather the demand of a population point adjusts to some extent to the available supply. In particular, there are studies on the demand for health services that show a positive correlation between the spatial accessibility and the use of health services.

Regarding the influence of spatial accessibility on the use of health services, Wennberg (1973) discovered a positive correlation between the number of physicians available and the demand for health services in his original study carried out in Vermont, US. This study was the starting point for his further research on the so-called unwarranted variation, which, on the one hand, refers to oversupply, that causes unnecessary overutilization which may even do more harm than good. On the other hand, it refers to undersupply (e.g., in low socioeconomic areas), which is further exacerbated due to the fact that access is difficult and expensive (Wennberg and Fowler, 1977, Wennberg, 2010, Wennberg, 2014). This variation shows that a greater number of available health services does not necessarily equal an improvement in supply. The latter depends rather on the appropriate spatial distribution. These findings underline again the inevitability of including the spatial component when examining the relationship between supply and demand.

Sturny and Widmer (2020) also investigated to what extent the accessibility of various health services differs between rural and urban areas in Switzerland. Their study showed that urban areas are generally better served than rural areas. In line with Wennberg's (1973) findings, they were also able to show that more services are used in urban areas.

To sum up, the spatial aspect also plays a major role when it comes to supply and demand ratios. Studies have therefore incorporated distance decay functions in various ways in order to provide a more comprehensive picture of areas affected by over- and undersupply. This line of research has also gained a foothold in Switzerland. However, in the studies of Sturny and Widmer (2020), Jörg et al. (2019) and Lenz et al. (2020), no attention is paid to preschool children with developmental delays. Based on the current state of research outlined above, the following two sections of this chapter will summarize again the important research gaps that have been identified so far and how they can be addressed in future research. Since early detection is a prerequisite for early intervention, the spatial impact on early detection is discussed first.

1.7. Spatial Accessibility of Early Detection in the Canton of Zurich

Early detection of developmental delays is important for many different reasons: For example, since the effectiveness of therapies is significantly greater the earlier they begin, early detection is crucial for preventing children from serious disadvantages in their future personal and professional life (Jenni et al., 2013a, Jenni et al., 2013b, Weber and Jenni, 2012, Lohaus and Vierhaus, 2015, Jenni and Sennhauser, 2016). Despite regular preventive medical checkups and despite the fact that these are guaranteed and often paid for by government subsidies or private insurances, there is a large number of missed cases of children with developmental delay (Weber and Jenni, 2012). The effectiveness of regular preventive medical checkups is undisputed, since they allow for a significantly earlier detection and thus a faster and more successful treatment of developmental delays (Ibid.). However, the current situation shows that paediatric checkups are frequent in the first two years of a child's life and decreases thereafter. Various reasons such as high costs (10% of the expenses are met by the patients themselves for medical consultations (*Selbstbehalt*) (Jenni and Sennhauser, 2016), a lack of understanding of risks, cultural background, mistrust of government-sponsored programs, and difficult housing conditions have already been identified as hampering the effectiveness of preventive measures (Weber and Jenni, 2012). It has not yet been analyzed, however, to what extent the spatial distribution of paediatricians, who refer 78% of the detected cases with a developmental delay (Moser, 2020) plays a role in early detection.

Due to the declining number of practitioners, the distribution of primary care is expected to no longer meet the needs of children and their families not only in rural, but also in urban agglomeration areas within the next few years (Jenni and Sennhauser, 2016). However, there are also uncertainties whether the paediatric workforce will be maintained at the current level due to different reasons e.g., tendency to work part time, age distribution of paediatricians (Ibid.). Hospital settings such as emergency departments and other ambulatory care services services will also continue to provide some primary care services (Hakim and Ronsaville, 2002, Jenni and Sennhauser, 2016). Furthermore, the scope of expertise of paediatricians is currently also broadening, especially in terms of prevention, screening, and anticipatory guidance to parents such as counseling regarding behavioral abnormalities, feeding, eating, sleeping problems, and other issues which further increases the importance of spatial accessibility of paediatricians (Jenni and Sennhauser, 2016). Taking all of these factors into account, a spatial analysis of access to healthcare becomes even more important.

In order to fill the existing research gap and assess the spatial accessibility of early detection in the canton of Zurich, the following research question will be addressed in this thesis:

> **Research Question 1**
> What is the spatial accessibility of paediatricians for preschool aged children in the canton of Zurich?

As a hypothesis, it can be expected that the spatial accessibility of paediatricians and thus the probability of detecting a developmental delay early enough is not the same for all children in the canton of Zurich depending on their place of residence. Presumably, urban regions have a higher spatial accessibility than rural areas and only few or no children at all are registered with developmental delay.

Furthermore, it will be examined whether spatial distribution also has an impact on the age at referral. Although the relationship between urbanity and early detection has been analyzed using numerous methods (Mandell et al., 2005, Murphy and Ruble, 2012, Kalkbrenner et al., 2011, Stahmer et al., 2019), to date there has been no study that relates the accessibility of paediatricians to the age at referral.

Especially for children with speech development delays, there is empirical evidence that therapy should start before the age of 36 months in order to achieve the best possible output (Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e.V., 2021). In the field of special needs education, the earlier therapy intervention takes place, the better (Lohaus and Vierhaus, 2015). In this regard, early detection is important, because of crucial time losses due to missed intervention opportunities. For target-oriented therapy, early detection and early intervention are the main requirements. Therefore, it is essential to identify areas that are disadvantageous to the age at referral. Research shows that it is likely that the accessibility of paediatricians is directly linked to early referral (Kalkbrenner et al., 2011, DeGuzman et al., 2017, Salinas et al., 2020).

The research gap regarding the interaction between spatial accessibility of paediatricians and age at referral is addressed with the following research question:

> **Research Question 2**
> To what extent does the spatial distribution of paediatricians influence early referral?

In this context, the hypothesis is that higher spatial accessibility of paediatricians is associated with earlier referral and poor spatial accessibility is associated with later referral.

In addition to early detection, however, there are also barriers with regard to early intervention that need to be overcome. Besides the problem of missed cases with regard to developmental delay, which can be analyzed by examining the impact of spatial accessibility on early detection, there are also interventions that don't take place despite having been allocated at the assessment. The extent to which the spatial accessibility plays a role regarding early intervention should therefore be analyzed, too.

1.8. Spatial Accessibility of Early Intervention in the Canton of Zurich

Once a developmental delay has been diagnosed, the next necessary step is early therapy intervention in order to achieve the best possible effect. Intervention through pedagogical-therapeutic measures such as speech therapy and special needs education are especially effective, because they can be highly individualized and thus offer good opportunities for children to either catch up on developmental delays at a young age or to develop strategies that strengthen resilience and coping (Weber and Jenni, 2012, Lohaus and Vierhaus, 2015, Stiftung Schweizer Zentrum für Heil- und Sonderpädagogik, 2021). Besides the actual improvement in the addressed area (cognitive, linguistic, motor, and/or social development), studies have shown that early intervention also provides support for the families and prevents other educational or emotional consequences in the further course of life (Bennett and Guralnick, 1991, Law et al., 2004, Bonnier, 2008, Orton et al., 2009, Weber and Jenni, 2012, Benzies et al., 2013).

Speech therapy, in particular, has been shown to be more effective when applied early in life and in an intensive manner (Weber and Jenni, 2012, Lohaus and Vierhaus, 2015). But also in special needs education, early interventions are significantly more effective due to the individual priorities that can be set in therapy (Lohaus and Vierhaus, 2015, Stiftung Schweizer Zentrum für Heil- und Sonderpädagogik, 2021). However, even if children are allocated a certain number of therapy hours, it is still not guaranteed that they will actually receive them (Morgan et al., 2012, Grant and Isakson, 2013, Little et al., 2015). Research shows that the accessibility of therapy slots has a direct impact on early intervention (Kalkbrenner et al., 2011, Murphy and Ruble, 2012, Drahota et al., 2020). In addition, paediatricians have already addressed that long waiting times, especially in finding a therapist, are a major weakness within the assessment procedure in the canton of Zurich (Moser, 2020). Following his line of argument, in the specific case of therapy measures for children with development delay, it may also depend on the spatial distribution of the therapy services whether the allocated hours can actually be attended. Scientific findings regarding the connection between spatial accessibility of therapists and the utilization of therapy hours, are not yet available.

Studies have already detected major barriers regarding a successful early intervention such as financial issues (e.g. type of health insurance, or means of transportation available) (Porterfield and McBride, 2007, Patten et al., 2012, Pantaleoni, 2012). Thus, if disadvantaged children also have to contend with low spatial accessibility, socioeconomic barriers are further compounded. For example, a monthly ticket for public transportation may be cheaper than a daily ticket, families with limited financial resources still have to buy the daily ticket. This again exemplifies that poor spatial accessibility may further intensify preexisting socioeconomic disadvantages. To what extent the preexisting disadvantages are intensified by low spatial accessibility has not yet been assessed.

In order the existing research gap and assess the spatial accessibility of early intervention in the canton of Zurich, the following research question will be addressed in this thesis:

> **Research Question 3**
> What is the spatial accessibility of therapists in speech therapy and special needs education for preschool aged children in the canton of Zurich?

As a hypothesis, it can be expected that the spatial accessibility of therapists is not the same for all children in the canton of Zurich depending on their place of residence. Also in the field of early intervention urban regions presumably have a higher spatial accessibility than rural ones. Where many cases are diagnosed, the spatial accessibility of therapists is expected to be higher in order to prevent further barriers in the early intervention of detected cases.

Furthermore, it will be examined whether spatial distribution also has an impact on the utilization of allocated therapy hours. Even though several studies already show that the utilization of early intervention and spatial accessibility are connected (Kalkbrenner et al., 2011, Murphy and Ruble, 2012, Drahota et al., 2020), to date there has been no study that relates the accessibility of therapists to the actual quantitative difference between allocated and served therapy hours. The results of previous studies show that children from disadvantaged neighborhoods or regions generally have more restricted access to health services than children from from wealthier neighborhoods or areas (Russell, 2007, Horstkotte and Zimmermann, 2008, Gettings et al., 2015, Westman Andersson et al., 2017, Salinas et al., 2020). However, whether this these socioeconomic factors also influence the utilization of allocated therapy hours has not yet been analyzed.

The research gap regarding the interaction between spatial accessibility of therapists and the difference between allocated and served hours is therefore addressed with the following research question:

> **Research Question 4**
> To what extent does the spatial distribution of therapists influence the utilization of early intervention measures?

In this context, the hypothesis is that higher spatial accessibility of therapists is associated with high utilization of therapy hours, since for the privileged zip codes spatial accessibility is not a barrier for early intervention.

In general, studies on children with developmental delay that also focus on spatial relations are quite rare. Although the FCA methodologies have already been applied to countless research questions in the field of child development, its application on the needs of children with developmental delays does not yet exist worldwide. For the canton of Zurich, valuable general statistical information is already available, but spatial components have been neglected so far.

The proposed research questions can be addressed through interdisciplinary geospatial analysis, which further contributes to raising important policy questions and more practice-driven research. Furthermore, the data that can be used to make specific comparisons between potential and revealed spatial accessibility and the conditions under which a FCA method can be profitably used for this purpose are presented in *chapter 2*. Before examining the methodological approach used in this thesis, the final section of this chapter summarizes some key definitions used in the analyis of the data in the following chapters.

1.9. Relevant Definitions

Bearing the aforementioned theories and concepts in mind, the most important definitions are listed in this section, followed by their respective explanations. This overview is intended to enhance understanding and create an unambiguous definition of these terms and of how they are used within this thesis:

- **Definition 1.9.1** *Accessibility.* Accessibility is the spatial relationship between the location of the healthcare demand and the location of the healthcare supply. Usually, this includes transportation resources, travel time, distance and cost. However, in this thesis only travel time will be used as the basic measure of distance with regard to accessibility (*Definition 1.2.5.3 Distance*). Accessibility and access are not synonyms, as the term access includes further factors. Accessibility, on the other hand, does not depend on any further qualitative factors such as organizational, financial and cultural barriers (based on Penchansky and Thomas, 1981).

- **Definition 1.9.2** *Availability.* Availability is the quantitative relationship of the volume of existing healthcare demand and healthcare supply (e.g. relationship between requested and available therapy hours). Supply includes the number and capacities of institutions or providers. Availability doesn't depend on any further qualitative factors such as organizational, financial and cultural barriers (based on Penchansky and Thomas, 1981).

- **Definition 1.9.3** *Spatial Accessibility.* Spatial accessibility refers to the combination of accessibility and availability. The relationship between the number and capacity of supply and the level of demand is thus combined with the distance between the two (based on Guagliardo, 2004).

- **Definition 1.9.4** *Potential Spatial Accessibility.* The potential spatial accessibility is a theoretical approach. Thus, all demand and supplies defined as possible are taken into account in order to establish the spatial accessibility based on them: In other words, it refers to the healthcare service supply, which is offered to the potential users, but without ensuring the automatic utilization of the offered services. The real numbers of patient flows are therefore neglected (based on Khan, 1992).

- **Definition 1.9.5** *Revealed Spatial Accessibility.* The revealed (or realized) spatial accessibility is an approach based on real numbers and patient flows. It takes both the actual access to the system and the service used into account. In this research, revealed spatial accessibility addresses the real numbers of patient flows from a perspective of demand, which results in a claims data analysis. With regard to demand, the real cases that make use of the specific kind of supply are examined, while the supply is measured by taking into account all potentially available health services (based on Khan, 1992).

- **Definition 1.9.6** *Spatial Accessibility Index.* The Spatial Accessibility Index (SPAI) is the gravity-based index of spatial accessibility calculated in three steps (3SFCA). The distance between supply and demand is weighted by negative power of travel times. The SPAI thus expresses in a quantitative, GIS-based index how beneficial the respective spatial accesibility is for a specific population (based on Luo and Wang, 2003 and Wan et al., 2012).

- **Definition 1.9.7** *Distance.* Distance is used in terms of travel time budget. If less time is needed for a distance, a health service has higher spatial accessibility than another, which may be closer in terms of space, but requires more travel time. Distance is therefore based solely on travel time and not on metric distance (based on Hägerstraand, 1970).

2. Methodological Approach

Since the analyses for the spatial accessibility of early detection and of early intervention are analogous in terms of the methodological approach with only minor differences (e.g., underlying data sources (*section 2.2 Data sources*)), the procedure is described for both research fields simultaneously only highlighting the differences between the two analyses. An overview of the descriptive statistics of the different data sources can be found in *table 2.2* and *table 2.3* for the demand data sets and in *table 2.6* and *table 2.8* for the supply data sets. For an overview of the methodological approaches the flowchart diagrams of the base approaches calculating the Spatial Accessibility Index (SPAI) are helpful. In regard of the spatial accessibility of early detection, *figure 2.13* shows the methodological approach for the potential spatial accessibility of paediatricians and *figure 2.14* for the revealed spatial accessibility based on speech therapy and special needs education cases. In regard of the spatial accessibility of early intervention, *figure 2.15* shows the methodological approach for the potential spatial accessibility for intervention through speech therapy and special needs education, *figure 2.16* shows the approach for revealed spatial accessibility.

For the analyses following the base approaches calculating the SPAI, two further flowchart diagrams are helpful: On the one hand, the approach for early detection, which considers the relationship between age at referral and the spatial accessibility of paediatricians (*figure 2.18*), and on the other hand, the approach for early intervention, which considers the relationship between the difference between allocated and served hours and the spatial accessibility of therapists (*figure 2.19*).

However, in order to understand the methodological approach, the study area and used data sources must first be described in more detail.

2.1. Study Area

The data used in this research refers to the study area of the canton of Zurich, which is why the relevant facts about the canton and the underlying geometry data sets are presented first. The main data set for the revealed spatial accessibility contains all first registered preschool children with developmental delay in 2017. Therefore, all other data and demographics are also used and analyzed for 2017 whenever possible (e.g. zip codes, population density). In 2017, the canton of Zurich was the most populous canton in Switzerland with approximately 1.5 million inhabitants, 115’986 of whom were preschool aged children (Kanton Zürich Statistisches Amt, 2018, Bundesamt für Statistik, STATPOP 2017, 2021). It counted as one of the most densely populated areas in Europe, whereas in relation to the cantonal population, the distribution of the target population group of preschool aged children is rather disparate with a range from 34 to 324 children per 1000 inhabitants, with below-average numbers of children in the center of Zurich and above-average numbers in zip codes near the cantonal borders. (*figure 2.1*) (Bundesamt für Statistik, STATPOP 2017, 2021).

The canton of Zurich is formed by 168 political municipalities (*Gemeinden*), represented by 254 different zip codes. A zip code does not always have to indicate a contiguous area, but several polygons can belong to one zip code. For a detailed overview see *figure C.1* in the *Appendix C: Zip Codes Classification*. On a larger scale, the canton is divided into twelve districts (*Bezirke*) as political units between the cantonal and municipal level (Kanton Zürich Statistisches Amt, 2018, Kanton Zürich Statistisches Amt, 2021). According to the urban/rural typology 2012 (*Stadt/Land-Typologie 2012*, most recent available typology and standard in spatial planning matters) of the Federal Statistical Office, 115 zip codes can be classified as urban, 97 zip codes as intermediate and 42 zip codes as rural, thus urban zip codes are represented in great proportion (*figure 2.2*) (Bundesamt für Statistik, Stadt/Land-Typologie 2012, 2021).

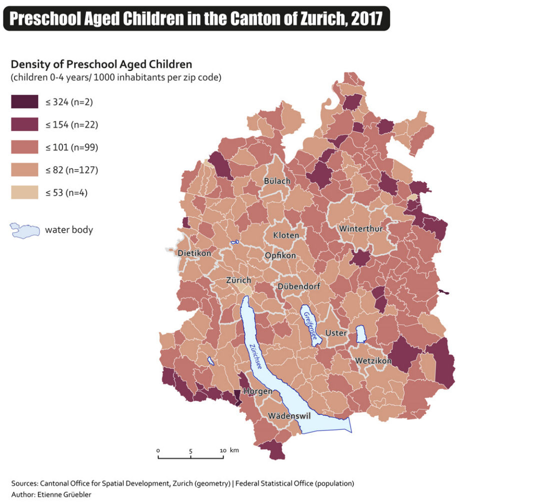

Figure 2.1: Density of preschool aged children in the canton of Zurich in 2017.

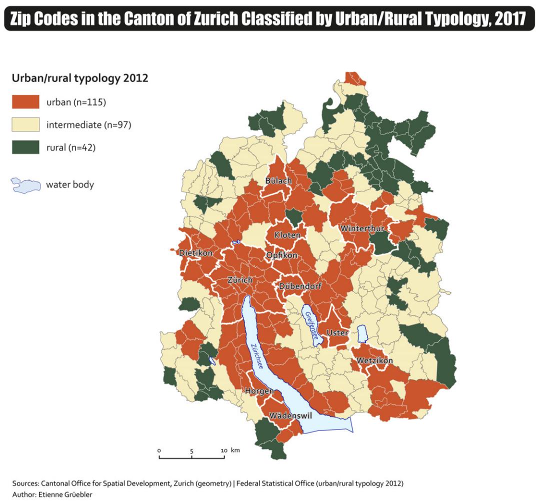

Figure 2.2: Zip codes in the canton of Zurich (2017) classified by the urban/rural typology 2012.

Since this research involves sensitive data, the data is summarized at different levels so that no conclusions can be drawn about individual persons. Thus, vetting analysis plans provide measures to protect the identities of human subjects. The rudimentary density maps are represented on district level (except for population density), as there might be several zip codes with only one paediatrician or one child assigned to therapy. The spatial accessibility is presented at zip code level, whereby for data protection reasons it is not shown in detail how many cases the average values are based on.

The geometry data sets on districts and on zip codes were both provided by the Cantonal Office for Spatial Development, Zurich. The data source of the zip codes is based on the official cadastral survey and is available in INTERLIS 1 format for the year 2017 (Cantonal Office for Spatial Development, Zurich, 2021). To convert the INTERLIS 1 format to a Shapefile the ogr2ogr-program was used (GDAL documentation, 2021). Further, the historical municipal and district boundaries are available via the GIS browser of the Canton of Zurich (Geographisches Informationssystem GIS-ZH, Zürich, 2021). Since the zip codes are not available in this data set, the zip code data set was joined to the district data set. The variables of the final data set with zip codes, districts and urban/rural typology 2012 can be found in *table 2.1*.

Table 2.1: Variables of geometry data set, canton of Zurich

Name	*Type*	*Description*
BFSNR	Integer	Number of the municipality from the Federal Statistical Office
ORTSCHAFTSNAME	String	Name of the municipality
PLZ	Integer	Zip code
Shape_Area	Double	Area of each zip code polygon
BEZIRKSNAME	String	Name of the district
Kategorien	String	Terminology from the urban/rural typology 2012
Kategorien_numb	Integer	Classified number from the urban/rural typology 2012

Within the study area three data sets are needed to apply FCA methods:

(i) a demand data set containing location and quantity of each population (*section 2.2.1 Demand*),

(ii) a supply data set containing location and capacity of each health service (*section 2.2.2 Supply*), and

(iii) a distance matrix representing the distances between demand and supply locations (*section 2.2.3 Distance Matrices*).

The properties of the different data sets are described in more detail in the following section.

2.2. Data sources

For both the impact on early detection and the impact on early intervention, potential is compared to revealed spatial accessibility. Therefore, both types of spatial accessibility require a suitable data set for the demand.

2.2.1. Demand

For the demand data, the location of the particular population is relevant, as well as the quantity at the particular population point (Luo and Wang, 2003).

Population of preschool aged Children

For the potential spatial accessibility, the data set of GEOSTAT of the year 2017 was used, which is based on the data of the Statistics of Population and Households (STATPOP) of the Federal Statistical Office. The STATPOP data set is based on a nationwide survey and draws on various registers of residents (registers of residents of municipalities and cantons, register of civil status (Infostar) of the Federal Office of Justice, central migration information system (ZEMIS) of the State Secretariat for Migration, Switzerland and the information system of diplomats and international officials (Ordipro) of the Federal Department of Foreign Affairs (Bundesamt für Statistik, STATPOP 2017, 2021). In this data set, population data are categorized by age and aggregated per hectare. The lowest age category includes all children under the age of 5 years, representing the target population group of preschool aged children. The hectare points in the data set are represented at the southwest corner point of each hectare. Since other studies using FCA methods take the midpoint of a population, for example the so-called census tract in the US (Wan et al., 2012, Luo, 2014, Luo, 2016), the hectare point was adjusted to the midpoint using *ArcGIS Pro* (*Esri software*). Within the canton of Zurich, 115986 preschool aged children were registered. The highest value for a single population point is 79, the lowest 3 (quantity at the particular population).

Since paediatricians are not necessarily used within the cantonal borders, a buffer of 5 km was used for the potential spatial accessibility of early detection based on a sensitivity analysis, in order to account for edge effects. With the buffer around the canton of Zurich this amounted to 152328 preschool aged children. The highest and lowest values for a populations point are within the canton of Zurich and are therefore identical (79 and 3). For the spatial accessibility of early intervention a buffer was intentionally omitted due to the fact that therapy measures (early intervention) are organized within the canton.

The descriptive statistics of both data sets used for the potential spatial accessibility can be found in *table 2.2*.

Table 2.2: Descriptive statistics of the population data sets for the potential spatial accessibility of early detection and early intervention based on the hectare population points. The data set shows for each populated hectare point how many inhabitants are present in the corresponding age group. Therefore, *Count* means the number of hectare data points, but *mean*, *median* and *range* refer to the quantity at the hectare points. The *sum* corresponds to the sum of all quantities (*Data set source: Bundesamt für Statistik, STATPOP 2017, 2021*).

Analysis	*Count*	*Sum*	*Sex*	*Mean*	*Median±SD*	*Range*
Early Detection	27327	152328	male=77614, female=74714	5.57	6±3.38	3-79
Early Intervention	20062	115986	male=59136, female=56850	5.78	6±3.6	3-79

Cases from the USNEs Assessments in 2017

For the revealed spatial accessibility, the data set contains all cases, which went to the USNEs for the standardized assessment in 2017 and got assigned one of the following early intervention services: Speech therapy, special needs education, low-vision training, and/or audio pedagogy. Low-vision training and audio pedagogy are special cases of special needs education; thus, these two types of therapy are included in special needs education for this analysis.

There were 1945 preschool children at the first assessment procedure and 1833 of them agreed upon the anonymized use of the data. Since one child can also have several first assessments in various areas (speech therapy and special needs education), this resulted in 1971 of the total 2410 cases that agreed.

The two cohorts of speech therapy and special needs education are analyzed separately with the corresponding health service (paediatricians or therapists). There are 1423 speech therapy cases and 548 special education cases. The density of speech therapy cases per 1000 preschool aged children is represented in *figure 2.3*, the density of special needs education cases per 1000 preschool aged children in *figure 2.4*. For the revealed spatial accessibility, the quantity at every population point is throughout 1, since each case was geocoded individually (NRP74, Project 15, 2021).

Some additional supplementary details about the cohort and the descriptive statistics of the data set for the revealed spatial accessibility can be found in *table 2.3*.

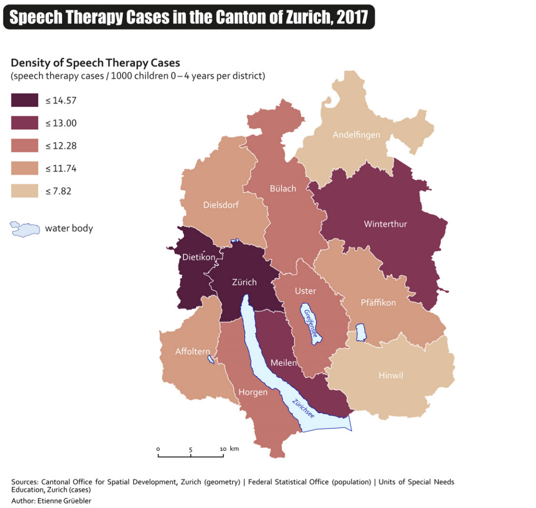

Figure 2.3: Density of cases which were assigned to speech therapy in the canton of Zurich in 2017.

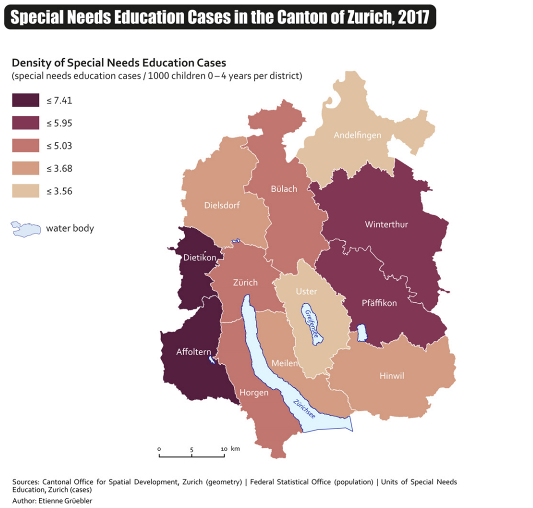

Figure 2.4: Density of cases which were assigned to special needs education in the canton of Zurich in 2017.

Table 2.3: Additional details and descriptive statistics of the data set based on all cases that were at the USNEs at the first standardized assessment in 2017, which is used to analyze the revealed spatial accessibility. The quantity at every population point is 1 throughout, since each case was geocoded individually (*Data set source: NRP74, Project 15, 2021*).

Assigned Therapy	*Cases*	*Sex*	*Age [m] (Mean)*	*Age [m] (Median±SD)*	*Age [m] (Range)*
Speech Therapy	1423	male=469, female=954	37.07	37±9.99	1-84
Special Needs Education	548	male=378, female=170	34.34	36±14.9	0-82

2.2.2. Supply

For the supply data, the location of the particular supply/health service (paediatrician or therapist) is relevant as well as the capacity of the particular supply/health service (Luo and Wang, 2003).

Because this study also looks at revealed accessibility, it assumes that every child would have a health service (paediatrician or therapist) available. This assumption is represented in the capacity: The rudimentary capacity number is set in relation to the preschool aged children for the potential spatial accessibility, for revealed spatial accessibility in relation to the cases with developmental delay. This strategy is also used because it is very difficult to estimate how many children can be treated with a given work capacity (e.g., if therapists also treat children at school age). In addition, conversations with therapists have revealed that some self-employed therapists adjust their capacity to some degree to meet the demand. Thus, it is realistic to assume that every child in the canton of Zurich should theoretically have a paediatrician and therapist at their disposal, but whether the supply/health service is within reasonable reach should be further examined. Based on this rationale, a normalization of the capacity of health services is applied. An example of the normalization can be seen in *table 2.4*.

Table 2.4: This is an example for the normalization of the capacity values. Due to the sensitive data, arbitrary data is used here to demonstrate the concept of the normalization. The example assumes a total demand population of **20**. The total of all capacities after normalization also returns 20.

	Capacity in workload percentage, patients or similar	*Calculation*	*Normalized Capacity*
Supply 1	100	$\frac{100}{195} \times 20$	10.256
Supply 2	60	$\frac{60}{195} \times 20$	6.154
Supply 3	35	$\frac{35}{195} \times 20$	3.59
Total Supplies	195	$10.256 + 6.154 + 3.59$	**20**

There is a difference between the spatial influence on early detection and the spatial influence on early intervention concerning the supply/health services. For early detection, the spatial accessibility of paediatricians is considered, for early intervention, the spatial accessibility of speech therapists and special needs educator is examined.

Paediatricians

The data set of the paediatricians is from the Medical Ambulatory Structure (MAS) survey from the Federal Statistical Office and covers the offer and organization of medical practices and outpatient centers. In general, all working physicians who are active in the outpatient sector, in the inpatient sector (including assistant physicians), or in other sectors (e.g. administration, insurance companies) are obliged to participate in this survey. Nevertheless, the participation rate of the MAS survey does not correspond to a complete census survey. For the reference year 2017, the overall participation rate of physicians in the canton of Zurich was 76% (Switzerland: 68%) (Bundesamt für Statistik, MAS, 2021, Bundesamt für Statistik, BFS Aktuell (MAS), 2021). All data of physicians who indicated pediatric and adolescent medicine as their main activity were taken into account. Within the canton of Zurich there are 115 paediatricians, who are used for the revealed accessibility. The density of paediatricians per 1000 preschool aged children is represented in *figure 2.5*. Again, a buffer of 5 km was employed for the potential spatial accessibility to account for edge effects, which resulted in 142 paediatricians.

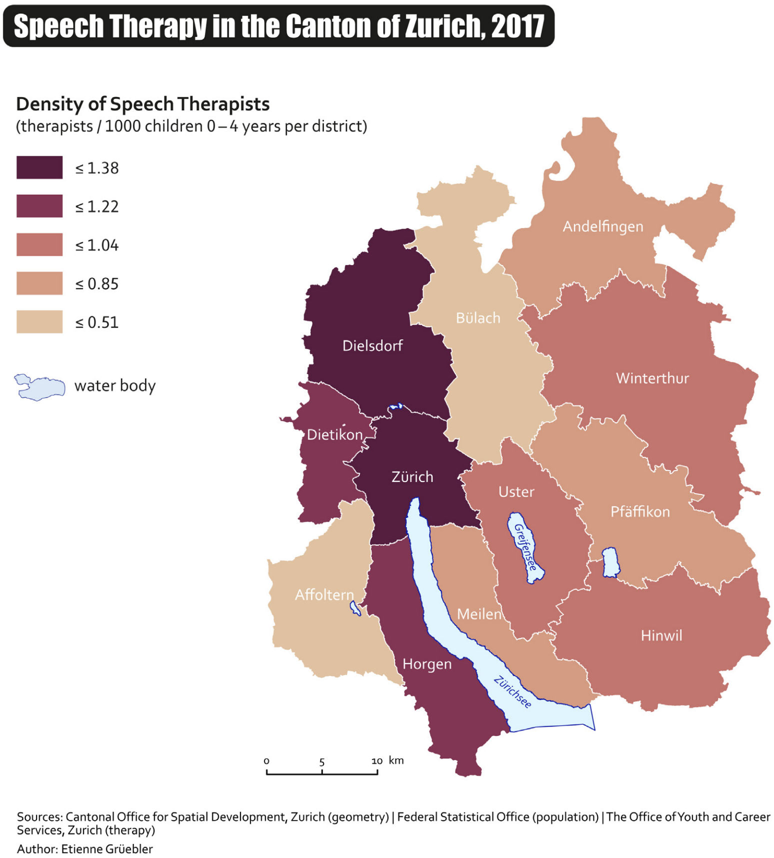

Figure 2.5: Density of paediatricians per 1000 preschool aged children in 2017.

In the density map, only the number – but not the capacity of each paediatrician – is included. For the capacity the total number of patients treated was available as well as the workload measured as the number of half-days with medical activity. Since the capacity is put in relation to the demand (normalization), the sensitivity analysis did not show a significant difference between the two parameters. The workload can vary between 4 and 6 hours per half day, which can make a difference of 20 hours per 10 half days and thus lead to more inaccuracies. The total number of patients was put in relation to the demand for the capacity. The relevant variables of the data set of the paediatricians can be found in *table 2.5*. The descriptive statistics of both data sets used for the spatial accessibility of early detection can be found in *table 2.6*.

Table 2.5: Relevant variables of the paediatricians data set, canton of Zurich

Name	*Type*	*Description*	*Fixed Value*
REF_YEAR	Integer	Data reference year	Fixed Value = 2017
MAIN_ACTIVITY_CD	String	The main activity is the activity on which the highest number in working days per year was spent. If the physician spends the same amount of time on more than one activity, indicate the one with the highest qualification.	Fixed Value = pediatric and adolescent medicine
longitude	Double	X coordinate in the Swiss coordinate system CH1903+/LV95	
latitude	Double	Y coordinate in the Swiss coordinate system CH1903+/LV95	
PATIENT_TOT_NB	Integer	Number of persons for whom at least one service (KVG or other payer) was provided in the practice during the reference year.	
Capacity	Double	PATIENT_TOT_NB normalized by the number of demand, all capacities added together equal all demand populations added together.	

Table 2.6: Descriptive statistics of the paediatricians data sets for the revealed and potential spatial accessibility of early detection. The data set shows for each paediatrician the location and the total number of patients treated. Thus, if multiple paediatricians are employed at the same location, they are scored as individual data set points. Therefore, *Count* means the number of paediatricians and *Sum* the total number of patients treated of all paediatricians. *Mean*, *Median* and *Range* also refer to the workload in number of patients treated (*Data set source: Bundesamt für Statistik, MAS, 2021*).

Kind of Spatial Accessibility	*Count*	*Sum*	*Mean*	*Median±SD*	*Range*
Revealed	115	218726	1919	1441±1811	38-14516
Potential	142	350033	2465	1620±3411	38-29457

Therapists

For early intervention, the spatial accessibility of therapists is considered and for both types of therapy (speech therapy and special needs education), Indeces (SPAI) are calculated separately. The basis for the data set on both types of therapy is provided by a list from the Office of Youth and Vocational Guidance (*Amt für Jugend und Berufsberatung (AJB)*) (Amt für Jugend und Berufsberatung ZH, 2021). The AJB uses this list to help families with referrals, so it is updated every quarter year. For this research, the workloads for each therapist and therapy institution (in percentages) were additionally collected and aggregated. Since the information on the workloads was newly collected, the most recent version of the therapists list was used (March 2021). However, the locations were compared to 2017 and it can be stated that there have been only minor changes.

Based on this list, the data for speech therapy is composed as follows: 15

therapy institutions and 105 self-employed therapists are working in the preschool sector in the canton of Zurich. The data for the institutions could be collected consistently; for 8 self-employed therapists the workload had to be estimated due to missing data. For the estimation the mean value of all self-employed therapists (speech therapy and special needs education) was used (60%). The exact mean was 62.91%, but to be sure not to simulate oversupply, the value was rounded down. The institutions were not taken into account for the estimation on purpose, as they have significantly higher values.

The data for special needs education is composed as follows: 10 therapy institutions and 41 self-employed therapists are working in the preschool sector in the canton of Zurich. The data for the institutions could also be collected consistently; for 3 self-employed therapists the workload had to be estimated due to missing data. For the estimation also the mean value of all self-employed therapists was used (60%).

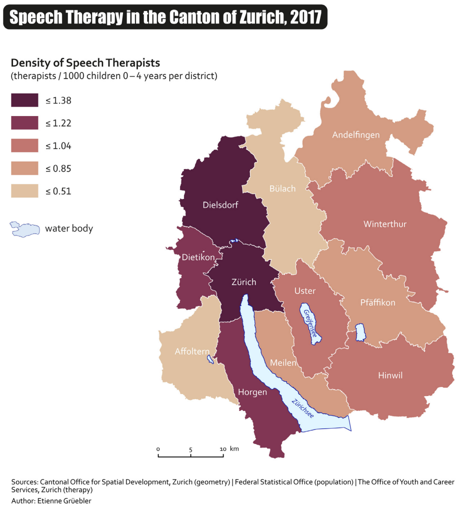

Figure 2.6: Density of speech therapists in the canton of Zurich in 2017.

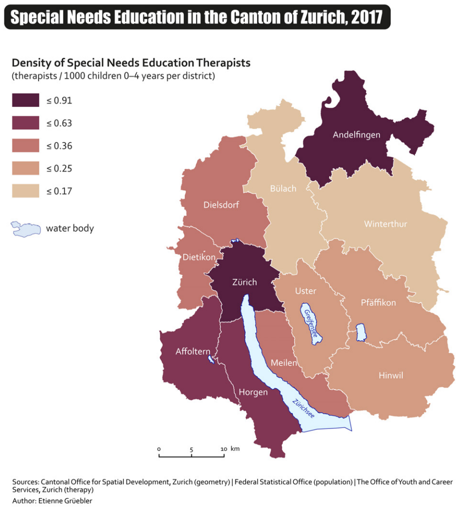

Figure 2.7: Density of special needs educators in the canton of Zurich in 2017.

The density of speech therapists per 1000 preschool aged children is represented in *figure 2.6*, the density of special needs educators per 1000 preschool aged children in *figure 2.7*. In the density map only the number but not the capacity of each paediatrician is included. The relevant variables of the data set of the therapists can be found in *table 2.7*. The descriptive statistics of the data sets used for the spatial accessibility of early intervention can be found in *table 2.8*.

Table 2.7: Relevant variables of the therapists data set, canton of Zurich

Name	*Type*	*Description*
TYPE	String	Therapy is divided into four categories: Independent therapists in speech therapy and special education and institutions in speech therapy and special education.
Address	String	Details of the complete addresses for each therapist.
Capacity_percent	Double	Total workload of each location of a therapy service (therapist or institution).
Capacity_normalized	Double	Capacity_percent normalized by the number of demand, all capacities added together equal all demand populations added together.

Table 2.8: Descriptive statistics of the therapists data sets for the spatial accessibility of early intervention. The data set shows for each therapist the location and the total workload capacity in percent. Since therapy institutions have significantly higher values, as several therapists work at the same location, the descriptive statistics are listed separately. However, there are also joint practices among the self-employed therapists, which is why the capacity there can also be higher than 100%. The estimated workload capacities of the missing data (8 for speech therapy, 3 for special needs education) have already been integrated into these statistics with a value of 60%. The statistical measures are based on the workloads in percent (*Data set source: Amt für Jugend und Berufsberatung ZH, 2021*).

Type of Therapy	*Count*	*Sum*	*Mean*	*Median±SD*	*Range*
Self-employed speech therapists	105	6170	58.8	60±32.2	5-230
Speech therapy institutions	15	2722	181	157±155	10-500
Self-employed special needs educators	41	2725	66.5	60±24	20-100
Special needs education institutions	10	3238	324	250±276	43-810

In the same way as for paediatricians, capacity was set in relation to demand (normalization). For the normalization, the number of cases and not the hours of therapy were deliberately used for the following reasons: First, the revealed accessibility should be comparable with the potential accessibility; second, it can be argued whether the allocated or served hours should be used for the normalization; and third, the information on the hours of therapy is incomplete, which would lead to greater bias.

Since the lists only contain addresses, they had to be geocoded first in order to use them for spatial statistics. Addresses were geocoded in *ArcGIS Pro* using the *Geocode Addresses Tool*. This tool assigns point coordinates to addresses with a certain accuracy expressed in a score from 0 to 100. A perfect match returns a score of 100 (Esri, 2021a). For speech therapy services, 111 of 120 addresses scored 100 and the lowest score was 95.23. For special needs education services, 46 of 51 addresses scored 100 and the lowest score was 98.29. Accordingly, the locations could be assigned very precisely.

2.2.3. Distance Matrices

The distance matrices represent the distances from a demand population point to all health services within the chosen threshold. Therefore, the following decisions had to be made for the creation of the distance matrices: The transportation mode (since the distances are to be used as time distances) and the choice of a suitable threshold.

For the distance matrices, the car was chosen as the transportation mode, following various successful studies on access to healthcare (e.g., Arcury et al., 2005, Moist et al., 2008, Jörg et al., 2019). It is evident that in Switzerland, especially in cities or areas close to cities, many people tend to travel by bike, on foot or public transport. Apparicio et al. (2017) was able to prove in his study for Montreal (CA) that a high correlation can be demonstrated specifically between travel time by car and travel time on foot or by bike (correlation > 0.90). The correlation is significantly lower for public transports (correlation ≈ 0.80). However, if we look at the real traffic behavior in Switzerland, we see that the car clearly dominates passenger traffic: In 2017 at 65% by far the most passenger kilometers were driven by car. Public transport accounts for only 24% (buses, trams and trains together) (Bundesamt für Statistik, 2018). Based on these facts, the car as transportation mode appeared to be to be the best approach for this study.

For the threshold, a time span of 20 minutes was used in the comparable Swiss study with FCA methods by Jörg et al (Jörg et al., 2019), which also seems appropriate for this study. The two largest cities Zurich and Winterthur have a distance of about 30 minutes by car. It is very likely that neither of the cities will make use of a supply in the other city. Furthermore, the two USNEs are in these two cities.

The distance matrices were generated in *ArcGIS Pro* (*Esri software*) using the *Network Analyst tool*. *Esri*'s traffic feeds come directly from HERE Data, a reliable online geodata service and navigation program with data based on billions of GPS and cell phone probe records per month (HERE, 2021, Esri, 2021b). Switzerland is among the countries that have full data coverage of historical, and live traffic information available (Esri, 2021b, Esri, 2021c). Thus, distance matrices were created for all the different demand and supply pairs. The following parameters were set:

- The direction of travel is from demand population point (origin) to the supply service point (destination) and the travel time is thus determined based on a directed network (Wang, 2015).
- No specific time was chosen for arrival or departure. Therefore, the traffic load is assumed to be average with no adverse effects from traffic congestion.
- The search tolerance that is used to locate the input features on the network is set to 2 km. With this parameter no origin or destination point was left unmatched.

Since the *Network Analyst tool* can calculate a maximum of 1000 origins per analysis, multiple matrices were created and then merged (especially for the potential spatial accessibility). For 4 demand population points (hectare level) among all preschool aged children (*STATPOP data set*), no paediatrician service within a 20-minute drive time could be identified; for 9 demand population points among all preschool aged children, no special education therapy service could be identified; and for 1 speech therapy case (address) among the first assessment cases in 2017 (*USNEs data set*), no paediatrician service could be identified. Since it could be ruled out that these points were incorrectly not assigned a supply due to the underlying road network (testing through higher time threshold), these population points were assigned a SPAI of 0. The count of the demand/supply pairs is shown in *table 2.9*.

Table 2.9: Distance matrices for the different demand/supply combinations

Demand	*Supply*	*Count of Combinations*
Preschool aged children	Paediatricians	906030
Speech Therapy Cases	Paediatricians	60266
Special Needs Education Cases	Paediatricians	22403
Preschool aged children	Speech Therapy Services	763257
Preschool aged children	Special Needs Education Services	330977
Speech Therapy Cases	Speech Therapy Services	62915
Special Needs Education Cases	Special Needs Education Services	10429

2.2.4. Age at Referral and Difference in Therapy Hours

In order to perform further analyses, two more variables are introduced: The age at referral for the impact on early detection and the difference between allocated and served hours for the impact on early intervention. These data are only used with the revealed spatial accessibility, because for the potential spatial accessibility all and not only the diagnosed children are used as data source and therefore have neither an age at referral nor a difference in therapy hours.

In the data set of all cases that were at the USNEs at the first standardized assessment in 2017, the date of assessment and the date of birth are available, as well as the indication of the allocated and served hours. From this information, the age at the first assessment could be derived, as well as the difference between allocated and served hours. Unfortunately, the data are not complete for the allocated and served therapy hours. This results in the further analysis on the spatial accessibility of early intervention in 921 (of 1423) cases for speech therapy and 402 (of 548) cases for special needs education. The data distribution of the age at referral is shown in *figure 2.8* for the speech therapy cases, in *figure 2.9* for special needs education cases. The data distribution of the difference between allocated and served therapy hours is shown in *figure 2.10* for the speech therapy cases, in *figure 2.11* for special needs education cases. The descriptive statistics of all data sets can be found in *table 2.10*.

Table 2.10: Descriptive statistics of the age at referral and difference in therapy hours for the further analyses on early detection and early intervention divided by the therapy types. The statistical measures for early detection are based on the age in month, the statistical measures for early intervention in hours. Minus values for the difference between allocated and served therapy hours mean that more hours were attended than were originally allocated at the assessment (*Data set source: NRP74, Project 15, 2021*).

Analysis	*Assigned therapy*	*Cases*	*Mean*	*Median±SD*	*Range*
Early Detection	Speech therapy	1423	37.07	37±9.99	1-84
	Special needs education	548	34.34	36±14.9	0-82
Early Intervention	Speech therapy	921	34.4	30.9±28.2	-15.6-100
	Special needs education	402	33.1	29.1±26.2	-50-100

By means of all the data sets described above, spatial accessibility can be calculated and related to the chosen factor for early detection (age at referral) and early intervention (difference between allocated and served hours). However, the spatial accessibility used in the further analyses must first be calculated. For the calculation of the spatial accessibility, the following two methodological procedures are necessary:

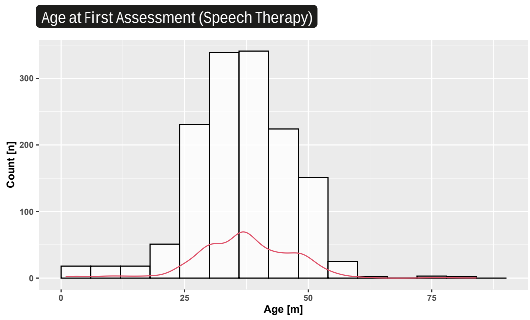

Figure 2.8: Data distribution of the age at referral for speech therapy cases in 2017. The red line is indicating the density geometry.

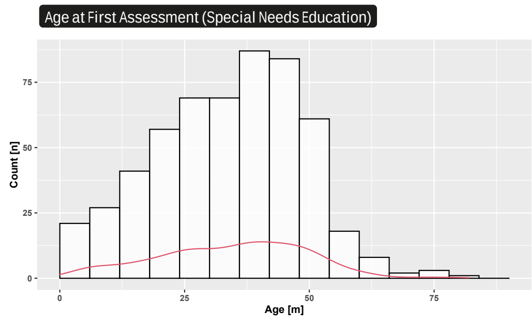

Figure 2.9: Data distribution of the age at referral for special needs education cases in 2017. The red line is indicating the density geometry.

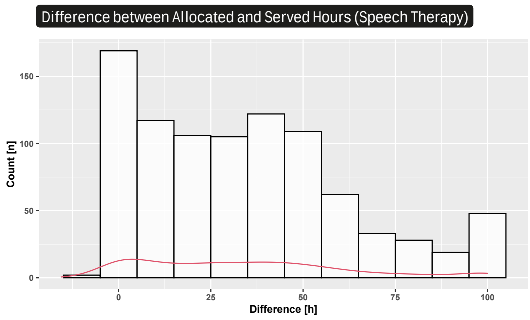

Figure 2.10: Data distribution of the difference between allocated and served therapy hours for speech therapy cases in 2017. The red line is indicating the density geometry.

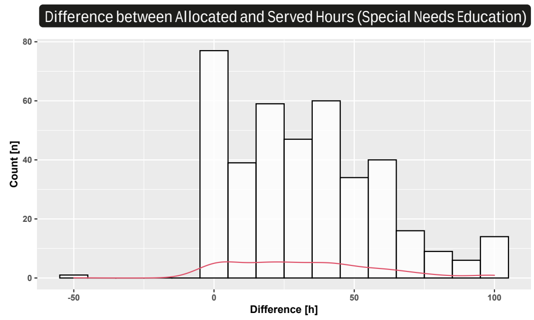

Figure 2.11: Data distribution of the difference between allocated and served therapy hours for special needs education cases in 2017. The red line is indicating the density geometry.

(i) implementing an FCA-method, in this case the 3SFCA method (*section 2.3.1 Three-Step Floating Catchment Area (3SFCA) Method*), and

(ii) determining a distance decay function (*section 2.3.2 Distance Decay Function*).

These two methodological steps are described in the following two sections.

2.3. Methods

2.3.1. Three-Step Floating Catchment Area (3SFCA) Method

Due to the fact that many enhancements have been introduced since the implementation of the original 2SFCA method, the suitable method for this research design was evaluated. For the conditions of this research, the 3SFCA method of the FCA set of methods is suitable to compute the spatial accessibility for the following reasons: The different supply services are gradually weighted less with increasing distance by means of the so-called selection weight, but the attractiveness of a supply service is not dependent on its size (as it would be when integrating the Huff model (Wang, 2015)). Although for many health services the capacity of supply may be relevant to the probability of demand, this assumption seems rather unrealistic in the area of therapy services. For example, self-employed therapists often adjust their capacity to some extent in response to demand. For paediatricians, larger services also have greater capacity and thus may be more popular. Nevertheless, paediatricians are often called in on the basis of recommendations and at the shortest possible distance so that they can be reached quickly in the event of an emergency. For example, a children's hospital has a large capacity, but it is very unlikely that it will be used for regular visits if a greater distance has to be covered. So, also for paediatricians, the size of the corresponding service has a much smaller influence on the choice and distance may be more of a guiding decision factor (Luo, 2014, Luo, 2016).

Due to the positive correlation between the availability and utilization of health services, which became recognizable in studies (Wennberg and Fowler, 1977, Wennberg, 2010, Wennberg, 2014), it can also be assumed that a connection between the spatial accessibility and the use of health services exists. It seems realistic that the demand of a population point adjusts to some extent to the available supply rather than assuming a constant demand. This is another reason for not integrating the Huff model in this research the way Jörg et al. 2019 have integrated it.

How the 3SFCA method can be implemented in general with the underlying data here is shown using the simulation system in *figure 2.12*. Compared to the 2SFCA method and the E2SFCA method, the 3SFCA method addresses the overestimation of demand (Wan et al., 2012). However, since the distance function is independent, a function suitable for this research must also be found. This is derived in the following section (*section 2.3.2 Distance Decay Function*), but first, the specific methodological procedures for the various analyses on spatial accessibility are briefly explained (independently of the implemented distance function).

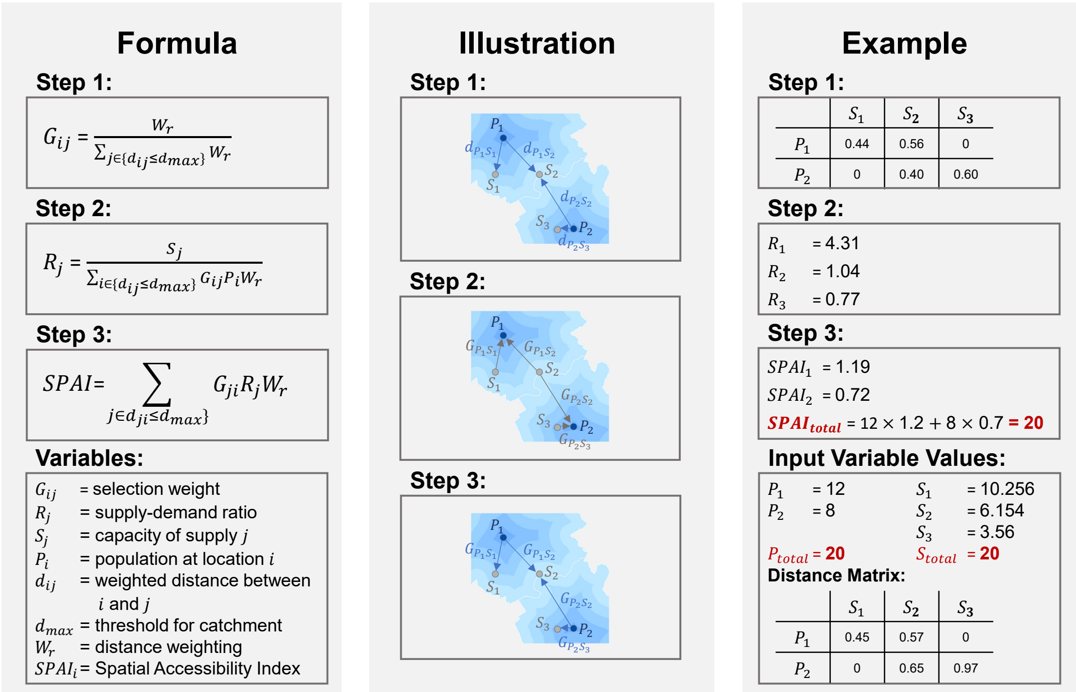

Figure 2.12: General implementation of the 3SFCA method within this research design presented by a simulation system, especially to show the relevance of the chosen parameters. Due to the normalization of the capacities of the supply services and the distance values between 0 and 1, also the SPAI values can be added and result in the total demand population. This is further important for the interpretation of the SPAI values, which will be looked at specifically in *section 2.3.3 Interpretation of the SPAI* (based on Jörg et al., 2019, *p.31*).

Spatial Accessibility of Early Detection

For the potential spatial accessibility concerning the spatial accessibility of early detection, the SPAI for all preschool aged children from the STATPOP data set as demand to paediatricians as supply is calculated. This results in SPAI values on hectare level, which are then averaged within the zip codes (*figure 2.13*).

For revealed spatial accessibility concerning the spatial accessibility of early detection the SPAI of paediatricians is calculated for all cases referred to speech therapy as well as the SPAI for all cases referred to special needs education in 2017. This results in SPAI values for the exact location of each case, which are then averaged within the zip codes for data protection reason. The procedure for speech therapy is on the left, the procedure for special needs education on the right. The procedures do not differ except for the demand data set used (*figure 2.14*).

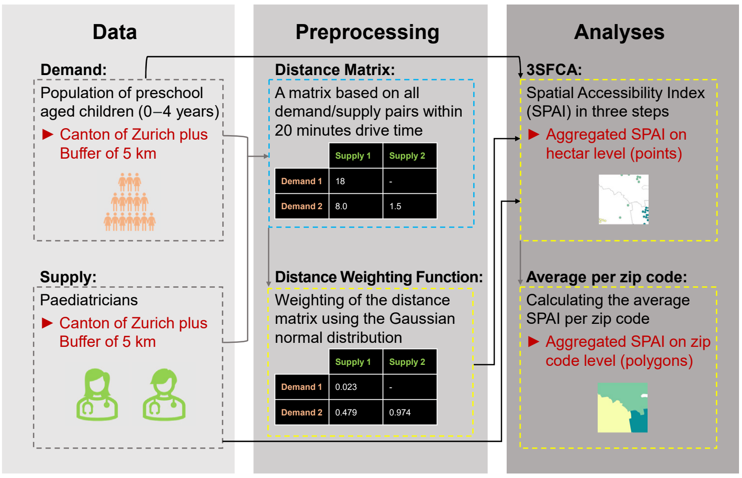

Figure 2.13: Flowchart of the methodological approach for the potential spatial accessibility of early detection. The blue framed step was implemented in *ArcGIS Pro*, the yellow framed steps in *RStudio*.

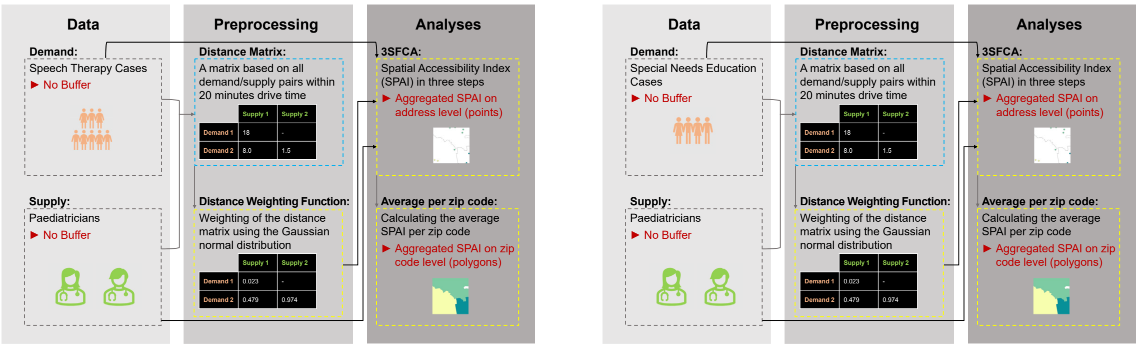

Figure 2.14: Flowcharts of the methodological approach for the revealed spatial accessibility of early detection based on speech therapy cases (on the left) and on special needs education cases (on the right). The blue framed step was implemented in *ArcGIS Pro*, the yellow framed steps in *RStudio*.

Spatial Accessibility of Early Intervention

For the potential spatial accessibility concerning the spatial accessibility of early intervention, the SPAI for all preschool aged children from the STATPOP data set as demand to either speech therapy services or special needs education services as supply is calculated. This results in SPAI values on hectare level, which are then averaged within the zip codes. The procedure for speech therapy is on the left, the procedure for special needs education on the right. The procedures do not differ except for the supply data set used (*figure 2.15*).

For revealed spatial accessibility concerning the spatial accessibility of early intervention the SPAI of speech therapy services is calculated from all speech therapy cases and the SPAI of special needs education services for all special

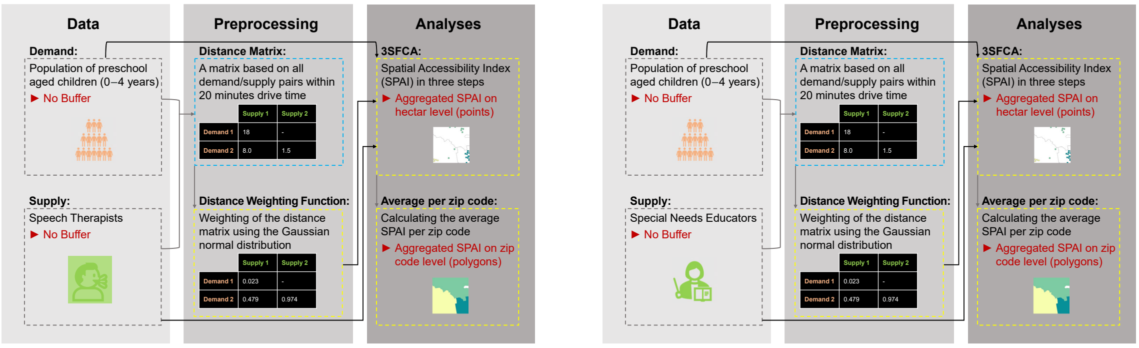

Figure 2.15: Flowcharts of the methodological approach for the potential spatial accessibility of early intervention based on speech therapy services (on the left) and special needs education services (on the right). The blue framed step was implemented in *ArcGIS Pro*, the yellow framed steps in *RStudio*.

needs education cases referred in 2017. This results in SPAI values for the exact location of each case, which are then averaged within the zip codes for data protection reasons. The procedure for speech therapy is shown on the left, the procedure for special needs education on the right. The procedures differ in the demand and supply data set used (*figure 2.16*).

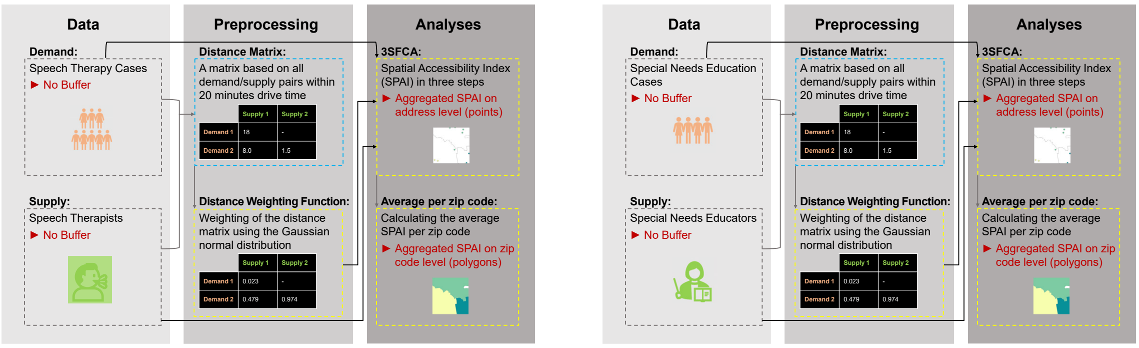

Figure 2.16: Flowchart of the methodological approach for the revealed spatial accessibility of early intervention based on speech therapy cases and services (on the left) and special needs education cases and services (on the right). The blue framed step was implemented in *ArcGIS Pro*, the yellow framed steps in *RStudio*.

The flowcharts show the exact methodological procedures. However, in order to get from the original distance matrix to the weighted distance matrix during preprocessing (necessary for all procedures), it is necessary to implement a distance decay function (Wang, 2015). This function will be derived in the next section.

2.3.2. Distance Decay Function

Distance decay functions are used to operationalize different distances (Wang, 2015). With regard to the spatial accessibility of health services, the function is used to quantify to what degree spatial accessibility is improved if a service is only 5 minutes away instead of the maximum selected threshold of 20 minutes and thus, to model the travel behavior of patients dependent on the distance (Jörg et al., 2019). Within FCA methods, a commonly used decay function is the Gaussian function (e.g., Luo and Qi, 2009, Dai, 2010, McGrail, 2012, Luo and Whippo, 2012, Donohoe et al., 2015, Bauer and Groneberg, 2016, Jörg et al., 2019). In addition, the gravity function, exponential function and logistic function have also been used as distance decay functions in FCA methods studies (*table 2.11*) (Wang, 2015, Bauer and Groneberg, 2016, Jörg et al., 2019).

Table 2.11: Overview of the distance weighting functions applied in FCA methods (*Jörg et al., 2019, p.29*).

Function	*Equation*
Gravity function	$f(d) = d^{-\beta}$
Exponential function	$f(d) = e^{-\beta \times d}$
Gaussian function	$e^{\frac{-(d^2)}{\beta}}$
Logistic function	$\frac{1}{1 + e^{-\beta \times (d - mean)}}$

For each of the functions, d denotes the distance and β the distance friction coefficient. The distance friction coefficient β determines the extent of the function. For these analyses, the distance friction coefficient was calculated based on various studies (e.g., Wang, 2015, Bauer and Groneberg, 2016, Jörg et al., 2019) for the condition $f(d_{\max)} \cong 0.01$. With this calculation, it is assumed that the distance weight at the maximum radius is close to zero (all supply locations outside the maximum radius are considered unreachable and thus correspond to a distance weight of zero). The relationship between distance and weighting is shown in *figure 2.17*.

The condition $f(d_{\max)} \cong 0.01$ at a maximum radius of $d_{\max} = 20$ results in a

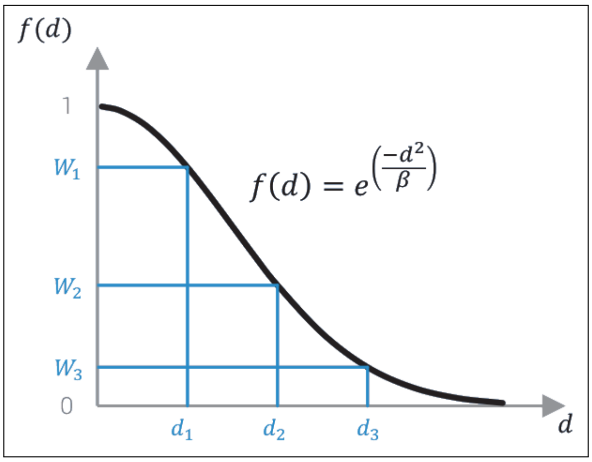

Figure 2.17: Gaussian function for continuous distance decay between supply and population locations within the maximum radius ($d_{\max}$) (*Jörg et al., 2019, p.29*).

distance friction coefficient of $\beta = 87$ (*Jörg et al., 2019, p.48*):

$$f(d_{\max}) \cong 0.01$$
$$e^{\frac{-(d_{\max}{}^2)}{\beta}} = 0.01$$
$$e^{\frac{-20^2}{\beta}} = 0.01$$
$$\beta = 87$$

Thus, a continuous Gaussian function is used for the distance decay with a distance friction coefficient β of 87, resulting in values between 0 and 1 where the function is more linear in the middle field than at the ends near 0 and 1.

2.3.3. Interpretation of the SPAI

In order to interpret the calculated SPAI appropriately, it must be determined which values signify good or bad spatial accessibility. How the SPAI values are to be interpreted is strongly dependent on the input parameters. Often, the values are divided into classes based on the distribution of values (e.g., quintiles or tertiles (low, medium, high)) and then evaluated primarily in relative terms (e.g., accessibility is better in some regions than in others) (e.g., Luo and Wang, 2003, Luo and Qi, 2009, Dai, 2010, McGrail, 2012, Luo, 2014, Luo, 2016, Jörg et al., 2019). In other studies, the SPAI values are normalized either with respect to the population in the cartographic visualized organizational unit (e.g., per census tract) or per 1000 inhabitants (Salze et al., 2011, Delamater, 2013, Mao and Nekorchuk, 2013). In general, however, the following assumptions always apply: The SPAI is higher (*Jörg et al., 2019, p.25*)

- the lower the demand is at at a location,
- the more health services are available,
- the greater their capacities are, and
- the closer or better spatially accessible the services are.

Since in this research, supply values have already been normalized with the assumption that every child would theoretically have a service at their disposal, the SPAI values do not require further normalization and are intuitive to interpret: With revealed spatial accessibility, the quantity of the demand at each address is 1. Thus, all added SPAI values result in the total population of the demand. With potential spatial accessibility, the quantity of the demand varies per location. However, if each value is multiplied by the corresponding quantity of the demand, all SPAI values can be added and result in the total population. Therefore, the value 1 corresponds to one slot or one hundred percent capacity of a supply service. This can of course be distributed over different supply services and it gives no indication of how close these different services are within the 20 minutes threshold. Thus, values below 1 are certainly confronted with undersupply and low spatial accessibility as they refer to less than one slot, values between 1 and 2 with moderate spatial accessibility and values above 2 should actually correspond to high spatial accessibility, since it is unlikely that values above 2 are comprised of health services, which are far away but have large capacities (due to the Gaussian function as distance decay). An overview of the normalized supply values and the corresponding SPAI values is shown in *table 2.12*.

Table 2.12: An example of the normalized supply value and how it refers to the SPAI of the corresponding demand population point.

$Population_1$	= 12	$Supply_1$	= 10.256
$Population_2$	= 8	$Supply_2$	= 6.154
		$Supply_3$	= 3.56
$\boldsymbol{Population_{total}}$	= 20	$\boldsymbol{Supply_{total}}$	= 20
$SPAI_{Population\ 1}$	= 1.19		
$SPAI_{Population\ 1}$	= 0.72		
$\boldsymbol{SPAI_{Population\ total}}$	$= 12 \times 1.2 + 8 \times 0.7$	= **20**	

Aggregation of the SPAI values

For the cartographic visualizations, the indices were aggregated and averaged at the zip code level. This measure was taken mainly since this research involves sensitive data. In addition, the size is sufficiently small that it is likely that population points within the zip codes have similar values. However, depending on the size and shape (some zip codes span two non-contiguous polygons) of the zip code, the range of values can vary considerably. Due to the distance decay based on the Gaussian function, differences can also occur within larger Zip codes with supply services with large capacities. The zip codes with the largest range for each map can be found in *table 2.13*.

Table 2.13: The zip codes with the largest range of SPAI values for each cartographic visualization

Research field	*Map*	*Zip code*	*Count Polygons*	*Range*
Early Detection	*figure 3.1*	8523	2	1.46
	figure 3.2	8044	2	1.1
	figure 3.3	8050	1	0.89
Early Intervention	*figure 3.6*	8932	1	2.35
	figure 3.7	8048	1	1.5
	figure 3.8	8400	1	2.52
	figure 3.9	8910	2	0.95

Classification of the SPAI values

Further, for the cartographic visualizations, the SPAI values were finally classified. The rationale of the class sizes is closely related to the interpretation of the values. Since the value 1 is attributed to a full available supply service slot, this value primarily signifies a hard threshold. Below that, children have less than a full supply service available and therefore face undersupply. This class was therefore categorized as *low* with respect to the SPAI and the integer value 1 is accounted towards the second class. A value above 1 and below 2 is classified as *moderate* in terms of spatial accessibility, because this way a child has between 1 and 2 supply services available, but the values might still be composed out of services which have a great capacity but are far away. For uniform handling, the integer value 2 was also assigned to the higher class. The values above 2 seem to indicate *high* spatial accessibility indicating oversupply, considering that all supply services within 20 min drive time were taken into account in the analysis (at least marginally due to the Gaussian function). All values above 2 are assigned to one class. This results in 3 classes for all analyses categorized in *low*, *moderate* and *high* spatial accessibility.

Once spatial accessibility has been calculated, aggregated, and visualized using the described approach, the next step is to relate it to the main factors for early detection (age at referral) and the utilization of early intervention (difference between allocated and served hours). This requires three further statistical steps:

(i) detect whether the target and the auxiliary variables are distributed normally (*Shapiro-Wilk Test*),

(ii) determine whether there is a correlation between the two variables (*Spearman's Rho Test*), and

(iii) assuming that the first two conditions are met, visualizing the relationships in an appropriate way (*Classification of the Bivariate Choropleth Maps*).

These three methodological steps are described in the following section.

2.3.4. Bivariate Choropleth Maps

For revealed accessibility, the data set of USNEs was used. Not all zip codes are covered with data on spatial accessibility. Therefore, only those zip codes, for which data are available for both variables, can be used for the bivariate choropleth maps. For the impact on early detection, all zip codes that have a SPAI value can be analyzed, since the variable on age at early referral is available (201 zip codes for speech therapy, 139 zip codes for special needs education). An overview of the methodological approach on early detection is shown in *figure 2.18*.

For the impact on early intervention, this selection is further limited because the data on allocated and served therapy hours are not complete (185 zip codes for speech therapy, 131 zip codes for special needs education). An overview of the methodological approach on early intervention is shown in *figure 2.19*.

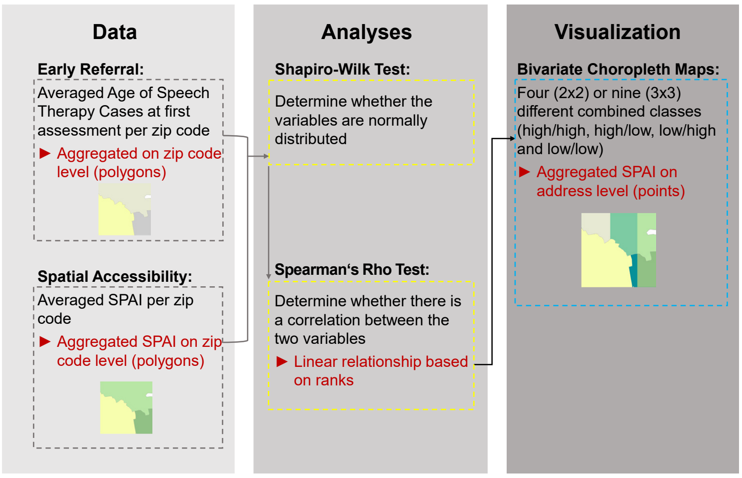

Figure 2.18: Flowcharts of the methodological approach for the relationship of age at referral and spatial accessibility of early detection based on speech therapy cases and spatial accessibility of paediatricians and special needs education cases and spatial accessibility of paediatricians. For both therapy cases the same methodological approach is used with different input data (speech therapy cases or special needs education cases). The yellow framed steps were implemented in *RStudio*, the blue framed step was implemented in *ArcGIS Pro*.

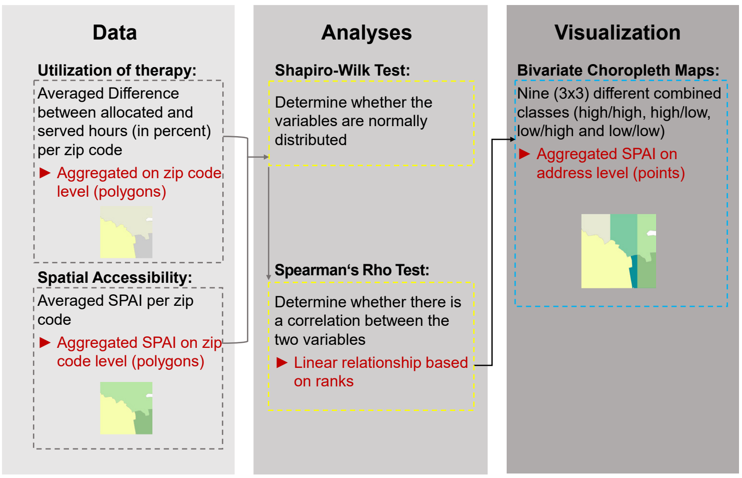

Figure 2.19: Flowcharts of the methodological approach for the relationship of difference between allocated and served therapy hours and spatial accessibility of early intervention based on speech therapy cases and spatial accessibility of therapy services and special needs education cases and spatial accessibility of therapy services. For both therapy cases the same methodological approach is used with different input data (speech therapy cases or special needs education cases). The yellow framed steps were implemented in *RStudio*, the blue framed step was implemented in *ArcGIS Pro*.

Shapiro-Wilk Test

The prerequisite for reasonable plotting of two variables in a bivariate map is that there is an association between the two variables (Nelson, 2020, Stevens, 2021). The statistic to describe this association is called correlation (Boslaugh, 2013). The most common measure of linear correlation is the Pearson Correlation Coefficient (ibid.). However, a necessary condition for the Pearson correlation test are normally distributed variables (Hauke and Kossowski, 2011). *Figure 2.8, 2.9, 2.10* and *2.11* have already shown at a first glance that the auxiliary variables are not likely to be normally distributed. Therefore, the first step is to test whether the variables to be visualized are normally distributed. For this reason, a Shapiro-Wilk test can be applied with the following hypotheses (Shapiro and Wilk, 1965):

H_0 : The variable is normally distributed.
H_1 : The variable is not normally distributed.

If the variables are suitable for a classical Pearson Correlation Test, H_0 would not be rejected and the test should be significant at a significance level of $\alpha = 0.05$. However, it is expected that the tests should not be significant at a significance level of $\alpha = 0.05$ and H_0 can be rejected to use the Spearman rank-order correlation test (Hauke and Kossowski, 2011, Boslaugh, 2013). The reasons why Spearman's Rho is expected to be a more appropriate coefficient is explained in more detail in the following section.

Spearman's Rho Test

Spearman's Rho coefficient is the most common correlation test for ordinal data, which means that the data is ordered but there are not equal distances between the different values of the data (Boslaugh, 2013). For this research design, it is likely that the Spearman's Rho fits better than the Pearson correlation test for the following reasons (based on Boslaugh, 2013 and Gibbons and Chakraborti, 2014):

- the variables are categorical data: The auxiliary variables (age at referral and difference between allocated and served therapy hours) are not expected to be continuous because visits to paediatricians occur at specific intervals (regular checkups) and assigned therapy hours have specific contingents,
- the variables can thus be analyzed in an ordinal manner,
- variables are not expected to be distributed normally (*figure 2.8, 2.9, 2.10* and *2.11*), and

- a linear relationship between the variables is still expected (precondition for correlation at all) but based on ranks.

For these reasons, a Spearman's Rho test can be applied with the following hypotheses (assuming that the Shapiro-Wilk tests could be rejected) (Spearman, 1904):

$H_0 : r = 0$ There is no correlation between the ranked pairs.
$H_1 : r <> 0$ The ranked pairs are correlated.

If there is a correlation between the target (SPAI values) and auxiliary variable (age at referral and difference between allocated and served therapy hours) the test should not be significant at a significance level of $\alpha = 0.05$. Further, the r value should indicate how strong the association between the variables is and whether it is positive or negative ($1 > r > -1$).

Classification of the Bivariate Choropleth Maps

Furthermore, if a correlation between the variables has been confirmed, the variables can be visualized in terms of their relationship. Bivariate choropleth mapping is a straightforward, descriptive method to use in public health decision-making for showing disparities (Carr et al., 2005, Cromley and Cromley, 2009, Robinson et al., 2011, Biesecker et al., 2020). Bivariate or multivariate maps represent two or more variables on one thematic map. Each variable is either divided into two or three classes, which leads to either four (2x2) or nine (3x3) different combined classes represented by different color shades (Nelson, 2020). These different classes show the two variables in a relative way (high/high, high/low, low/high and low/low) in each represented unit (e.g., county or zip code). The relationship is visualized and showed descriptively and spatially (ibid.).

Bivariate mapping is a very prevalent way of representing two variables - provided there is an association between the two variables. The represented unit (e.g., county or zip code) is independent of its neighbours (not as for local spatial autocorrelation) (Abdishakur, 2021). As such, critical zip codes with low SPAI values can clearly be indicated and linked to the auxiliary variable (age at referral and difference between allocated and served therapy hours), which helps to easily understand the represented data by policy makers. Therefore, it is an intuitive way for this study to showcase the relationship between spatial accessibility and age at referral as well as the difference between allocated and served therapy hours.

To create effective bivariate choropleth maps, some aspects have to be considered. The first and most straightforward step is to simplify the data by classifying the relevant variables (Battersby, 2021). More precisely, it must be decided whether two or three categories are to be displayed for the attributes, and thus either four (2x2) or nine distinct colors (3x3) (ibid.).

In this research design, there is a hard threshold of 36 months for early detection of speech developmental delays, with a start of therapy intervention being significantly more effective before than after (Jenni et al., 2013a, Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e.V., 2021). Therefore, for the analysis of speech therapy cases, it makes sense to divide the age group by the threshold of 36 months for early detection and thus visualize four distinct categories (2x2). This hard threshold does not exist for special needs education, which is why a more fine-grained gradation is used here. Both variables are divided into tertiles and nine distinct colors are represented (3x3). This also applies to the analyses on spatial accessibility to early intervention.

The selection of the visualized categories is the most prerequisite step. All further decisions of visualization were made in dependence with the rudimentary choropleth maps representing the SPAI values. These decisions are explained in more detail in the following section.

2.3.5. Effective Map Data Visualization

For the evaluation of thematic maps, the following steps are necessary: Read, analyze and interpret (Brewer, 2016). Since in this thesis an interdisciplinary issue is addressed, the visualizations should be as intuitive to read as possible, but also conform to cartographic rules. Further, the analyses highlight problems that should also be underlined visually. Cognitive research has long been concerned with the extent to which the representation of facts is related to people and their decision-making (e.g., Larkin and Simon, 1987, Scaife and Rogers, 1996). In this sense, a great deal of attention is paid here to the presentation of the content and its interpretation.

A main feature of this thesis are thematic maps: Univariate and bivariate choropleth maps. Brewer (2016) provides a good basis for the cartographic rules of choropleth maps, which is why most decisions are based on this. Since the choice of color was a key task for these maps, the considerations are briefly outlined. Several of the used variables increase quantitatively from low to high and therefore, the use of sequential color schemes was necessary. The only exceptions are zip codes with no registrations or no data. Depending on the purpose, a discreet color (grey) or a color that would divergently continue (orange) the sequential color scheme was used. The company CARTO provides data-driven color schemes which were further used (CARTO, 2021).

Another feature is the link between the univariate and bivariate maps, because they are thematically linked. However, using the color scheme of the SPAI values as an axis of the bivariate map could be misleading, since the values do not match all the low values of the x-axis in the bivariate maps. This is where the idea of color matching in the diagonal came from, so that the sequential character of low/low to high/high is maintained. In addition, the same colors represent the target classes in all analyses this way. The development of the bivariate color scheme is based on various guides and examples (Nelson, 2020, Stevens, 2021, Grossenbacher, 2021, Battersby, 2021, Abdishakur, 2021).

Based on this theme specific, newly developed bivariate color scheme, it was tested via common tools for perception by people with color vision deficiency.

3. Results

The major contribution of this thesis are different choropleth maps presenting SPAI values based on the implementation of the 3SFCA method. According to the approach explained in the previous chapter (*chapter 2 Methodological Approach*), for both parameters (early detection and early intervention) the spatial accessibility to the relevant healthcare services (paediatricians and therapists) was first examined and represented in choropleth maps. Then, Shapiro-Wilk and Spearman's Rho tests were performed to examine whether the relevant variables are normally distributed and the target variable (SPAI values) correlate with the auxiliary variables (age at referral or the difference between allocated and served hours) to finally visualize the variables in bivariate choropleth maps with a descriptive regard to their spatial correlation.

The map of the zip codes *figure C.1* and the classification of the zip codes in *table C.1* in the *Appendix C: Zip Codes Classification* may provide a helpful overview for understanding the maps on spatial accessibility thoroughly.

3.1. Spatial Accessibility of Early Detection

First, a general overview of the advantageous and disadvantageous regions with regard to potential early detection was obtained. For this reason the spatial accessibility of paediatricians with the total population of preschool aged children in the canton of Zurich as the demand was considered. Although all children should see a paediatrician at regular intervals in general, it is especially important for children with developmental delays to ensure early detection (Weber and Jenni, 2012, Jenni et al., 2013a). Therefore, the revealed spatial accessibility of the cases requiring speech therapy and special needs education will be investigated in a second step. For revealed spatial accessibility, the data also shows in which zip codes there were no children at the USNEs for the standardized assessment in 2017.

3.1.1. Spatial Accessibility of Paediatricians in the Canton of Zurich

Potential Spatial Accessibility

For the potential spatial accessibility of early detection (*figure 3.1* and *table 3.1*) most zip codes were classified as low (n = 190, median = 0.642). There is even a zip code with 4 hectares population point with SPAI values that are zero (orange polygon) at the edge of the canton. But since a buffer of 5 km was used, it should not necessarily be because of the edge effect.

Hot spots of moderate spatial accessibility are mainly found around the Lake Zurich, above all on the right shore of the lake, near the children rehabilitation center (Affoltern am Albis) and greater cities (Zurich, Winterthur and Uster). Only two zip codes (8548, 8523) are classified with high spatial accessibility. These are in the north-west of the canton and are connected by another 5 zip codes with moderate spatial accessibility. This should neither be due to edge effects because of the buffer.

In particular, disparities are also evident in the larger cities of Zurich and Winterthur: On the periphery, spatial accessibility is lower than in the core city.

Revealed Spatial Accessibility for Speech Therapy Cases

The spatial accessibility for revealed spatial accessibility for speech therapy cases (*figure 3.2* and *table 3.2*) is largely in line with the potential spatial accessibility: Consistently, the lowest values are most represented (n = 127). The mean and median values are slightly higher than for the potential spatial accessibility (mean + 0.197, median + 0.177), but are also classified in the low spatial accessibility range. One zip code has a SPAI value of 0, which means that first registrations could be achieved despite the non-existing spatial accessibility according to the definitions of this study. However, based on the sensitivity analysis the zip code is only very slightly outside the catchment area, and the population hectar points of the potential spatial accessibility could all be assigned within this zip code. Therefore, the zip code was not specifically highlighted on the map.

The hot spots with moderate to high spatial accessibility are more extended at the expense of the zip codes with no registrations due to lower demand in the surrounding area. Moderate to high values are mainly in zip codes with low spatial accessibility (e.g. district Andelfingen: Zip codes 8465, 8466, 6467 and 8468). Therefore, there are also a few more zip codes that were classified with high spatial accessibility (n = 8).

Approximately one fifth of the zip codes were classified as no registrations (n = 52). Most of them are located in the north of the canton and/or on the periphery of the canton.

Revealed Spatial Accessibility for Special Needs Education Cases

The distribution of revealed spatial accessibility of special needs education cases (*figure 3.3* and *table 3.3*) also largely corresponds to the potential spatial accessibility: Although there are no SPAI values that are zero, most zip codes are classified in the category with low spatial accessibility (n = 83). The overall median is almost the same as for the speech therapy cases (-0.006), compared with the potential spatial accessibility the mean is considerably higher (+ 0.306) and is even in the moderate spatial accessibility range (1.03). This increased mean value is due to the significantly more established hot spot with high spatial accessibility values at the right shore of Lake Zurich.

Hot spots with moderate to high spatial accessibility are also more extended at the expense of zip codes without registrations (similar to the speech therapy cases), but there are more zip codes with no registrations than for speech therapy cases (n = 114)). This appears logical when considering the total number of cases (1423 speech therapy cases, 548 special needs education cases), yet the distribution clearly shows that the zip codes with no registrations are also mostly associated with low spatial accessibility classified zip codes (besides Andelfingen (already indicated for speech therapy) also Bülach, Dielsdorf and Pfäffikon).

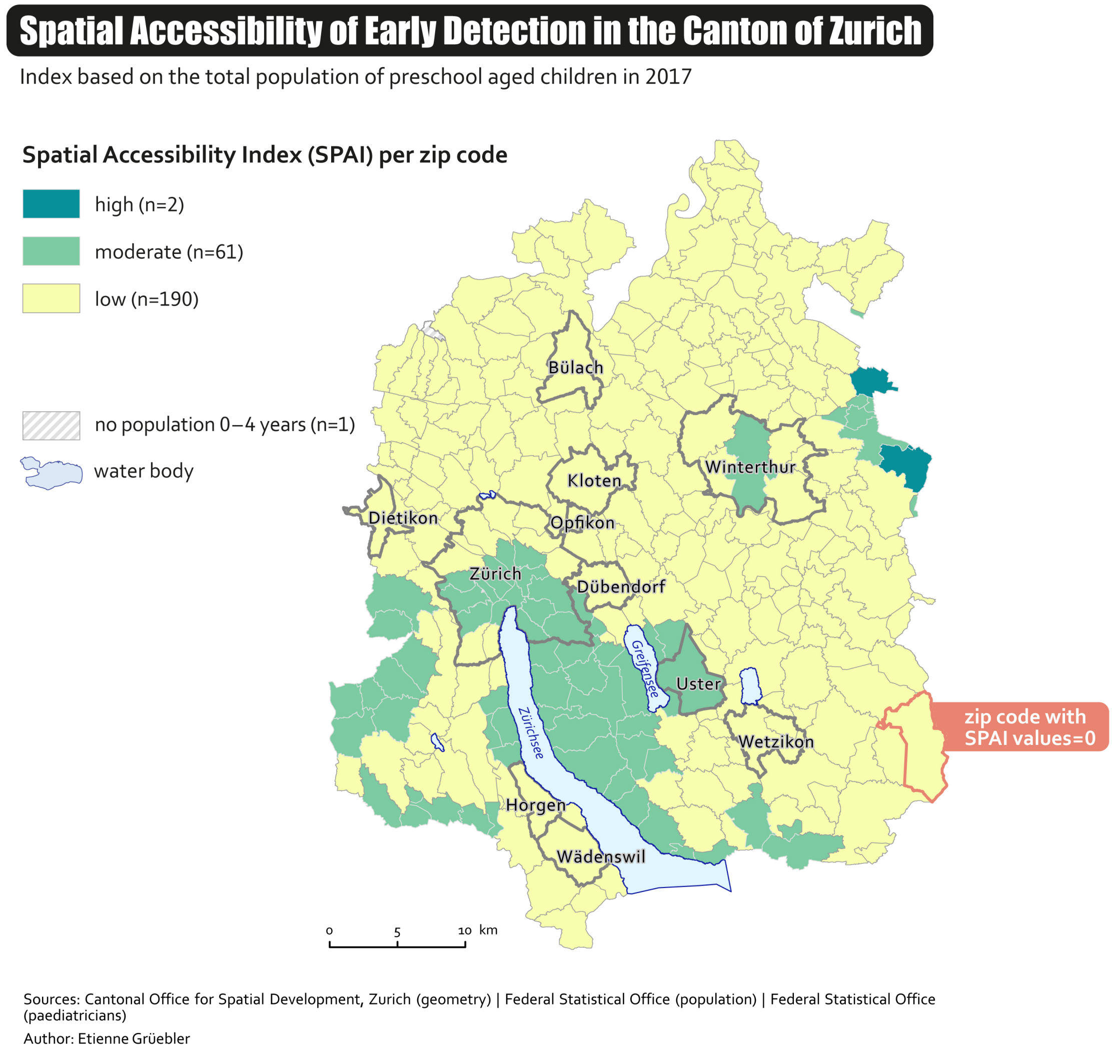

Figure 3.1: Spatial Accessibility Index SPAI for total population of preschool aged children (demand) and paediatricians (supply) per zip code (n = 253), 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

Table 3.1: Descriptive statistics of the SPAI values per zip code (demand = total population of preschool aged children (0-4 years), supply = paediatricians) in the canton of Zurich, 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

	Count	*Mean*	*Median±SD*	*Minimum*	*Maximum*
Overall	253	0.724	0.642±0.401	0.0283	2.25
High	2	2.25	2.25±0.00372	2.25	2.25
Moderate	61	1.24	1.21±0.167	1.01	1.74
Low	190	0.543	0.528±0.25	0.0283	0.998

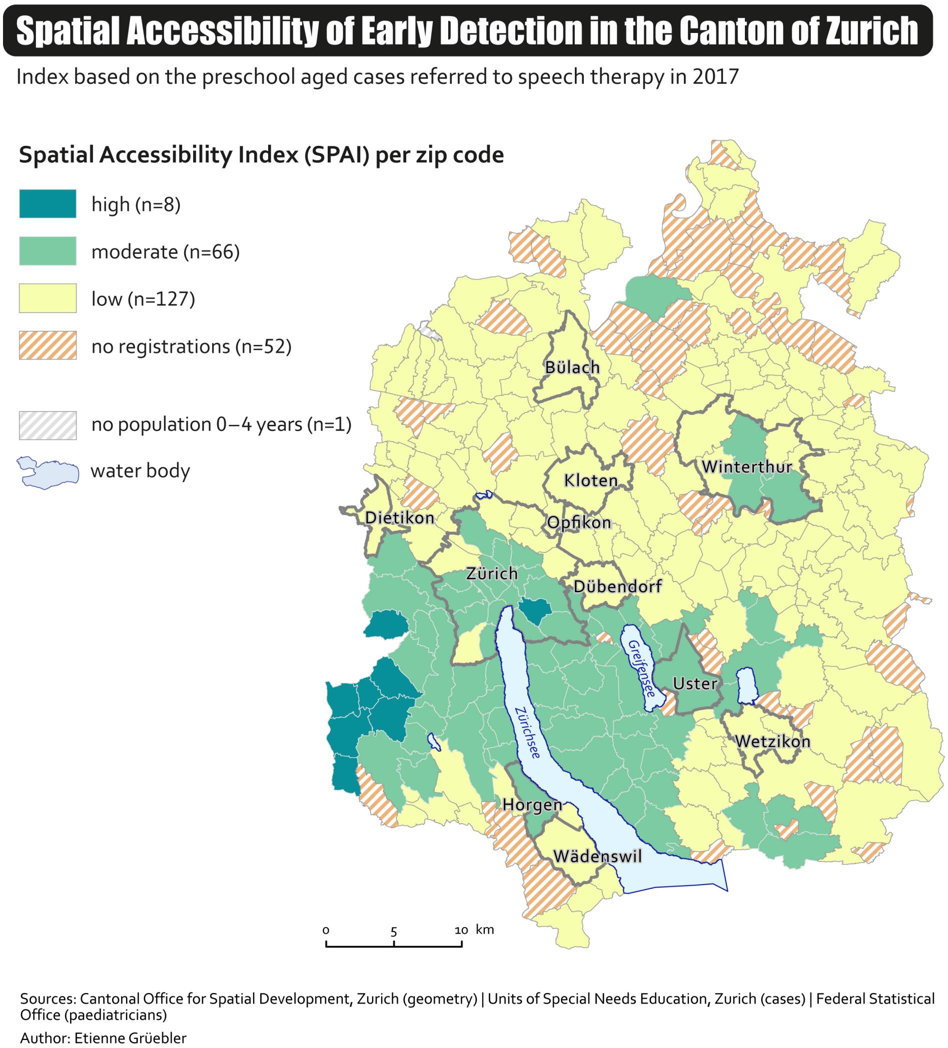

Figure 3.2: Spatial Accessibility Index SPAI for cases referred to speech therapy (demand) and paediatricians (supply) per zip code (n = 253), 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

Table 3.2: Descriptive statistics of the SPAI values per zip code (demand = cases referred to speech therapy, supply = paediatricians) in the canton of Zurich, 2017.

	Count	*Mean*	*Median±SD*	*Minimum*	*Maximum*
Overall	201	0.921	0.819±0.602	0	3.43
High	8	2.71	2.75±0.553	2.08	3.43
Moderate	66	1.4	1.36±0.284	1.01	1.999
Low	127	0.561	0.534±0.255	0	0.987

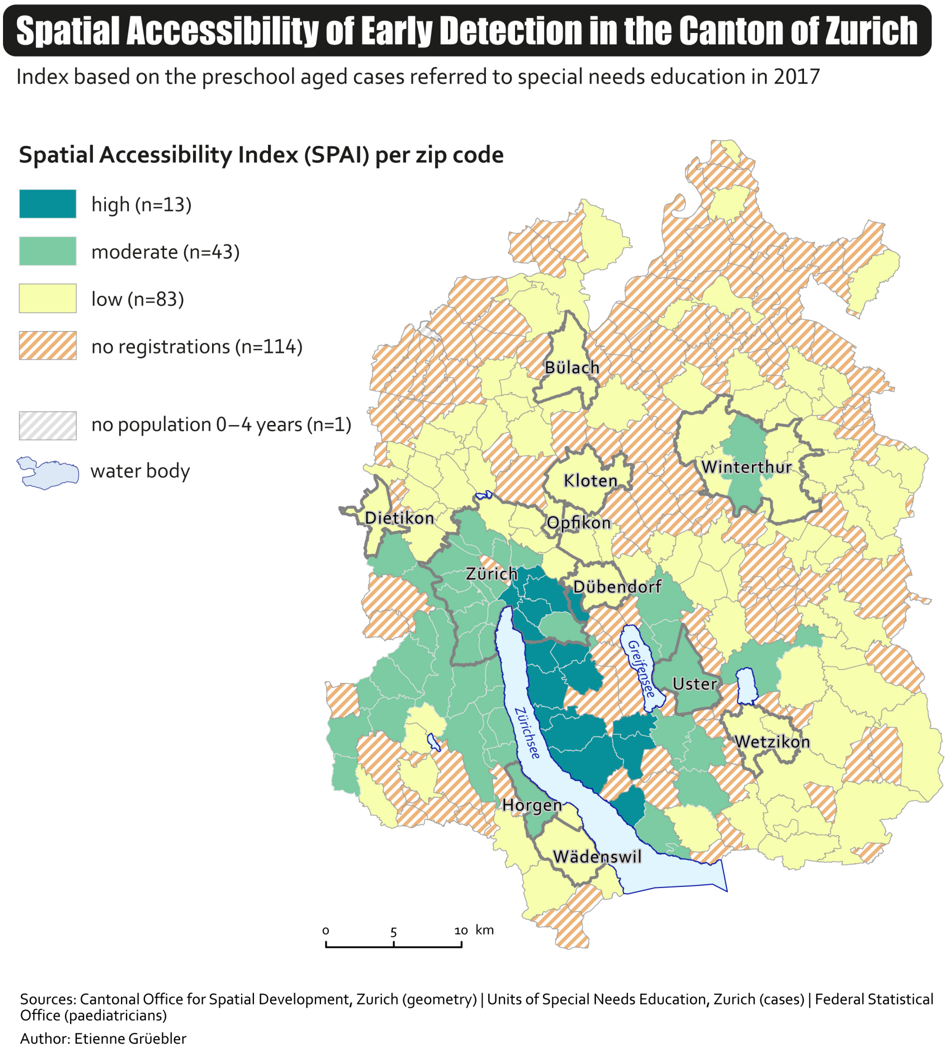

Figure 3.3: Spatial Accessibility Index for cases referred to special needs education (demand) and paediatricians (supply) per zip code (n = 253), 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

Table 3.3: Descriptive statistics of the SPAI values per zip code (demand = cases referred to special needs education, supply = paediatricians) in the canton of Zurich, 2017.

	Count	*Mean*	*Median±SD*	*Minimum*	*Maximum*
Overall	139	1.03	0.813±0.629	0.0219	2.84
High	13	2.35	2.38±0.223	2.04	2.84
Moderate	43	1.47	1.47±0.257	1	1.93
Low	83	0.594	0.621±0.237	0.0219	0.986

3.1.2. Connection between Spatial Accessibility and Early Referral

Previous studies have already discussed factors that may have an influence on the age at referral. For speech therapy, children should start therapy before the age of 36 months to get the best possible output. Therefore, the threshold of 36 months was chosen for the classification into high and low for speech therapy. For special needs education, the younger the better, which is why the classification is based on tertiles.

Since the correlation has no direct relationship to the bivariate maps (e.g., does not provide a direct indication of classification), the pretests for correlation are calculated based on the zip code values and the data are classified afterwards for the visualizations.

Table 3.4: Descriptive statistics of the statistical pretests for the bivariate choropleth maps. First, all variables are tested for normal distribution with the Shapiro-Wilk test to perform after a Spearman's Rho correlation test. Here, the age at referral is set in relation to the SPAI values. Therefore, a negative Spearman's Rho coefficient indicates a positive correlation between early referral and spatial accessibility as a low age corresponds to early referral, a high age to late referral.

Shapiro-Wilk Tests		
Type of Therapy	*Variable*	*p-value*
Speech Therapy	SPAI values	1.52e-11
Speech Therapy	Age at referral [m]	5.41e-09
Special Needs Education	SPAI values	0.000000369
Special Needs Education	Age at referral [m]	0.0143
Spearman's Rho Tests		
Type of Therapy	*p-value*	*r-value*
Speech Therapy	0.0411	-0.131
Special Needs Education	0.0089	-0.134

Speech Therapy

For the speech therapy cases, the correlation for spatial accessibility and age at referral is weak, negative, and significant ($r = -0.131$, $p < 0.05$), which means that a small positive correlation exists between spatial accessibility and early referral (as early referral is based on young age at referral). However, if the values are divided with the suggested thresholds from the literature, the most represented group in the bivariate map (*figure 3.4*) is classified with late referral and high spatial accessibility (n = 66). This group is followed closely by the target groups indicating a connection between spatial accessibility and early referral: Early referral and high spatial accessibility (n = 54) and late referral and low spatial accessibility (n = 42).

The spatial patterns show that especially in the agglomerations around the cities of Winterthur, Kloten and Bülach and partly in and around Wetzikon children with low spatial accessibility are referred late. Children who can benefit from early referral and high spatial accessibility are mainly found in and around Zurich, close to the rehabilitation center (Affoltern am Albis), an additional hot spot compared to the rudimentary spatial accessibility maps form zip codes in the district of Hinwil (zip codes 8330, 8335, 8332 and 8332).

The zip codes on the right shore of Lake Zurich, which have particularly high spatial accessibility of paediatricians, are classified with late referral, with the exception of zip code 8703.

Special Needs Education

For special needs education, the correlation for spatial accessibility and age at referral is also weak, negative, and significant ($r = -0.131$, $p < 0.05$), which means that a small positive correlation exists between spatial accessibility and early referral as it is based on young age at referral.

In the bivariate map for this analysis (*figure 3.5*), the visual classification goes hand in hand with the correlation. The correlation is highlighted by the most represented groups: High spatial accessibility and early referral (n=19), medium and moderate (n=20), and low spatial accessibility and late referral (n=18).

The spatial patterns show that especially in the north-west of the canton, a large area is classified with zip codes with late referrals and low spatial accessibility as well as in the agglomerations around the cities of Winterthur and Bülach.

Children who can benefit from early referral and high spatial accessibility or at least moderate conditions are mainly found in and around Zurich, close to the rehabilitation center (Affoltern am Albis) as well as on both shores of Lake Zurich.

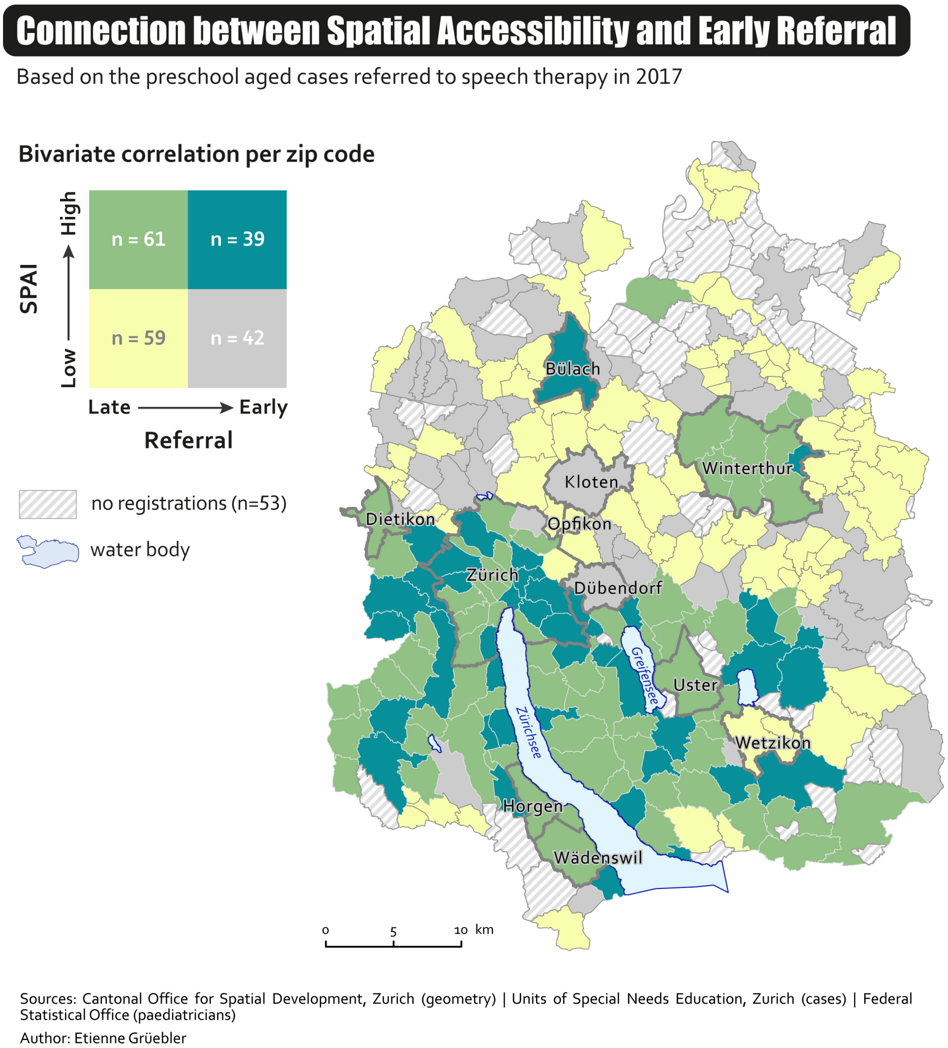

Figure 3.4: Bivariate choropleth map representing the connection between spatial accessibility (SPAI values) and early referral (age at referral) for speech therapy cases. The variables are classified as follows: For spatial accessibility, the median of 0.819 applies as a threshold due to the skewed number distribution with predominantly low values (< 0), for the referral variable, below 36 months refers to early and above 36 months to late referral for speech therapy. Petrol values indicate a positive correlation (high spatial accessibility and early referral). Yellow values indicate low spatial accessibility and late referral.

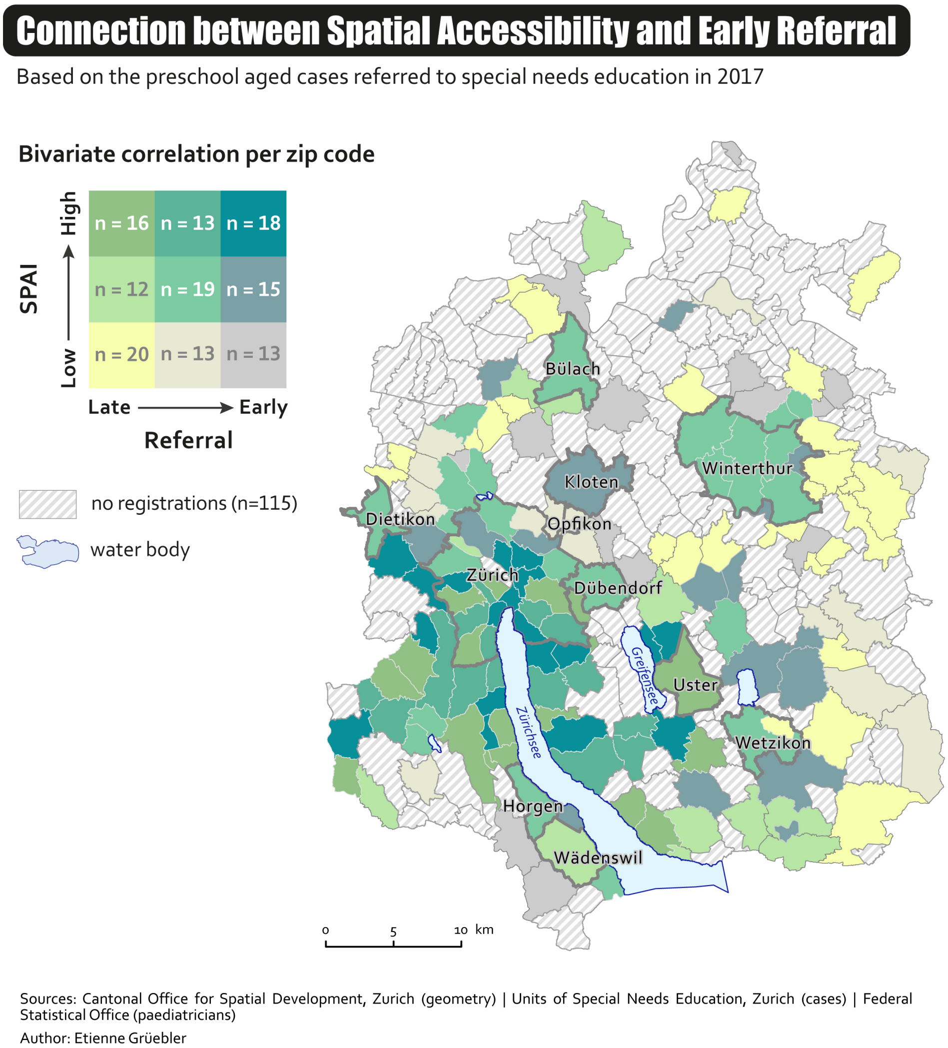

Figure 3.5: Bivariate choropleth map representing the connection between spatial accessibility (SPAI values) and early referral (age at referral) for special needs education cases. Both variables are classified based on the tertiles of the value distributions: For spatial accessibility, the thresholds 0.67 and 1.22 divide the values into three groups, for referral, below 30 months refers to early and above 39 months to late referral for special needs education. Petrol values indicate a positive correlation (high spatial accessibility and early referral). Yellow values indicate low spatial accessibility and late referral.

3.2. Spatial Accessibility of Early Intervention

The first condition for early intervention for children with developmental delay is early detection. After referral, a child receives a guaranteed number of hours. In reality, however, there are always deviations for a variety of reasons. First, a general overview of the advantageous and disadvantageous regions with regard to potential early intervention was obtained. For this reason the spatial accessibility of therapy services with the total population of preschool aged children in the canton of Zurich as the demand was considered. After, the revealed spatial accessibility for the cases requiring speech therapy and special needs education was implemented. The data of revealed spatial accessibility data also shows zip codes with no registrations at the USNEs in 2017, which can also be put in relation to the distribution of potential spatial accessibility. Due to the different spatial distribution, both therapy types are analyzed separately.

3.2.1. Spatial Accessibility of Speech Therapy in the Canton of Zurich

Potential Spatial Accessibility of Speech Therapy

For the potential spatial accessibility of early speech therapy (*figure 3.6* and *table 3.5*) the zip codes are predominantly classified with low spatial accessibility (n = 253), but also include many counts in the moderate spatial accessibility class with an insufficient median (0.737). In this analysis, there are no hectar raster points with SPAI values equal to zero.

Zip codes with moderate spatial accessibility can be found on the left shore of Lake Zurich and, similar to the map on early detection, at the cities of Winterthur and Zurich. Hot spots of high spatial accessibility appear along the border to the canton of Thurgau (district Andelfingen) and around the children rehabilitation center (Affoltern am Albis). Due to the fact that therapy is organized within a canton edge effects can be disclaimed for this analysis. Rather, this effect could be accredited to a larger therapy institution.

Within the city of Zurich, similar disparities appear as for early detection with low spatial accessibility on the periphery, however, there are fewer affected zip codes with low spatial accessibility within Zurich (n = 5) than for early detection.

Revealed Spatial Accessibility of Speech Therapy

The spatial patterns between potential and revealed accessibility of speech therapy (*figure 3.7* and *table 3.6*) are very similar: The mean (+ 0.124) and median (+ 0.116) are only slightly higher than for potential spatial accessibility.

The same hot spots around the children rehabilitation center (Affoltern am Albis) and boarder to the canton of Thurgau also apply, but enlarging by quite a bit at the expense of no registration zip codes. As a result, a third hot spot is created around Wetzikon. The area around Wetzikon shows significantly higher disparities than in the values for potential spatial accessibility and zip codes with considerably higher accessibility on expense of no registrations zip codes.

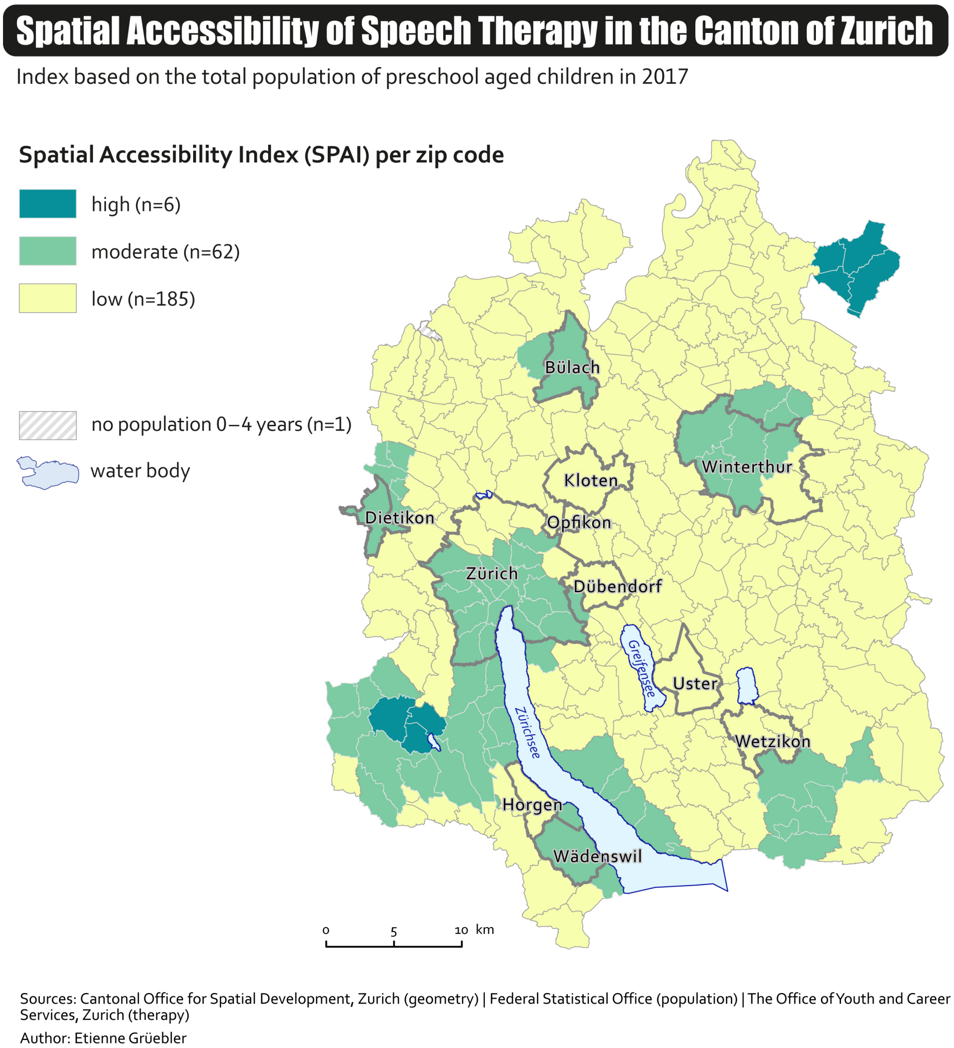

Figure 3.6: Spatial Accessibility Index for total population of preschool aged children (demand) and speech therapists (supply) per zip code (n = 253), 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

Table 3.5: Descriptive statistics of the SPAI values per zip code (demand = total population of preschool aged children (0-4 years), supply = speech therapists) in the canton of Zurich, 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

	Count	*Mean*	*Median±SD*	*Minimum*	*Maximum*
Overall	253	0.845	0.737±0.553	0.0147	5.17
High	6	3.61	3.23±0.922	2.88	5.17
Moderate	62	1.34	1.27±0.269	1	1.98
Low	185	0.591	0.631±0.242	0.0147	0.997

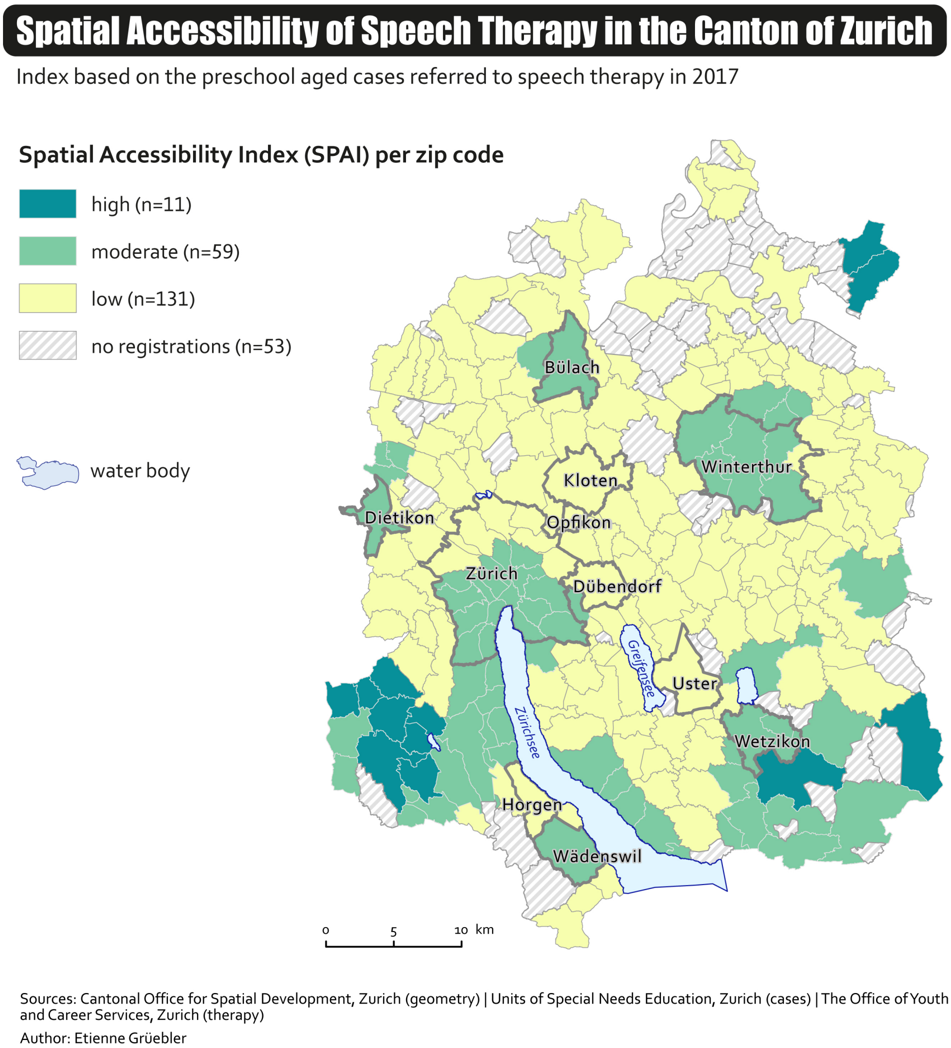

Figure 3.7: Spatial Accessibility Index for cases referred to speech therapy (demand) and speech therapists (supply) per zip code (n = 253), 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

Table 3.6: Descriptive statistics of the SPAI values per zip code (demand = cases referred to speech therapy, supply = speech therapists) in the canton of Zurich, 2017.

	Count	*Mean*	*Median±SD*	*Minimum*	*Maximum*
Overall	201	0.969	0.853±0.63	0.105	4.09
High	11	2.91	2.92±0.736	2.04	4.09
Moderate	59	1.34	1.29±0.249	1.01	1.91
Low	131	0.64	0.652±0.233	0.105	0.994

3.2.2. Spatial Accessibility of Special Needs Education in the Canton of Zurich

Potential Spatial Accessibility of Special Needs Education

For the potential spatial accessibility of special needs education (*figure 3.8* and *table 3.7*) an exceptionally large proportion of zip codes are at 70% in the lowest class (n = 195), which are distributed over a very wide area. There are 3 zip codes with hectar points of SPAI equal to zero (orange polygons), which are on the edge of the canton, but since therapy slots are allocated within the canton, this doesn't show an edge effect in data but disadvantages towards the cantonal boarder to the canton of Thurgau and St. Gallen.

Clear hot spots of high spatial accessibility are in the core of the larger cities Zurich, Winterthur, Bülach and around the rehabilitation center (Affoltern am Albis) with 12 zip codes classified as high spatial accessibility. This large number of high classified zip codes (n = 12) and the large number of low classified zip codes (n = 195) show above average inequities in spatial distribution compared to the other analyses.

In line with the potential spatial accessibility of speech therapy, some moderate classified zip codes can be found on the left shore of Lake Zurich.

Revealed Spatial Accessibility of Special Needs Education

The spatial patterns between potential and revealed accessibility of special needs education (*figure 3.9* and *table 3.8*) are very similar. However, the no registration zip codes are distributed very widely over the low spatial accessibility values in the map on potential spatial accessibility. The median is slightly higher (+ 0.168), but the mean is quite higher (+ 0.236) and very close to 1 (0.983).

Compared to the potential spatial accessibility on the right shore of Lake Zurich is higher. The right shore of Lake Zurich is additionally classified as moderate at the expense of zip codes with no registrations. Zip codes with no registrations are more often in locations with moderate spatial accessibility (e.g., district Bülach (Hochfelden and Stadel b. Niederglatt) and district Andelfingen (Kleinandelfingen and Alten)), thus reinforcing already existing hot spots besides those zip codes (city center of Zurich and Bülach).

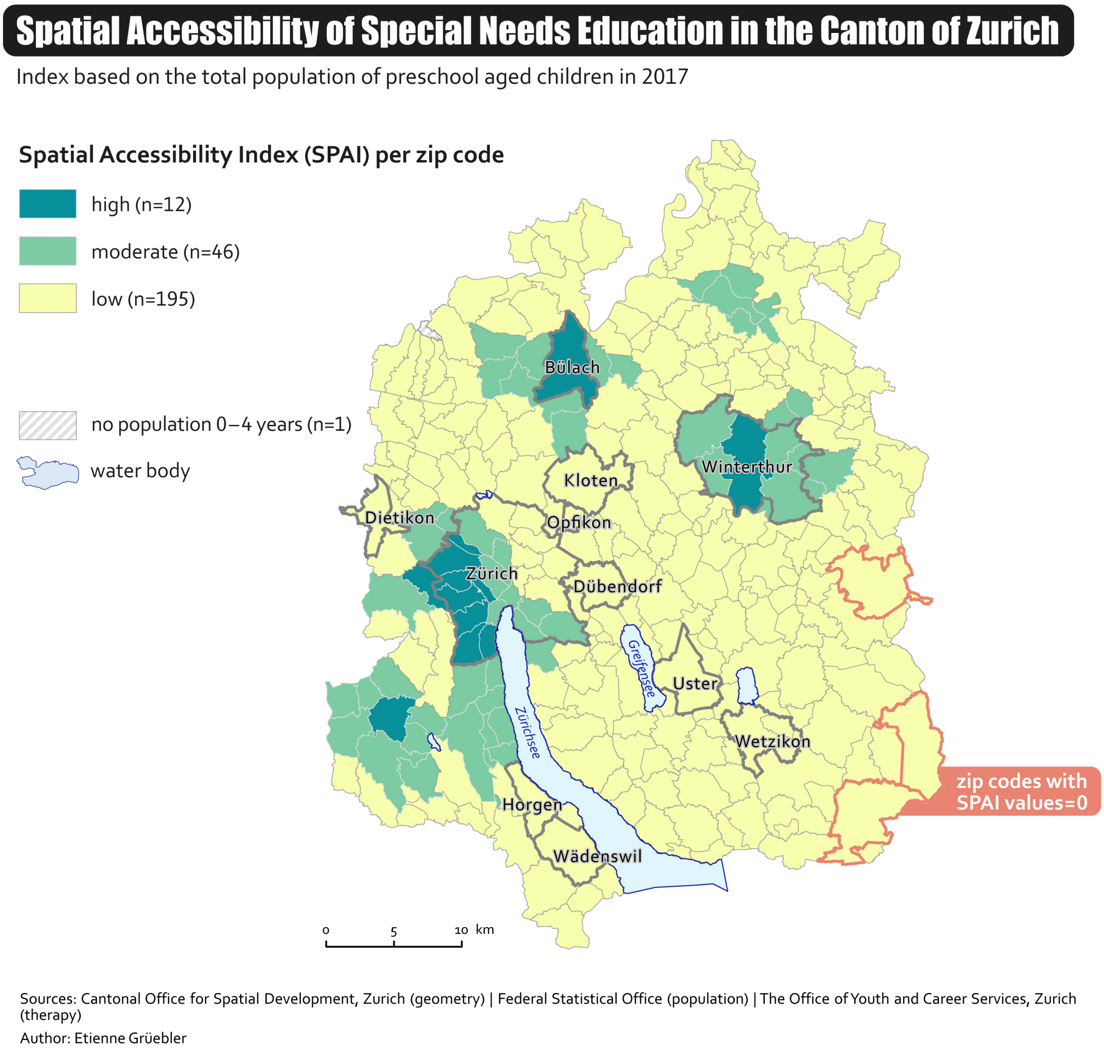

Figure 3.8: Spatial Accessibility Index for total population of preschool aged children (demand) and special needs educators (supply) per zip code (n = 253), 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

Table 3.7: Descriptive statistics of the SPAI values per zip code (demand = total population of preschool aged children (0-4 years), supply = special needs educators) in the canton of Zurich, 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

	Count	*Mean*	*Median±SD*	*Minimum*	*Maximum*
Overall	253	0.747	0.617±0.595	0	3.74
High	12	2.56	2.36±0.596	2	3.74
Moderate	46	1.36	1.31±0.268	1.01	1.94
Low	195	0.49	0.474±0.253	0	0.997

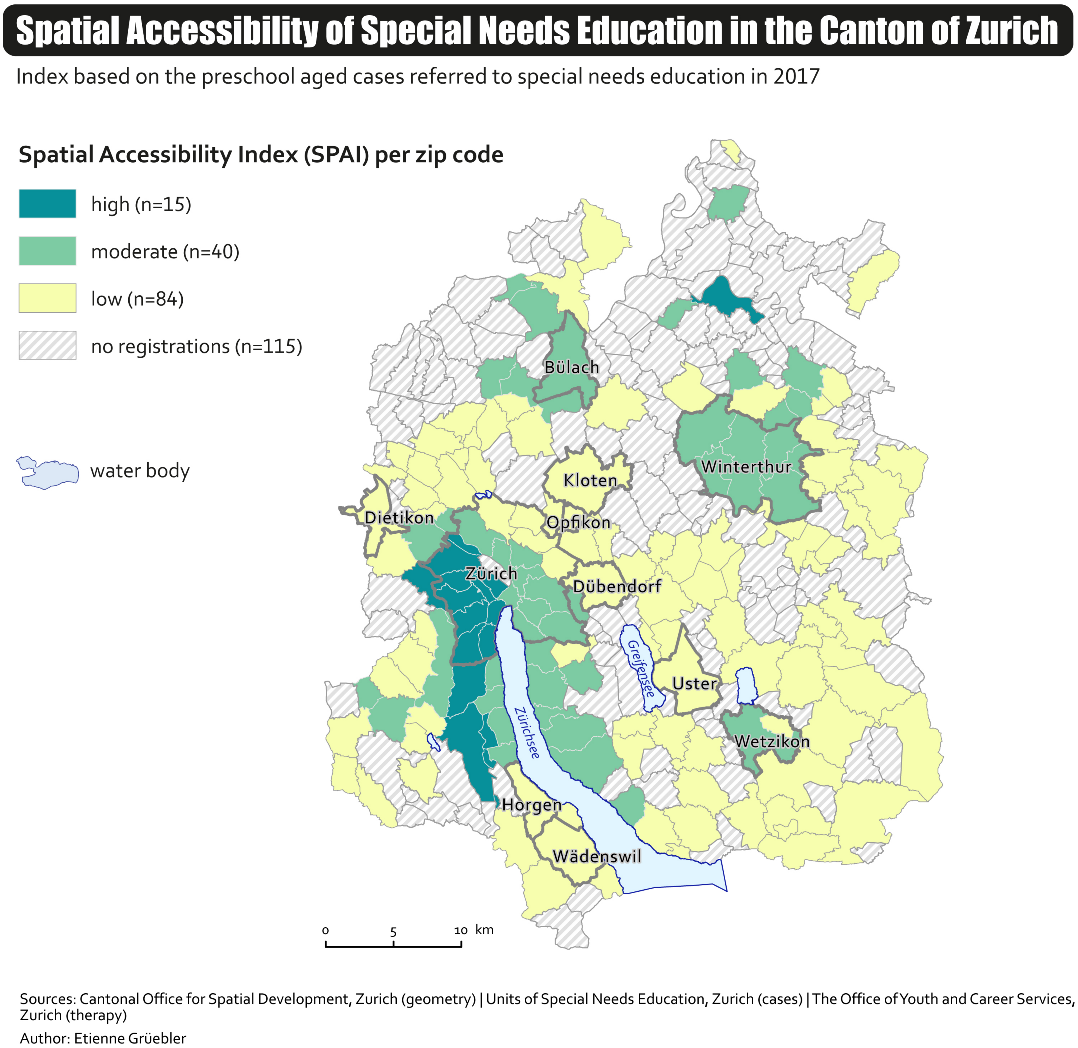

Figure 3.9: Spatial Accessibility Index for cases referred to special needs education (demand) and special needs educators (supply) per zip code (n = 253), 2017. Since one zip code (5462) has no population between 0-4 years, the overall count is only 253 of the total 254 zip codes.

Table 3.8: Descriptive statistics of the SPAI values per zip code (demand = cases referred to special needs education, supply = special needs educators) in the canton of Zurich, 2017.

	Count	*Mean*	*Median±SD*	*Minimum*	*Maximum*
Overall	139	0.983	0.785±0.797	0.0433	4.25
High	15	2.79	2.55±0.743	2.05	4.25
Moderate	40	1.31	1.26±0.254	1	1.87
Low	84	0.503	0.486±0.241	0.0433	0.998

3.2.3. Connection between Spatial Accessibility and Early Intervention

In previous studies, it was observed that even with effective standardized assessment procedures, the allocated therapies may not be implemented. Therefore, in the following it will be examined to what extent a difference between allocated and served therapy hours is related to the spatial accessibility of the respective therapists. The classification of the SPAI variable is based on tertiles, the difference in hours is divided in below 0, between 0 and 50% discrepancy and above 50%.

Since the correlation has no direct relationship to the bivariate maps (e.g., does not provide a direct indication of classification), the pretests for correlation are calculated based on the zip code values and the data are classified afterwards for the visualizations.

Table 3.9: Descriptive statistics of the statistical pretests for the bivariate choropleth maps. First, all variables are tested for normal distribution with the Shapiro-Wilk test to perform after a Spearman's Rho correlation test. The variable *difference in therapy hours* assigns the difference between the allocated and served hours. Here the age at referral is set in relation to the SPAI values. Therefore, a negative Spearman's Rho coefficient indicates a positive correlation between early referral and spatial accessibility as a low age corresponds to early referral, a high age to late referral. Here the difference between the allocated and served therapy hours is set in relation to the SPAI values. Therefore, a negative Spearman's Rho coefficient indicates a positive correlation between utilization of therapy and spatial accessibility as a low difference corresponds to high utilization, a high difference to low utilization of therapy.

Shapiro-Wilk Tests		
Type of Therapy	*Variable*	*p-value*
Speech Therapy	SPAI values	1.49e-16
Speech Therapy	Difference in therapy hours	0.0000338
Special Needs Education	SPAI values	3.25e-12
Special Needs Education	Difference in therapy hours	0.00397
Spearman's Rho Tests		
Type of Therapy	*p-value*	*r-value*
Speech Therapy	0.841	-0.0135
Special Needs Education	0.0249	-0.181

Speech Therapy

For speech therapy, the correlation with spatial accessibility and utilization of therapy hours, is weak, negative, and not significant (r= -0.0135, $p > 0.05$). Therefore, a bivariate map for this connection is not meaningful. The map can be found in *figure D.1* in the *Appendix D:* **??** but will not be further discussed within this thesis, as a connection between spatial accessibility and utilization of speech therapy can be rejected.

Special Needs Education

For special needs education, the correlation for spatial accessibility and utilization of therapy hours is weak, negative, and significant (r = -0.181, $p < 0.05$) which means that a small positive correlation exists between spatial accessibility and utilization of therapy as the second variable based on the difference between allocated and served therapy hours.

In the bivariate map (*figure 3.10*), classes with moderate/moderate (n = 50) and high spatial accessibility and moderate utilization (n = 55) are the most represented. The moderate utilization of therapy hours is thus mainly found in and around larger cities (e.g., Zurich, Winterthur, Bülach, Uster and Wetzikon).

However, especially the yellow zip codes with low/low (n = 13) show four clear clusters: Between Kloten and Uster (zip codes 8602 and 8305), Dietikon and surrounding (zip codes 8953, 8955 and 8108), between Wetzikon and Winterthur (zip codes 8483, 8487 and 8487) and multiple zip codes in the south of Wetzikon. On the other hand, the postal codes with high/high are randomly distributed (zip codes 8802, 8704).

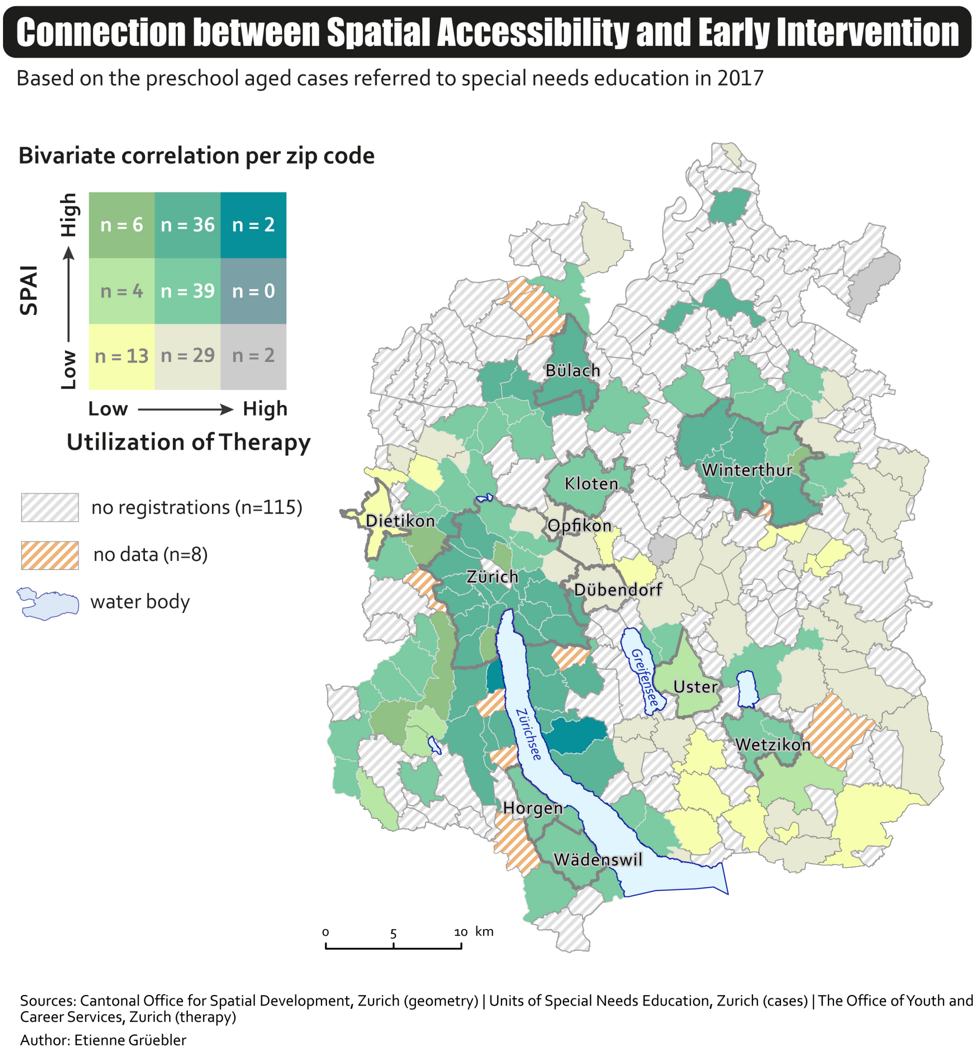

Figure 3.10: Bivariate choropleth map representing the connection between spatial accessibility (SPAI values) and early intervention (difference between served and allocated therapy hours) for special needs education cases. The variables are classified as follows: The spatial accessibility variable is classified based on the tertiles of the value distribution (thresholds of 0.55 and 1.09), the utilization of therapy is evaluated in percent. Since there are also cases that utilize more hours than originally allocated, a high utilization means the utilization of all allocated hours (100%) or more. If less than half of the allocated hours were used (<50%), this refers to low utilization of therapy. Petrol values indicate a positive correlation (high spatial accessibility and high utilization of therapy). Yellow values indicate low spatial accessibility and low utilization of therapy.

4. Discussion

In this chapter, the results presented in the last chapter are critically discussed according to the stated research questions and the findings are related to previous research. Each research question is discussed in a separate section and the specific limitations are pointed out at the end of each section. Further, at the end of the chapter there is a section with the general limitations of the methodological approach and a section on research implications for future research. The map of the zip codes *figure C.1* and the classification of the zip codes in *table C.1* in the *Appendix C: Zip Codes Classification* may provide a helpful overview for understanding the discussion thoroughly.

4.1. Spatial Accessibility of Early Detection

The first part of this thesis is devoted to spatial impacts on early detection. Since there is no data available for the canton of Zurich in this area, the first part of the analysis looks at spatial accessibility of paediatricians in general, and then relates this to early referral.

4.1.1. RQ 1 - Spatial Accessibility of Paediatricians in the Canton of Zurich

In terms of spatial accessibility, the first research question was posed as follows:

> **Research Question 1**
> What is the spatial accessibility of paediatricians for preschool aged children in the canton of Zurich?

For a full picture, revealed spatial accessibility (*figure 3.2* and *figure 3.3*) was calculated in addition to the potential spatial accessibility (*figure 3.1*), which is usually assessed with the FCA methodologies. The data of revealed spatial accessibility also shows zip codes with no registrations at the USNEs in 2017. The zip codes with no registrations can be considered as follows: Due to the prevalence rate of 4-8% (Olusanya et al., 2018), it can be assumed that cases should actually occur in all zip codes, especially in zip codes with high density of preschool aged children (*figure 2.1*) and for speech therapy with the significantly higher prevalence rate of 15% (*Late Talkers*) (O'Hare and Bremner, 2016). Therefore, it is more likely that cases are missed in the zip codes with no registrations. For revealed spatial accessibility, zip codes with no registrations increase the spatial accessibility in the surrounding zip codes as only detected cases were used as demand population points in those maps (*figure 3.2 and 3.3*). For those maps, if a zip code is ranked higher compared to the potential spatial accessibility, it means that the spatial accessibility was higher in reality. If the class does not change, this additionally emphasizes the poor accessibility, since no advantage was derived from the distribution of cases.

At first glance, all three maps showing the spatial accessibility of paediatricians (*figure 3.1, 3.2 and 3.3*) show great disparities. In particular, the yellow zip codes (n = 190 for potential spatial accessibility, n = 127 and n = 83 for revealed spatial accessibility) with low spatial accessibility dominate and the median of 0.642 for potential spatial accessibility shows that most zip codes have a spatial accessibility of only 65% for a slot at a paediatrician. This clearly indicates that there are significant barriers to early detection in the canton of Zurich due to insufficient spatial accessibility. Zip code 8496 *Steg im Tösstal* even shows that there are hectare population points that have SPAI values of zero. This means that this population has no access to a paediatrician within 20 minutes.

Further, the comparison of revealed and potential spatial accessibility reveals that zip codes with no registrations are predominantly found in zip codes with low spatial accessibility for both types of therapy cases. Kalkbrenner et al. (2011) observed in their study conducted in central North Carolina, US, that in addition to urbanity, the density of specialists and psychologists and proximity to a medical school led to significantly earlier diagnoses (3-16 months) among children with autism spectrum disorder (ASD). The spatial distribution in the canton of Zurich supports these findings, as in this study area, fewer preschool aged children are diagnosed in zip codes with lower spatial accessibility of paediatricians.

Zip codes with moderate to high spatial accessibility are mainly found on the right shore of Lake Zurich, in larger cities (Zurich, Winterthur and Uster) and near the children rehabilitation center (Affoltern am Albis). Another hot spot appears in the north-east of the canton (between the high classified zip codes 8548 and 8523) and other zip codes with moderate values in the south-west (zipcode 8934 and 6340). A comparison with the density of all preschool aged children in the canton of Zurich (*figure 2.1*) for those two areas (hot spot in the south-west and the north-east) shows that the density is high there. Even though the 3SFCA method addresses the problem of demand overestimation, it is in the nature of the formula that health services in close proximity to larger populations also have a larger impact (*figure 2.12*) (Jörg et al., 2019). Thus, it is reasonable to assume that a paediatrician with higher capacity, which was due to proximity weighted heavily (using Gaussian function), will be located in these catchment areas. But looking at the revealed spatial accessibility of speech therapy, it is apparent that in these areas, the zip codes classification changes to low spatial accessibility, and for special education, they have no registrations. This means that in these areas, the demand for speech therapy is above average (the zip codes around these regions are even ranked higher than for potential spatial accessibility) and that special education cases are still not accounted for in this area.

However, for the other hot spots, the explanations relate more to qualitative aspects, as the density of preschool aged children is rather low in these areas. The fact that the three largest cities in the canton of Zurich (Zurich, Winterthur and Uster) have hot spots of moderate spatial accessibility supports many studies on early detection of developmental delays that have already evaluated urban areas as preferred over rural areas (Skinner and Slifkin, 2007, Kalkbrenner et al., 2011, Murphy and Ruble, 2012, DeGuzman et al., 2017, Drahota et al., 2020). But also in line with previous Swiss studies on other health services, this study detects that urban areas are better served (Sturny and Widmer, 2020, Lenz et al., 2020). Although this study confirms earlier findings, it adds further insight within cities. Within Zurich and Winterthur there are major differences in the degree of spatial accessibility. The hot spots are primarily in the core cities. A comparison with the social space monitoring study of Zurich shows that the zip codes with low spatial accessibility (e.g., 8046, 8052, 8050 and 8051) compared with the last available data from 2014 and 2015 is largely associated with low income and also with the proportion of foreign-born inhabitants (Präsidialdepartement, Kanton Zürich, 2021). Especially for children with a speech developmental delay, this association is quite devastating, as multiple languages are a stressor in speech development already (Lohaus and Vierhaus, 2015, Müllner, 2020). For speech therapy, however, there are no zip codes without registrations in the city of Zurich. However, the zip code (8005) with no registrations in the special needs education analysis shows a share of foreign-born children of 40% (Präsidialdepartement, Kanton Zürich, 2021). The density of preschool children is distributed relatively even in the city of Zurich, which is why it is surprising that the degree of spatial accessibility nevertheless varies so much. Winterthur shows the same tendencies: Urban areas with highly stressed social status associate with zip codes with low spatial accessibility (Wuerth, 2021). Within cities, there seems to be an association between spatial accessibility and socioeconomic status. Financial resources have already been detected as highly important to obtain a paediatrician checkup for developmental delays at all (Porterfield and McBride, 2007, Patten et al., 2012, Pantaleoni, 2012). Thus, with further disadvantage due to poorer spatial accessibility already existing stressors are further exacerbated. Following the call of Jenni & Sennhauser (2016) for additional primary care paediatricians in the future, the results of this study suggest that there is an urgent need already now. At best, these additional paediatricians would not reinforce existing practices but cover additional areas that are less served.

Along with the paediatric care comes the discussion point about the further hot spot of moderate spatial accessibiltiy around the children rehabilitation center (Affoltern am Albis). Hospitals mean large capacities at specific, few localities, which causes great differences in terms of spatial accessibility (Hakim and Ronsaville, 2002). Moreover, hospitals are more likely to be visited for emergency visits, even if they provide some primary care services (Jenni and Sennhauser, 2016). Due to the location of the children rehabilitation center at the edge of the canton, there are only a few zip codes that benefit from this service within reasonable reach. This highlights the further problems that fewer and larger health services would bring, as predicted by Jenni & Sennhauser (2016).

The hot spots shift to some extent for revealed spatial accessibility, as only detected cases were used as demand population points in those maps (*figure 3.2 and 3.3*): Spatial accessibility strengthens in favor of detected children at the expense of undetected children. In this context, it is particularly interesting that especially in the case of already moderate cases, spatial accessibility is improved, for speech therapy cases in the area of Affoltern am Albis (zip codes 8912, 8913, 8909, 8910 and 8908) and for special needs education cases on the right shore of Lake Zurich (zip codes 8702, 8126, 8703 and 8704), while for low classified zip codes the undersupply remains (especially in the area of urban agglomerations such as the agglomeration around Winterthur (zip codes 8413, 8442, 8472 and 8404 and the agglomeration around Zurich (zip codes 8952, 8102, 8103 and 8105)). This shows that the unequal opportunities are additionally aggravated for children with higher spatial accessibility at the expense of children with poor spatial accessibility. Considering that regular preventive medical checkups at the paediatrician are considered essential for early detection (Weber and Jenni, 2012, Jenni et al., 2013a), the spatial distribution plays a decisive role in whether these checkups can be received at all. This could be another explanation that the use of pediatric checkups is high in the first two years of life and decreases thereafter (Jenni and Sennhauser, 2016). This explanation is also supported by Jones et al. (2016), who discovered in their study in Cincinnati, US, that preventive services of paediatricians within the first 15 months are more likely not to be used in areas with the highest poverty and lowest vehicle ownership.

The disadvantaged zip codes, which more likely result in no registrations are particularly evident in comparison between revealed and potential spatial accessibility. While the basic spatial patterns remain relatively the same, for speech therapy there are almost no zip codes with no registrations that are not in yellow areas for potential spatial accessibility. These tendencies are less evident in special needs education, probably not at least because fewer children are identified for this therapy type in general (*figure 2.4*). However, these distortions could also be due to limitations, which leads to the relevant limitations for the research design on the first research question.

Limitations

Although great effort was made to develop the research design as suitable as possible, there are still some uncertainties and limitations which could not be eliminated. In the following, the uncertainties regarding research question 1 are discussed and their handling justified:

Data The incompleteness of the data on the paediatricians in the canton of Zurich is a major limitation. For the reference year 2017, the overall participation rate of physicians in the canton of Zurich was 76% (Switzerland: 68%) (Bundesamt für Statistik, MAS, 2021, Bundesamt für Statistik, BFS Aktuell (MAS), 2021). The missing 24% represent a large gap in terms of spatial distribution. The spatial accessibility hot spots suggest that there are nevertheless denser areas and the descriptive statistics show that there are sites with very different capacities (range 38-14516 patients treated for revealed spatial accessibility, range 38-29457 patients treated for potential spatial accessibility). Because of these uncertainties, particular attention was also paid to discuss the comparison between potential and revealed spatial accessibility, as these differences can be discussed with the same underlying supply service data. However, this is the most comprehensive available data set of this kind in Switzerland. Therefore, new data would have to be collected for more reliable statements.

Points with SPAI=0 The SPAI values on hectar or address level which correspond to zero do not seem to matter. There have been referrals for both speech therapy and special needs education in these zip codes. It is reasonable to assume that this limitation is directly related to the lack of data on paediatricians. It is likely that in those areas, a paediatrician may be available who is missing in the data set. This limitation could in further research be addressed with a validation analysis which additionally includes the actual referring paediatricians of the cases.

Referral Entity In this research, the spatial accessibility of early detection was deliberately reduced to paediatricians, who perform the referrals in most detected cases. However, for a more complete picture, other referral entities could be considered, such as the mother consultants from the child and youth care centers (*kjz*), who may also refer the children to a paediatrician first.

RQ 1 in a Nutshell

To recapitulate, the potential spatial accessibility shows that there are large differences in the spatial accessibility of paediatricians. This further exacerbates already existing disadvantages. In addition, the maps of revealed spatial accessibility confirm that children with higher spatial accessibility are more likely to be identified, as the zip codes with no registrations are mainly located in regions with low spatial accessibility. To gain further insight, this connection will be discussed in more detail in the next section.

4.1.2. RQ 2 - Connection between Spatial Accessibility and Early Referral

Previous research has shown that there is a relationship between urbanity and early referral (Mandell et al., 2005, Murphy and Ruble, 2012, Kalkbrenner et al., 2011, Stahmer et al., 2019). To what extent the actual spatial accessibility plays a role within has not been analyzed yet. Therefore, in terms of this connection the second research question was posed as follows:

> **Research Question 2**
> To what extent does the spatial distribution of paediatricians influence early referral?

A visual, descriptive approach was taken to discuss this connection. As a prerequisite, a correlation test was performed. Since only a weak, positive correlation between spatial accessibility and early referral could be found for both therapy types, at first glance there is no predominant correlation (yellow and petrol zip codes do not dominate), but interesting spatial patterns become apparent for both therapy types.

In both therapy types there are many self-employed therapists, which is why the spatial distribution for speech therapy (*figure 2.6*) and special needs education (*figure 2.7*) can be very different from a supply point of view. In terms of cases, on the other hand, there are many referrals to both types of therapy, while others are assigned only to either speech therapy or special needs education (*figure 2.4 and figure 2.4*). In addition, demand for speech therapy is significantly higher (n=1423) than for special needs education (n=548). Therefore, the connection between spatial accessibility and speech therapy (*figure 3.4*) or special needs education (figure 3.5) is addressed in separate sections below.

Speech Therapy
For speech therapy cases the most represented class is confronted with high spatial accessibility and late referral (n = 66). A clear correlation between high spatial accessibility and early referral (n = 42) does not seem to exist. Nevertheless,

the critical class with low spatial accessibility and late referral, which intervenes at preschool age but after the most effective 36 months (Jenni et al., 2013a, Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e.V., 2021), is strongly represented (n = 54). There are significantly disadvantaged zip codes, which cluster spatially and are mostly in line with low potential spatial accessibility.

The hot spots of low spatial accessibility and late referral highlight especially the agglomerations around the cities of Winterthur and Bülach and partly in and around Wetzikon. In particular, areas at the cantonal borders are also affected, which means that poor spatial accessibility at borders is definitely not related to edge effects, but children there are also referred later. DeGuzman et al. (2017) and Chen et al. (2007) further related late referral to urban/rural classification. While this tendency could be confirmed for the rudimentary spatial accessibility of early detection, it becomes evident that zip codes with low spatial accessibility and late referral are rather intermediate to urban when considering the urban/rural classification for the canton of Zurich (*figure 2.2*). This trend is also not consistent with the nationwide study by Stülb et al. (2019). They too, when analyzing predictors of behavior problems in healthy preschool children (which could include, in part, children with mild developmental delays), found that rural areas had higher prevalence rates of behavior problems than urban areas. Nevertheless, studies from Sweden (Larsson and Frisk, 1999, Black and Krishnakumar, 1998) confirm the connection here that codes of urban and intermediate classification may be more affected.

What can be added to these findings is that the affected zip codes hit many of the zip codes that are in the highest density class of preschool aged children (*figure 2.1*). This means that not only these areas are disadvantaged but also an above average number of children.

Further, the hot spots of high spatial accessibility and early referral are less in line with the analysis on potential spatial accessibility. The catchment area of USNE Zurich shows more zip codes with high spatial accessibility and early referral than the catchment area of USNE Winterthur.

Particularly interesting are the zip codes at the right shore of Lake Zurich, which were almost consistently classified with high spatial accessibility but late referral. This means that in these regions, other mechanisms play a decisive role. Weber & Jenni (2012) have identified the following additional reasons for lack of early detection: A lack of understanding of risks, specific cultural backgrounds, mistrust of government-sponsored programs, and difficult housing conditions. Of these reasons, a lack of understanding of risks seems most likely for this region, as these zip codes have a high socioeconomic level (Präsidialdepartement, Kanton Zürich, 2021).

Special Needs Education
For special education, the weak positive correlation between spatial accessibility and early referral is visually apparent. The classes low spatial accessibility/late referral (n = 18), moderate/moderate (n = 20), and high/early (n = 19) are most represented, which is different from speech therapy. But also in the case of special education, the disadvantaged zip codes are mostly located in areas with low potential spatial accessibility. The yellow zip codes mostly correspond to the bivariate choropleth map of speech therapy cases: The agglomerations around the cities of Winterthur and Bülach and south-east of Wetzikon. For special needs education no zip code in the south-west part of the canton (at the left shore of Lake Zurich and below) is classified as low/late.

That both forms of therapy show similar spatial patterns reinforces DeGuzman et al. (2018) findings, as they note in their study that although some children with increased travel times were screened, others with similar travel problems may be missed. They also worked with a data set of revealed ASD cases in Virginia, US, finding wide disparities in access and age at first assessment (Ibid.).

Comparing the bivariate choropleth maps with the density map of preschool aged children (*figure 2.1*) the connection between density of population and poor classification is less pronounced than for speech therapy cases. However, the similar spatial patterns for low/late ranked zip codes call for action in those areas. A final assessment cannot yet be made on the basis of this visual, descriptive analysis, which is why the corresponding limitations are discussed below.

Limitations

The aim was not to create a complete picture of all possible variables influencing early referral, but rather to look at two variables together based on literature. In general, the following limitations come together for the second research question:

Choice of the Thresholds For the visualization of two variables in bivariate choropleth map, the variables must be classified adequately (Biesecker et al., 2020). Mostly this is done either on the basis of quantiles or meaningful, literature-based classifications (Biesecker et al., 2020, Nelson, 2020 and Stevens, 2021). As a result, both variables were divided into tertiles for the analysis of special needs education. To keep the maps of special needs education and speech therapy comparable, the spatial accessibility values of speech therapy were also divided by the median in addition to the literature-based threshold of 36 months for early referral. As a result, the spatial accessibility of some zip codes was ranked higher than in the rudimentary spatial accessibility maps where classes were divided by the means of content. However, since the connection between spatial accessibility and early referral was much more about spatial patterns than about exact numbers, this approach was chosen.

Nevertheless, it must be stated that the classification of the data has a great influence and that very different statements can be represented on the basis of the same data.

No Registrations Due to the data conditions, zip codes with no registrations could not be included in the correlation test. This would certainly be further informative, but data would have to be available to show how many of the no registrations actually qualify as missed cases, e.g., by comparing with cases detected at school age.

RQ 2 in a Nutshell

In summary, there are definitely spatial patterns where the weak correlation between spatial accessibility and early referral is evident which for both therapy types are in the agglomerations around the cities of Winterthur and Bülach. However, these zip codes are located as spatial clusters and there is not a general trend. Although the maps provide a spatial overview of the distribution of the variables, no conclusive assessment can be made yet based on the visual approach. In order to identify further relevant aspects, the following section considers the spatial accessibility of early intervention in more detail.

4.2. Spatial Accessibility of Early Intervention

The second part of this thesis was devoted to spatial impacts on early intervention. Since there is no data available for the canton of Zurich in this area either, the first part of the analysis looks at spatial accessibility of therapists in general, and then relates this to utilization of therapy.

4.2.1. RQ 3 - Spatial Accessibility of Therapists in the Canton of Zurich

In terms of spatial accessibility, the third research question was posed as follows:

> **Research Question 3**
> What is the spatial accessibility of therapists in speech therapy and special needs education for preschool aged children in the canton of Zurich?

For a full picture, revealed spatial accessibility (*figure 3.7* and *figure 3.9*) was looked at in addition to the potential spatial accessibility (*figure 3.6* and *figure 3.8*), which is usually assessed with the FCA methodologies. In general, the zip codes with no registrations for the spatial accessibility of early intervention can be handled differently than for early detection. Whereas in the case of early detection it can be assumed that cases are missed in these zip codes, for early intervention it is evident that there was no need in these zip codes in the reference year of 2017. Therefore, if this resulted in certain zip codes being ranked higher in the revealed spatial accessibility maps (*figure 3.7* and *figure 3.9*), these zip codes actually had better opportunities to find a therapy slot in reality.

For this analysis, the spatial distribution for speech therapy and special needs education can also be very different, both from a supply perspective and in terms of cases assigned to one or both therapy types. Therefore, both types of therapy are addressed in separate sections below.

Speech Therapy

A first impression shows that yellow zip codes (n = 185 for potential spatial accessibility and n = 131 for revealed spatial accessibility) representing low spatial accessibility dominate and the median of 0.737 for potential spatial accessibility shows that for most zip codes, about 75% of a slot is available at a speech therapist. This higher median despite the large number of low-classified zip codes shows that there is a strong imbalance within the canton of Zurich. Although the mean of 75% basically shows higher spatial accessibility to speech therapists than to paediatricians (65%), 185 zip codes face low spatial accessibility. This shows that some regions are significantly favored, which leads to a higher median. Especially for children with speech development delays there is empirical evidence that therapy should start before the age of 36 months to achieve the best possible output (Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e.V., 2021). In order to find a therapy slot as quickly as possible after an assessment without missing out on valuable months for early intervention, it is essential that the distribution of therapy services is as even and fair as possible, which is not given in the case of the canton of Zurich.

Both potential and revealed spatial accessibility are dominated by yellow zip codes with low spatial accessibility. This shows that there are generally too few providers, as already stated by Drahota et al. (2020). In their study, they found a lack of ASD service providers especially in areas with low socioeconomic status and rural areas. A comparison with the urban/rural typology (*figure* 2.2) shows a different distribution for the canton of Zurich. Although the city centers of Zurich, Winterthur, Bülach, Wädenswil and Dietikon have moderate to high spatial accessibility, there are also cities such as Uster, Dübendorf, Kloten, Opfikon and Horgen that have low spatial accessibility. Wetzikon holds a unique position: While the city is ranked low in potential spatial accessibility, spatial accessibility in reality is moderate. The revealed demand could therefore be met in 2017.

In addition, the potential spatial accessibility shows two strong clusters of high spatial accessibility, which are in rural areas (the children rehabilitation center (Affoltern am Albis) and boarder to the canton of Thurgau). The children rehabilitation center also has a special position here, but the demand for Affoltern appears to be smaller, as the area still represents a stronger hot spot in terms of revealed spatial accessibility. The fact that the two hot spots of high spatial accessibility are at the borders of the canton is critical. Speech therapy is organized within the canton, which is why therapy services at the edge are significantly less accessible in terms of distance than central ones. The fact that the residence characteristics are more complex than just urbanity is also confirmed by Morgan et al. (2012). They show in a multivariate logistic regression with children born in the US in 2001 that the location of the place of residence (e.g., northeast, midwest, south) can have a greater influence than its urbanity.

Within the cities of Zurich and Winterthur, similar patterns can be observed as for the spatial accessibility of paediatricians. In Zurich, the revealed spatial accessibility shows that zip codes switch from moderate to low, which means that demand there must be disproportionately high. In Winterthur, on the other hand, there is a zip code that switches from low to moderate, which means that demand is less high.

The spatial patterns for speech therapy do not match previous findings completely (e.g., urban/rural tendencies), which is why a closer look at special needs education seems even more interesting.

Special Needs Education

The first impression shows that for special needs education, the hot spots of high and low spatial accessibility polarize much more than in the other analyses. In particular, of all analyses, potential spatial accessibility shows the highest value for high spatial accessibility (n = 12) but also the highest value for low spatial accessibility (n = 195). As such, 70% of the zip codes are classified as low, an exceptionally large proportion of zip codes distributed over a very wide area. In addition, the median of 0.617 is the lowest of all three analyses on potential spatial accessibility and shows that in average only 60% of a slot are available which is much worse than for speech therapists (75%). These inequalities are further reinforced in revealed spatial accessibility. Although the mean of 0.983 in this analysis is closest to 1 of all analyses, there are still many yellow zip codes (n = 84). The unequal distribution is thus further intensified in revealed spatial accessibility.

For special needs education, there is a clear hot spot of high spatial accessibility zip codes in the core of larger cities (Zurich, Winterthur and Bülach) as well as the children rehabilitation center (Affoltern am Albis). Thus, for speech education, a clear tendency towards higher spatial accessibility in core cities can be identified, even though many urban zip codes were also classified as low and support earlier findings partially (Skinner and Slifkin, 2007, DeGuzman et al., 2017, Drahota et al., 2020). However, there are stronger tendencies towards the core cities, i.e. suburban areas are not favored, in contrast to the study by Drahota et al. (2020).

The children rehabilitation center also has a special position here. In contrast to the speech therapy analysis, there is also a greater demand, since the hot spot is weaker in terms of revealed spatial accessibility. The same trend is also evident in Winterthur and Bülach. In contrast, an oversupply occurs on the left side of the lake, where significantly more zip codes are classified as high when looking at revealed spatial accessibility.

Within the city of Zurich, similar patterns can be observed as for the spatial accessibility of speech therapy and paediatricians. In Zurich, the revealed spatial accessibility shows that some zip codes switch from low to moderate, which means that demand there is met relatively well.

As in the paediatricians study, potential spatial accessibility has hectar raster points with SPAI values that are zero. Two of the three zip codes show low spatial accessibility also in revealed spatial accessibility, which is why it can be assumed that there is very acute undersupply. Nevertheless, this can only be assumed on the basis of the research design presented here. This further leads to certain limitations.

Limitations

In this analysis, too, are uncertainties and limitations despite great effort to create a suitable research design. The following aspect is specifically to be discussed for the third research question:

Data Since the information on the therapists' workload was missing in the data of 2017, the most recent version of the therapists list was used (March 2021). However, the locations were compared to those of 2017, and while it was determined that there were only minor changes, they may still impact the analysis.

Further, for 8 self-employed speech therapists and 3 self-employed special needs educators the workload had to be estimated due to missing data. The estimates are based on the mean value of 62.91% and rounded down to 60% in order to avoid simulating oversupply. Nevertheless, the estimation of the workload percentages provides further uncertainty regarding the data set.

RQ 3 in a Nutshell

To summarize, the potential spatial accessibility shows that there are large differences in the spatial accessibility of therapists. In particular, there are also differences between speech therapy and special needs education. While for speech therapy there are two hot spots of high spatial accessibility on the edges of the canton, special needs education is mainly in favor of the core of larger cities. Additionally, when the spatial accessibility analyses are compared to the density of preschool aged children, it becomes apparent that in many regions (e.g., northwest) where demand is high, spatial accessibility is low. Moreover, in other regions (e.g. left shore of Lake Zurich) the oversupply is increasing the spatial accessibility, i.e., the demand is less than the supply. This is also shown in the maps of revealed spatial accessibility, where the classification of the corresponding zip codes changes. The extent to which this plays a role in the utilization of therapy is discussed in more detail in the next section.

4.2.2. RQ 4 - Connection between Spatial Accessibility and Utilization of Therapy

Previous research has shown that there is a relationship between the utilization of therapy and spatial accessibility (Kalkbrenner et al., 2011, Murphy and Ruble, 2012, Drahota et al., 2020). Therefore, in terms of this connection the fourth research question was posed as follows:

> **Research Question 4**
> To what extent does the spatial distribution of therapists influence the utilization of early intervention measures?

A visual, descriptive approach was taken to discuss this connection. As a prerequisite, a correlation test was performed. Since for speech therapy the correlation was not significant (r= -0.0135, $p > 0.05$), the bivariate map for this connection is not meaningful. The map can be found in **??** *(figure D.1)*, but the discussion on the connection between utilization of therapy and spatial accessibility will only be based on special needs education (*figure 3.10*). For special needs education, a weak, positive correlation could be found. At first glance, there is no predominant correlation (yellow and petrol zip codes do not dominate), but interesting spatial patterns become apparent.

For special needs education cases, the most represented class is confronted with moderate spatial accessibility and moderate utilization of therapy (n = 40). These zip codes are mainly located in the agglomerations around the cities of Zurich, Winterthur and Bülach. They are also present in the cities themselves, where the predominant class is high spatial accessibility and moderate utilization. From this it can be concluded that in cities, therapy is moderately utilized - regardless of whether spatial accessibility is high or only moderate. In terms of utilization of therapy, the tendencies of studies admitting a better position regarding early intervention in urban and intermediate areas can be confirmed (Skinner and Slifkin, 2007, Pantaleoni, 2012, Drahota et al., 2020, Dallman et al., 2021) even if this tendency was not evident from the rudimentary spatial accessibility maps. The cities of Wetzikon, Kloten, Wädenswil and Horgen also have a moderate utilization of therapy. Therefore, it is evident that within cities, other mechanisms, such as family-centered helpgiving practices highlighting the importance of early intervention, certainly play a significant role (Dunst et al., 2007).

An exception in this respect is the city of Dietikon. There are four clusters formed by the zip codes with low spatial accessibility and low utilization of therapy (n = 13): In the agglomerations around the cities of Winterthur, Dübendorf/Opfikon and Wetzikon as well as in the city of Dietikon and its surroundings. While all of these zip codes are rated intermediate to urban according to urban/rural typology (*figure 2.2*), Dietikon is the only city that faces low spatial accessibility and low utilization of therapy. In terms of disadvantage, the studies showing a worse position regarding early intervention in rural areas cannot be confirmed (Skinner and Slifkin, 2007, Pantaleoni, 2012, Drahota et al., 2020, Dallman et al., 2021), even if they work in the positive direction. This shows that more detailed spatial analyses have a profitable use, since differences cannot be attributed to urban/rural typology alone. One of the yellow zip codes (8636) is confronted with hectar population points with SPAI values of zero in the analysis on potential spatial accessibiliy of special needs education (*figure 3.8*). One further yellow zip code (two polygons representing zip code 8487) is adjacent to such a zip code. Most of the low classified zip codes are located in the northern part of the canton (around Wetzikon). The extent to which low spatial accessibility has an impact on the utilization of therapy cannot be assessed conclusively. However, these facts strengthen the initial assumption.

The extent to which high spatial accessibility positively influences the utilization of therapy cannot be assessed on the basis of the only two zip codes classified as high/high (zip codes 8704 and 8802). They are both located at Lake Zurich (one on the right shore, one on the left shore). Due to the low number and its locations, a spatial pattern cannot be profitably identified for these.

A final assessment cannot yet be made on the basis of this visual, descriptive analysis, which is why the corresponding limitations are discussed below.

Limitations

Since one map was already eliminated through the correlation test due to a non-significant result, there are some limitations worth mentioning for research question 4:

Choice of the Thresholds For the visualization of two variables in bivariate choropleth maps, the variables must be classified adequately (Biesecker et al., 2020). This is commonly done either on the basis of quantiles or meaningful, literature-based classifications (Biesecker et al., 2020, Nelson, 2020 and Stevens, 2021). However, it must be stated that the classification of the data has a great influence and that very different statements can be represented on the basis of the same data.

For the variable of the difference between allocated and served therapy hours, there were minus values (in the sense of more therapy hours attended than were originally allocated), which is why a division into tertiles seemed inappropriate. Therefore, the zero and minus values were assigned to high and the positive values were divided at the median for classes low and moderate. The initial aim of this analysis was to describe the connection between spatial accessibility and utilization of therapy in terms of spatial patterns. For further research, the data situation would certainly have to be examined more closely. This will be further elaborated in the following.

Data The variable of allocated and served therapy hours was not fully available for all cases. Therefore, fewer values are available for the zip codes and the statistical tests were also based on fewer values. Indeed, this could also be the reason for the correlation for speech therapy being not significant. Further, there are also very disparate reasons for the differences between allocated and served hours (e.g., moving away, no therapy slot, no need). In order to be able to make more precise statements about the relationship between spatial accessibility and utilization of therapy hours, further research is necessary.

RQ 4 in a Nutshell

In summary, for special needs education, four clusters of disadvantaged zip codes can be located. However, there is no linear trend that is visually apparent. Furthermore, there was no significant correlation at all for speech therapy. Urbanity can explain preferred zip codes relatively well, but conversely, rural areas are not necessarily disadvantaged, and most disadvantaged zip codes are also classified as intermediate to urban. However, low spatial accessibility and low utilization of therapy clusters in the city of Dietikon and in the northern part of the canton. Although the map provides a spatial overview of the distribution of the variables, no conclusive assessment can be made yet based on the visual approach.

4.3. General Methodological Limitations

Theory Based Approach This research design is a theory-based approach. In addition to the further referral entities already mentioned, there are other influences, such as sociological factors or the proportion of immigrants (e.g. through second language acquisition), which play a role in early detection and early intervention. For this purpose, additional variables could be integrated, such as a socioeconomic index, or other density maps could be used for comparison (e.g. immigrants per 1000 inhabitants). Qualitative studies would also be helpful to determine other impacts, such as the extent to which the municipalities provide awareness campaigns. Such programs would also have to be examined more closely and put into relation. Another benefit are interviews with families. Hodgetts et al. (2015) found in their study that optimizing services works particularly well when the needs of families are communicated by them. It would be particularly interesting to find out in underserved regions to what extent spatial accessibility is a barrier from their point of view.

Average Values per Zip Codes For this research, the values per zip code were averaged due to the sensitive data. The average values do not take into account differences within the analysis regions, in this case within one zip code. Therefore, the smallest possible area should be selected within which the values are averaged (Polzin, 2014). However, there are large deviations within the zip codes, which then add up to an average (*2.13*). Nevertheless, differences within the larger cities (Winterthur and Zurich) could be discussed based on the results.

Choice of the Specific FCA Method Another limitation is the choice of the specific FCA method. This was selected on literature-based decisions, but as already indicated, each method has its advantages and disadvantages. The disadvantages of the 3SFCA method are that the attractiveness of a health service is reduced only to its capacity, only relative distances are considered (because distance is divided per distance), and the total demand is not constant (dependent on the sum of distances to supplies). These aspects have been eliminated with the MH3SFCA method, but this method as well has the disadvantage that the capacities cannot be set in relation to the population. Thus, with the MH3SFCA method, the conclusion cannot be drawn that the SPAI value 1 corresponds to a slot. Therefore, for an intuitive overview the 3SFCA method was certainly a good choice. What the distribution would look like with the MH3SFCA method for the potential spatial accessibility is shown in *section D* in the *Appendix D:* **??**.

Other papers evaluating different methods usually discuss their implementation (e.g., Ngui and Apparicio, 2011, Luo and Whippo, 2012, Bauer and Groneberg, 2016, Jörg et al., 2019, Wang, 2020). Due to the importance of the topic of early detection and early intervention, this has been omitted here in favor of a discussion of the content rather than the method. In addition, the data provided the opportunity to compare potential spatial accessibility with revealed spatial accessibility, which is definitely valuable for this research topic. However, the calculations in R were designed to enable the functions to be subsequently enriched by the other methods and then published as a package.

Choice of the Transportation Mode In this research design, the car was chosen for the distance matrices as transportation mode based on the transportation behavior in Switzerland (Bundesamt für Statistik, 2018). Since no specific travel time was selected when creating the distance matrix, there are no delays due to congestion. Besides congestion, however, such an approach is also problematic in that it ignores other factors that affect travel time, such as the time it takes to find a parking space and the time it takes to walk to and from the parking slot. The urban areas and the transit through the cities may have been rated a little higher as a result. Salonen & Toivonen (2013) stated in their study in Helsinki that spatial accessibility in urban areas is higher than in rural for the majority of US and European urban regions. This would reinforce the findings of this research that rural zip codes are at a disadvantage compared to urban areas.

To address these limitations, a comparison with a distance matrix based on public transport would be interesting, or in general the use of a multi-transportation mode 2SFCA method (Mao and Nekorchuk, 2013).

Visual Approach through Bivariate Choropleth Maps Cognitive research has long been concerned with the extent to which the representation of facts is related to people and their decision-making (e.g., Larkin and Simon, 1987 and Scaife and Rogers, 1996). The visual representation therefore plays a decisive role, which is why a visual, descriptive approach that can be grasped as intuitively and quickly as possible was chosen here. However, some own decisions had to be made (e.g., thresholds, color schemes), which were based on literature and tested by means of sensitivity analyses, but which could also be further illuminated statistically. The use of LISA (*Local Spatial Autocorrelation*) maps was deliberately avoided, since neighboring cells already show similar values with a high probability due to the applied FCA methodologies. Nevertheless, these could possibly provide further insights.

In general, what certainly would provide further insights in a next step would be a logistic regression model taking further factors into account. Even if an important factor has been filtered out based on literature, it can be expected that other factors have a stronger effect on the selected variables due to the weak correlation.

4.4. Implications for Future Research

The results of this thesis are a first step towards a better understanding of the spatial distribution of early detection and early intervention among preschool aged children in the canton of Zurich. The analyses are by no means conclusive and further research appears to have potential in three areas in particular:

Linear Regression Model The analysis of spatial accessibility using the 3SFCA method provides a good basis for further research on influences on early detection and early intervention of preschool aged children. A number of studies have considered other factors (e.g., specific medical, socioeconomic, racial-ethnic conditions) (e.g., Morgan et al., 2012, Marrus and Hall, 2017, Wang et al., 2019) or analyzed the spatial component in terms of urbanity (Skinner and Slifkin, 2007, Murphy and Ruble, 2012, DeGuzman et al., 2017, Drahota et al., 2020). Through this analysis, a more sophisticated picture of the spatial component was created than based on urbanity. These results could now be put in relation to other factors in the context of further research. This has already been touched upon in this thesis by the use of bivariate choropleth maps, but to make a statistically more robust analysis, building a linear regression model would be an interesting approach.

Qualitative Research The chosen research design for this thesis made it possible to identify certain regions in which spatial accessibility is lower than in others, both in terms of early detection and early intervention. Additional qualitative methods would help to detect the extent of which these regions are affected by these disadvantages in reality. Several studies have already used qualitative approaches to identify the needs of families with children with developmental delays more precisely (e.g., Wiggins et al., 2006, Russell, 2007, Patten et al., 2012, Pickard and Ingersoll, 2016, Robinson et al., 2017). As such, it would be interesting to find out more about the needs of disadvantaged zip codes and thus to obtain further insights in the sense of the various dimensions of accessibility based on the already conducted spatial accessibility analyses (1.5).

FCA Methods Finally, as a follow-up to the already conducted analyses based on the 3SFCA method, further methodological analyses could be conducted. The variations of the FCA methods are vast and there are several possibilities that could strengthen, change or improve the findings discovered in this thesis. Of particular interest in this context would be extensions to the FCA methods that can be integrated independently of the underlying base model (e.g., Integrated 2SFCA method (Bauer and Groneberg, 2016) focusing on different distance decay function, Inverted 2SFCA method (Wang, 2018) focusing on the supplies instead of the demands in the sense of a crowdedness index, Multi-Transportation-Mode 2SFCA method (Mao and Nekorchuk, 2013) focusing on different transport modes). Furthermore, a method comparison in the sense of Joerg et al. (2019) would be interesting.

5. Conclusion

The workflow of this thesis began with a comprehensive literature review, which revealed that although the impact of spatial accessibility on early detection and early intervention is beyond question, such studies are still lacking for the canton of Zurich. Bearing this in mind, this research contributes to a better understanding of the mechanisms of early detection and early intervention and, in particular, to a more sophisticated knowledge of the spatial component that goes beyond urban/rural classification. Based on these analyses, zip codes could be identified which experience an additional disadvantage due to low spatial accessibility.

Specifically, four research questions were raised in this thesis to address the identified research gaps, two relating to early detection and two focusing on early intervention. Content-based, this thesis provides the following contributions:

Early Detection The analyses revealed large differences in the spatial accessibility of paediatricians with extensive areas of the canton being affected by low spatial accessibility. The clusters show that spatial accessibility is higher for zip codes around Lake Zurich and in greater cities (Zurich, Winterthur, and Uster). Zip codes with no registrations are mainly located in regions with low spatial accessibility. The connection between early referral and spatial accessibility of paediatricians shows a general trend of weak and positive correlation which predominantly appears in zip codes in the northern part of the canton in agglomerations.

Early Intervention In line with the analyses on early detection, the analyses revealed differences in the spatial accessibility of therapists with large areas of the canton being affected by low spatial accessibility. However, the spatial patterns show slightly different clusters. While for speech therapy there are two hot spots of high spatial accessibility on the edges of the canton, special needs education is mainly in favor of the core of larger cities. The connection between utilization of therapy and spatial accessibility of therapists is in general concerns not evident and for speech therapy the correlation is not significant. However, for special needs education the connection between low utilization and low spatial accessibility of therapists in the city of Dietikon as well as in the northern part of the canton becomes apparent.

To obtain these insights, the successful FCA methods were used. Although these methodologies are very popular in GIS research for various healthcare topics, only the rudimentary 2SFCA method has been implemented as an R package so far. For this thesis, the 3SFCA and MH3SFCA methods have additionally been implemented, and implementation for further FCA methods will be continued in the near future. Thus, this thesis provides one further contribution on a technical level:

Implementation of the FCA in R The implementation of the FCA methods will soon be available as an R package on , which makes it easily accessible and facilitates its implementation in further healthcare topics.

This Master's thesis provides a relevant and promising starting point for further research, both in terms of content and technical aspects. Further in-depth research exploring different strands of this topic not only promise to broaden the understanding on early detection and early intervention, but also might be applied to ultimately enhance early diagnosis and access to therapy for preschool aged children in the future.

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A. Code

In this section the relevant chunks of the R Code is presented. The steps, which were executed for all maps, are presented here exemplarily and not for all variables individually. For the FCA methods the function with the necessary input parameters is described.

Some preprocessing steps such as the normalization of the supply capacities were performed in Excel. The visualizations were realized in ArcGIS and Adobe Illustrator. An overview of all the used software can be found in the *Appendix B: Software*. The code for the initialization of the data is exemplified under *Initialization of the Data*.

A.1. FCA Methods

In this section the key functions of the FCA method package are listed. As the development of the package will be further continued, this code represents the state of the functions used to discuss the research questions and produce the additional results in the *Appendix D: Additional Results, MH3SFCA Method*. The function returns a *dataframe* containig the demand vector p and for every point a SPAI value. No further packages are necessary to perform the methods.

Listing 1: FCA methods: *get.spai()*

```
Arguments
p         a vector referring to point coordinates (demand) in
   ↪ ascending order
s         a vector referring to point coordinates (supplies) in
   ↪ ascending order
D         a matrix, usually a distance matrix
method    a character value to define the FCA method: "3SFCA" or
   ↪ "MH3SFCA"

get.spai <- function(p, s, D, method) {
  if (method == "3SFCA")
    {
    step1 <- sweep(D, 2, colSums(D), FUN="/")
    step2 <- s / colSums(t(step1)*p*t(D)) # t(D) so that vector
       ↪ p multiplies the correct values
    step3 <- colSums(sweep(step1, 1, step2, FUN="*")*D)
    spai <- step3
}
```

```
    else if (method == "MH3SFCA")
    {
    step1 <- sweep(s*D, 2, colSums(s*D), FUN="/")
    step2 <- s / colSums(p*t(step1)) # t(step1) so that vector p
       ↪ multiplies the correct values
    step3 <- colSums(step1*D*step2)
    spai <- step3
    }

  else{stop("wrong␣parameters")}

return(data.frame(names(p), spai))
}
```

Listing 2: Distance Decay Function: *get.distance.weights()*

```
get.distance.weights <- function(D, d0, functiond0 = 0.01,
impFunction) {
  if (impFunction == "gaussian")
    {
    D[is.na(D)] <- 0
    b = -(d0^2)/(log(functiond0))
    D <- exp(-D^2/b)
    }
  else{stop("wrong␣parameters")}

  return(D)
}
```

A.2. Initialization of the Data

Code to set up R environment and prepare the data.

Listing 3: Initialization

```
# settings
rm(list=ls()) # clean up the environment
options(scipen=3) # display digits, not the scientific version
options(warning=TRUE) # show warnings
options(digits=3) # round for 3 digits
par(mfrow=c(1,1)) # reset plot placement to normal 1 by 1

# default repository
```

```r
local({r <- getOption("repos")
       r["CRAN"] <- "http://cran.r-project.org"
       options(repos=r)
})

# function so that package get installed if not already
pkgTest <- function(x)
  {
    if (!require(x,character.only = TRUE))
    {
      install.packages(x,dep=TRUE)
        if(!require(x,character.only = TRUE)) stop("Package not 
           ↪ found")
    }
}

# packages
pkgTest("sf") # apply function to install
library(sf) # or call library

# import data
setwd("//files.geo.uzh.ch/private/egrueebl/data/project folder")
dataFolder <- file.path(getwd(), "data") # data folder
figureFolder <- file.path(getwd(), "figures") # figures folder
outputFolder <- file.path(getwd(), "output") # output folder

# read shapefile for demand (for FCA methods not necessairy a
   ↪ shapefile, also possible for data tables)
demand <- st_read(dsn="data", layer="demand_layer")
demand$Origin_ID <- as.integer(demand$ID)
demand$p <- as.integer(demand$quantity)
demand <- demand[,c("Origin_ID", "p", "geometry")]

# read shapefile for supply
supply <- st_read(dsn="data", layer="supply_layer")
supply$Destination_ID <- as.integer(supply$ID)
supply <- supply[,c("Destination_ID", "capacity", "geometry")]

# assign CRS
demand <- st_transform(demand, crs = 2056)
supply <- st_transform(supply, crs = 2056)
```

```
# Read OD_matrix.df
OD_matrix.df1 <- read.csv(file = "data/OD_matrix_statpop_
    ↪ silvester_s1_s2_all_14000.csv", sep = ",", header = TRUE,
    ↪ stringsAsFactors = FALSE)
OD_matrix.df2 <- read.csv(file = "data/OD_matrix_statpop_
    ↪ silvester_s1_s2_all_20062.csv", sep = ",", header = TRUE,
    ↪ stringsAsFactors = FALSE)
OD_matrix.df <- rbind(OD_matrix.df1, OD_matrix.df2)

# subset useful columns of OD matrix
OD_matrix.df <- OD_matrix.df[,c("ORIGIN_ID", "DESTINATION_ID", "
    ↪ TOTAL_TRAVELTIME")]

OD_matrix.df <- OD_matrix.df[ which(OD_matrix.df$DESTINATION_ID
    ↪ %in% supply$Destination_ID), ] # subset matrix for s1 or s2
    ↪  therapies

# create matrix for travel time
OD_matrix_time.df <- as.data.frame.matrix(xtabs(TOTAL_TRAVELTIME
    ↪ ~DESTINATION_ID+ORIGIN_ID, OD_matrix.df)) # is sorted
    ↪ ascending
OD_matrix_time <- data.matrix(OD_matrix_time.df) # assign data.
    ↪ matrix class
OD_matrix_time[is.na(OD_matrix_time)] <- 0 # remove NAs

# bring demand and supply in ascending order to work with
    ↪ distance matrix
m_originid <- unique(OD_matrix.df$ORIGIN_ID)
m_originid <- as.data.frame(m_originid)
p1 <- left_join(m_originid, demand, by = c("m_originid" = "
    ↪ Origin_ID"))
p1 <- p1[order(p1$m_originid),] # sort ascending for
    ↪ calculations
p <- p1 %>%
  select(p) %>%
  unlist(use.names = FALSE) # select demand variable
names(p) <- p1 %>%
  select(m_originid) %>%
  unlist(use.names = FALSE)

# supply
m_destinationid <- unique(OD_matrix.df$DESTINATION_ID)
```

```
m_destinationid <- as.data.frame(m_destinationid)
s1 <- left_join(m_destinationid, supply, by = c("m_destinationid
    ↪ " = "Destination_ID"))
s1 <- s1[order(s1$m_destinationid),] # sort ascending for
    ↪ calculations
s <- s1 %>%
  select(capacity) %>%
  unlist(use.names = FALSE) # select demand variable
names(s) <- s1 %>%
  select(m_destinationid) %>%
  unlist(use.names = FALSE)
```

A.3. Average and Range per Zip code

Code to calculate the average per zip code.

Listing 4: Average and Range per Zip Code

```
library(sf)
library(dplyr) # to perform joins

Results$names.p. <- as.numeric(Results$names.p.) # merge spai to
    ↪  sf-data
demand <- left_join(demand, Results, by = c("Origin_ID" = "names
    ↪ .p."))
demand_NA <- demand[is.na(demand$spai),] # detect SPAI = 0
    ↪ values
demand$spai[is.na(demand$spai)] <- 0 # assign NA-values to zero,
    ↪  as they don't have a reachable health service and aren't
    ↪ included in FCA-function
demand.point <- sf::st_cast(demand, "POINT") # SPAI as points
demand.point <- st_transform(demand,point, crs = 2056)

zipcodes <- st_read(dsn="data", layer="AV_PLZ_ohneSeen2017") #
    ↪ load zip code data
zipcodes <- st_transform(zipcodes, crs = 2056) # assign crs
zipcodes_intersect <- st_intersection(demand.point, zipcodes) #
    ↪ intersect SPAI with zipcode borders
# create matrix for time
zipcodes_intersect.df <- as.data.frame.matrix(xtabs(spai~Origin_
    ↪ ID+PLZ, zipcodes_intersect)) # is sorted ascending

range_SPAI <- as.data.frame(range_SPAI) # empty df
```

```
range_SPAI <- apply(zipcodes_intersect.df, 2, FUN = function(x)
    ↪ {min(x[x > 0])}) # detect min value per zip code
range_SPAI$max <- apply(zipcodes_intersect.df, 2, FUN = function
    ↪ (x) {max(x[x > 0])}) # detect max value per zip code
colnames(range_SPAI)[1] <- "min" # detect min value per zip code
range_SPAI$difference <- range_SPAI$max-range_SPAI$min # range
    ↪ through difference
range_SPAI <- range_SPAI[order(-range_SPAI$difference),] # sort
    ↪ descending for overview of biggest ranges

average_SPAI <- aggregate(zipcodes_intersect[, 3], list(zipcodes
    ↪ _intersect$PLZ), mean) # mean SPAI per zipcode (zipcodes_
    ↪ intersect[, 3] = SPAI column, zipcodes_intersect$PLZ = PLZ
    ↪ of zipcodes) NOTE: PLZ has duplicates (multiple zip codes
    ↪ per PLZ, must be taken into acount for statistics) ->
    ↪ unique values
average_SPAI <- data.frame(average_SPAI) # save as df
average_SPAI <- average_SPAI %>%
  select(Group.1, spai) %>%
  distinct(Group.1, spai, .keep_all = TRUE)

zipcodes <- left_join(zipcodes, average_SPAI, by = c("PLZ" = "
    ↪ Group.1"), copy = FALSE) # join average SPAI to polygon sf
    ↪ (Group.1 = unique ID of zip codes in average_SPAI)

zipcodes_polygons_subset <- zipcodes_polygons[complete.cases(
    ↪ zipcodes_polygons$spai), ] # extract zipcodes with cases

st_write(zipcodes_polygons_subset, dsn = "output", layer = "3
    ↪ SFCA_per_zip_code.shp", driver = "ESRI_Shapefile",
    ↪ overwrite = FALSE, update = TRUE)
```

A.4. Bivariate Choropleth Maps

Prepare variables for bivariate choropleth maps. The visualization is performed in ArcGIS and Adobe Illustrator.

Listing 5: Bivariate Choropleth Maps

```
library(sf)
library(dplyr) # to perform joins
```

```
demand.point <- sf::st_cast(demand, "POINT") # convert df to sf
    ↪ for intersection
demand.point <- st_transform(demand,point, crs = 2056) # assign
    ↪ crs
zipcodes_polygons <- zipcodes
zipcodes_intersect <- st_intersection(demand.point, zipcodes_
    ↪ polygons) # intersect demand with zipcode borders

zipcodes_intersect$aux <- as.double(zipcodes_intersect$aux) #
    ↪ auxiliary variable (either age at referral [m] or
    ↪ difference in therapy hours [])
zipcodes_intersect <- zipcodes_intersect[complete.cases(zipcodes
    ↪ _intersect$aux), ] # extract zipcodes with cases

zipcodes_intersect.df <- as.data.frame.matrix(xtabs(aux~Origin_
    ↪ ID+PLZ, zipcodes_intersect)) # matrix with auxiliary
    ↪ variable per zip code (PLZ)
range_aux <- apply(zipcodes_intersect.df, 2, FUN = function(x) {
    ↪ min(x[x > 0])}) # detect ranges of auxiliary variables per
    ↪ zipcode
range_aux <- as.data.frame(range_hours) # empty df
range_hours$max <- apply(zipcodes_intersect.df, 2, FUN =
    ↪ function(x) {max(x[x > 0])}) # detect max value per zip
    ↪ code
colnames(range_hours)[1] <- "min" # detect min value per zipcode
range_hours$range <- range_hours$max-range_hours$min # detect
    ↪ range through difference
range_hours <- range_hours[order(-range_hours$range),] # sort
    ↪ descending for overview

average_hours <- aggregate(zipcodes_intersect[, 4], list(
    ↪ zipcodes_intersect$PLZ), mean) # mean auxiliary variable
    ↪ per zipcode (zipcodes_intersect[, 4] = aux column, zipcodes
    ↪ _intersect$PLZ = PLZ of zipcodes) NOTE: PLZ has duplicates
    ↪ (multiple zip codes per PLZ, must be taken into acount for
    ↪ statistics) -> unique values
average_aux <- data.frame(average_hours) # save as df
average_aux <- average_aux %>%
  select(Group.1, aux) %>%
  distinct(Group.1, aux, .keep_all = TRUE)

zipcodes <- left_join(zipcodes, average_hours, by = c("PLZ" = "
```

```
    ↪ Group.1"), copy = FALSE) # join average auxiliary variable
    ↪ to polygons

zipcodes <- zipcodes[complete.cases(zipcodes$spai), ] # extract
    ↪ zipcodes with cases, relevant for computing descriptive
    ↪ statistics

tertiles_aux <- zipcodes %>% # tertiles for auxiliary variable
   pull(aux) %>%
   quantile(probs = seq (0, 1, length.out = 4))
zipcodes <- zipcodes %>%
   mutate(aux_tert = ifelse(zipcodes$aux >= tertiles_aux[3], 2,
      ↪ 0)) %>%
   mutate(aux_tert = ifelse(zipcodes$aux < tertiles_aux[3] &
      ↪ zipcodes$aux >= tertiles_aux[2], 1, aux_tert)) # assign
      ↪ values to three groups (tertiles)

# tertiles for spai
tertiles_spai <- zipcodes[!duplicated(zipcodes$PLZ), ] %>%
  pull(spai) %>%
  quantile(probs = seq (0, 1, length.out = 4))
zipcodes <- zipcodes %>%
  mutate(spai_tert = ifelse(zipcodes$spai >= tertiles_spai[3],
     ↪ 2, 0)) %>%
  mutate(spai_tert = ifelse(zipcodes$spai < tertiles_spai[3] &
     ↪ zipcodes$spai >= tertiles_spai[2], 1, spai_tert))

zipcodes <- zipcodes[complete.cases(zipcodes$aux_tert), ] #
    ↪ extract zipcodes with cases

st_write(zipcodes, dsn = "output", layer = "bivariate_maps.shp",
    ↪  driver = "ESRI_Shapefile", overwrite = TRUE, update = TRUE
    ↪ )
```

A.5. Shapiro-Wilk and Spearman's Rho test

Listing 6: Statistical Tests

```
library(sf)
library(stats) # for the tests

shapiro_test <- shapiro.test(data$aux) # perform the shapiro-
   ↪ wilk test
qqPlot_car <- qqPlot(data$aux) # qqPlots to look at distribution
cor_test <- cor.test(test$spai, test$age_m_, method = "spearman"
   ↪ ) # correlation tests: specify method ("pearson", "spearman
   ↪ " etc.)
```

A.6. Descriptive Statistics

All tables with descriptive statistics were calculated by the means of this function.

Listing 7: Descriptive Statistics: *get.stats()*

```
library(base-package)

get.stats <- function(var)
  {
sum <- sum(test$diff)
mean <- mean(test$diff)
median <- median(test$diff)
sd <- sd(test$diff)
min <- min(test$diff)
maximum <- max(test$diff)

return(data.frame(sum, mean, median, sd, min, maximum))
}
```

A.7. Histograms

Listing 8: Histograms

```
library(ggplot2) # for histogram function
library(extrafont) # for labeling

h <- ggplot(data=demand, aes(aux)) +
  geom_histogram(aes(),
```

```
                    binwidth = 6,
                    breaks=seq(0, 90, by = 6),
                    col="black",
                    fill="white",
                    alpha=0.8) +
  geom_density(aes(y = ..count..), col=2) +
  labs(title="Title", x="Age␣[m]␣or␣Therapy␣Hours␣[h]", y="Count
     ↪ ␣[n]") +
    theme(text=element_text(size = 10, family="Impact", face="
       ↪ bold"), plot.title = element_text(size = 12))
cairo_pdf(filename = "filname.pdf", width = 7, height = 4)
```

B. Software

Software Version	*Description, area of application*
Adobe Illustrator 25.4.1	Vector-based design and drawing program; used to produce legends and finalize visualizations
ArcGIS Pro 2.4.3	GIS Software Products (*Esri); used to visualize the results in an approprioate way*
Citavi 6.10	Reference manager; used to manage the literature
LaTeX 3.10	High-quality typesetting system; used to render the thesis
RStudio 4.04	An integrated development environment (IDE) for R; used to perform all calculation and analyses

C. Zip Codes Classification

This section provides some additional information to understand the results thoroughly. The figure below shows all zip codes of the canton of Zurich and how many polygons belong to each zip code. Thereafter, a table lists the classification of the zip codes for all maps.

Overview of the Zip Codes in the Canton of Zurich

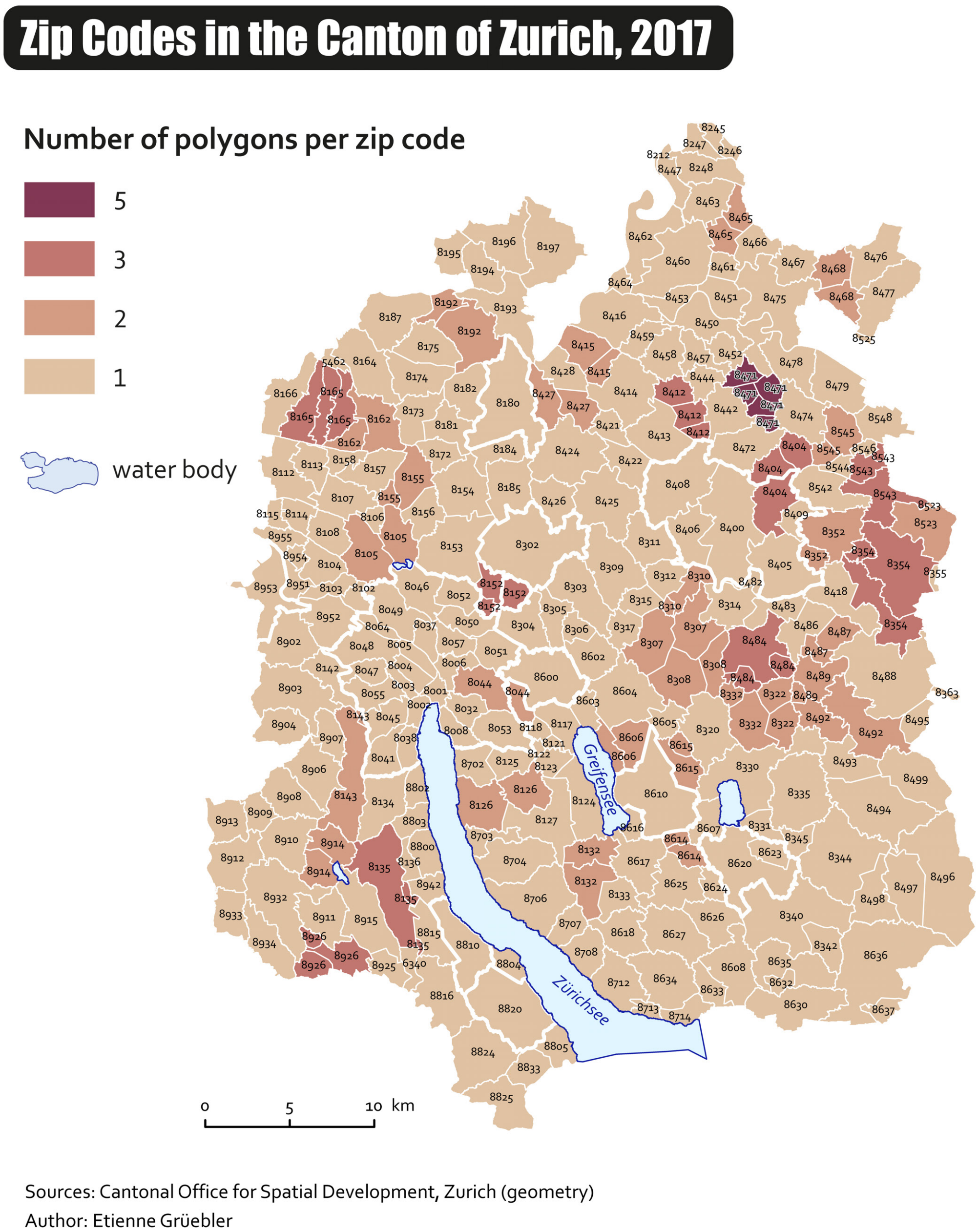

Figure C.1: Map of all zip codes in the canton of Zurich originated from the data from 2017. Since several polygons can belong to one zip code, the map was classified accordingly by number of polygons per zip code.

Classified Zip Codes

Table C.1: Classification of the zip codes for the different maps.

Map	*Class*	*Zip Codes*
figure 3.1	high (n=2)	8523 ; 8548
	moderate (n=61)	8926 ; 8925 ; 6340 ; 8934 ; 8713 ; 8714 ; 8712 ; 8708 ; 8630 ; 8632 ; 8912 ; 8707 ; 8942 ; 8913 ; 8910 ; 8608 ; 8136 ; 8909 ; 8706 ; 8133 ; 8800 ; 8132 ; 8704 ; 8908 ; 8703 ; 8803 ; 8906 ; 8126 ; 8904 ; 8127 ; 8702 ; 8125 ; 8123 ; 8122 ; 8124 ; 8045 ; 8008 ; 8903 ; 8002 ; 8053 ; 8118 ; 8055 ; 8032 ; 8606 ; 8003 ; 8047 ; 8001 ; 8610 ; 8004 ; 8044 ; 8005 ; 8006 ; 8037 ; 8355 ; 8400 ; 8523 ; 8543 ; 8544 ; 8546 ; 8548 ; 8525
	low (n=190)	8825 ; 8833 ; 8824 ; 8805 ; 8816 ; 8135 ; 8820 ; 8933 ; 8911 ; 8804 ; 8815 ; 8932 ; 8633 ; 8634 ; 8915 ; 8810 ; 8914 ; 8637 ; 8618 ; 8635 ; 8627 ; 8626 ; 8342 ; 8636 ; 8624 ; 8625 ; 8614 ; 8340 ; 8134 ; 8617 ; 8802 ; 8623 ; 8498 ; 8907 ; 8620 ; 8041 ; 8038 ; 8143 ; 8497 ; 8345 ; 8607 ; 8331 ; 8121 ; 8344 ; 8142 ; 8615 ; 8496 ; 8117 ; 8494 ; 8335 ; 8603 ; 8902 ; 8605 ; 8048 ; 8064 ; 8493 ; 8330 ; 8499 ; 8320 ; 8952 ; 8600 ; 8051 ; 8322 ; 8332 ; 8604 ; 8492 ; 8050 ; 8103 ; 8102 ; 8951 ; 8049 ; 8602 ; 8489 ; 8308 ; 8484 ; 8953 ; 8152 ; 8954 ; 8306 ; 8104 ; 8495 ; 8052 ; 8046 ; 8955 ; 8304 ; 8317 ; 8305 ; 8363 ; 8307 ; 8108 ; 8115 ; 8114 ; 8487 ; 8310 ; 8105 ; 8315 ; 8106 ; 8303 ; 8486 ; 8488 ; 8314 ; 8107 ; 8153 ; 8312 ; 8483 ; 8155 ; 8156 ; 8482 ; 8309 ; 8112 ; 8113 ; 8302 ; 8158 ; 8157 ; 8311 ; 8418 ; 8354 ; 8426 ; 8154 ; 8352 ; 8405 ; 8162 ; 8172 ; 8406 ; 8185 ; 8425 ; 8184 ; 8409 ; 8181 ; 8165 ; 8422 ; 8173 ; 8166 ; 8424 ; 8404 ; 8408 ; 8542 ; 8421 ; 8174 ; 8427 ; 8182 ; 8412 ; 8164 ; 8413 ; 8472 ; 8545 ; 8471 ; 8175 ; 8180 ; 8428 ; 8442 ; 8414 ; 8415 ; 8187 ; 8444 ; 8192 ; 8474 ; 8457 ; 8459 ; 8458 ; 8193 ; 8479 ; 8478 ; 8416 ; 8194 ; 8452 ; 8195 ; 8450 ; 8453 ; 8464 ; 8451 ; 8461 ; 8196 ; 8197 ; 8468 ; 8475 ; 8467 ; 8460 ; 8465 ; 8466 ; 8477 ; 8462 ; 8476 ; 8463 ; 8212 ; 8447 ; 8248 ; 8246 ; 8247 ; 8245
figure 3.2	high (n=8)	8933 ; 8912 ; 8913 ; 8910 ; 8909 ; 8908 ; 8904 ; 8032

	moderate (n=66)	8713 ; 8135 ; 8933 ; 8712 ; 8932 ; 8630 ; 8810 ; 8914 ; 8912 ; 8942 ; 8618 ; 8913 ; 8635 ; 8910 ; 8608 ; 8909 ; 8706 ; 8133 ; 8800 ; 8132 ; 8704 ; 8908 ; 8703 ; 8803 ; 8134 ; 8617 ; 8126 ; 8802 ; 8904 ; 8127 ; 8907 ; 8038 ; 8702 ; 8143 ; 8125 ; 8607 ; 8123 ; 8122 ; 8124 ; 8045 ; 8008 ; 8903 ; 8002 ; 8053 ; 8118 ; 8055 ; 8032 ; 8142 ; 8003 ; 8047 ; 8001 ; 8610 ; 8004 ; 8044 ; 8005 ; 8603 ; 8902 ; 8605 ; 8330 ; 8037 ; 8057 ; 8332 ; 8049 ; 8405 ; 8400 ; 8416
	low (n=127)	8825 ; 8833 ; 8926 ; 8805 ; 8925 ; 8820 ; 8804 ; 8815 ; 8633 ; 8634 ; 8915 ; 8627 ; 8626 ; 8636 ; 8624 ; 8625 ; 8614 ; 8340 ; 8623 ; 8620 ; 8041 ; 8344 ; 8496 ; 8494 ; 8335 ; 8048 ; 8064 ; 8493 ; 8320 ; 8952 ; 8600 ; 8051 ; 8322 ; 8604 ; 8492 ; 8050 ; 8103 ; 8102 ; 8951 ; 8602 ; 8489 ; 8308 ; 8484 ; 8953 ; 8152 ; 8954 ; 8306 ; 8052 ; 8046 ; 8955 ; 8304 ; 8317 ; 8305 ; 8307 ; 8108 ; 8115 ; 8114 ; 8487 ; 8105 ; 8315 ; 8106 ; 8303 ; 8486 ; 8488 ; 8314 ; 8107 ; 8153 ; 8483 ; 8155 ; 8309 ; 8112 ; 8302 ; 8157 ; 8311 ; 8418 ; 8354 ; 8426 ; 8154 ; 8352 ; 8162 ; 8172 ; 8406 ; 8185 ; 8184 ; 8409 ; 8181 ; 8165 ; 8422 ; 8173 ; 8166 ; 8424 ; 8404 ; 8523 ; 8408 ; 8542 ; 8174 ; 8427 ; 8182 ; 8412 ; 8543 ; 8164 ; 8544 ; 8413 ; 8472 ; 8545 ; 8471 ; 8180 ; 8442 ; 8187 ; 8444 ; 8192 ; 8548 ; 8474 ; 8457 ; 8193 ; 8450 ; 8453 ; 8196 ; 8197 ; 8475 ; 8477 ; 8476 ; 8463 ; 8447 ; 8248 ; 8246 ; 8245
figure 3.3	high (n=13)	8708 ; 8706 ; 8132 ; 8704 ; 8703 ; 8126 ; 8702 ; 8125 ; 8008 ; 8032 ; 8001 ; 8044 ; 8006
	moderate (n=43)	8713 ; 8135 ; 8708 ; 8810 ; 8912 ; 8942 ; 8910 ; 8909 ; 8706 ; 8800 ; 8132 ; 8704 ; 8908 ; 8803 ; 8625 ; 8134 ; 8617 ; 8906 ; 8126 ; 8802 ; 8907 ; 8041 ; 8038 ; 8702 ; 8143 ; 8125 ; 8053 ; 8055 ; 8032 ; 8142 ; 8606 ; 8003 ; 8001 ; 8004 ; 8902 ; 8006 ; 8048 ; 8064 ; 8330 ; 8057 ; 8604 ; 8049 ; 8400
	low (n=83)	8824 ; 8805 ; 8816 ; 8934 ; 8820 ; 8911 ; 8804 ; 8634 ; 8630 ; 8914 ; 8632 ; 8635 ; 8608 ; 8636 ; 8340 ; 8623 ; 8620 ; 8344 ; 8496 ; 8494 ; 8335 ; 8493 ; 8320 ; 8952 ; 8600 ; 8051 ; 8492 ; 8050 ; 8103 ; 8102 ; 8602 ; 8308 ; 8953 ; 8152 ; 8104 ; 8052 ; 8046 ; 8955 ; 8304 ; 8317 ; 8305 ; 8307 ; 8108 ; 8114 ; 8487 ; 8105 ; 8106 ; 8486 ; 8107 ; 8483 ; 8155 ; 8482 ; 8302 ; 8157 ; 8354 ; 8154 ; 8352 ; 8405 ; 8172 ; 8406 ; 8184 ; 8409 ; 8181 ; 8173 ; 8424 ; 8404 ; 8523 ; 8408 ; 8542 ; 8413 ; 8472 ; 8545 ; 8180 ; 8442 ; 8192 ; 8474 ; 8459 ; 8193 ; 8450 ; 8197 ; 8477 ; 8463 ; 8245
figure 3.6	high (n=6)	8914 ; 8910 ; 8525 ; 8468 ; 8477 ; 8476

	moderate (n=62)	8805 ; 8934 ; 8713 ; 8135 ; 8820 ; 8911 ; 8804 ; 8712 ; 8932 ; 8915 ; 8708 ; 8630 ; 8914 ; 8632 ; 8912 ; 8707 ; 8942 ; 8913 ; 8635 ; 8910 ; 8136 ; 8909 ; 8706 ; 8342 ; 8800 ; 8908 ; 8803 ; 8340 ; 8134 ; 8498 ; 8041 ; 8038 ; 8702 ; 8045 ; 8008 ; 8053 ; 8055 ; 8032 ; 8003 ; 8047 ; 8001 ; 8004 ; 8044 ; 8005 ; 8006 ; 8048 ; 8037 ; 8057 ; 8050 ; 8953 ; 8954 ; 8114 ; 8406 ; 8404 ; 8408 ; 8182 ; 8472 ; 8180 ; 8525 ; 8468 ; 8477 ; 8476
	low (n=185)	8825 ; 8833 ; 8824 ; 8926 ; 8925 ; 8816 ; 6340 ; 8933 ; 8714 ; 8815 ; 8633 ; 8634 ; 8810 ; 8637 ; 8618 ; 8627 ; 8608 ; 8133 ; 8626 ; 8132 ; 8704 ; 8703 ; 8636 ; 8624 ; 8625 ; 8614 ; 8617 ; 8906 ; 8126 ; 8616 ; 8623 ; 8904 ; 8127 ; 8907 ; 8620 ; 8143 ; 8497 ; 8125 ; 8345 ; 8607 ; 8331 ; 8123 ; 8122 ; 8124 ; 8121 ; 8903 ; 8344 ; 8118 ; 8142 ; 8615 ; 8496 ; 8606 ; 8610 ; 8117 ; 8494 ; 8335 ; 8603 ; 8902 ; 8605 ; 8064 ; 8493 ; 8330 ; 8499 ; 8320 ; 8952 ; 8600 ; 8051 ; 8322 ; 8332 ; 8604 ; 8492 ; 8103 ; 8102 ; 8049 ; 8602 ; 8489 ; 8308 ; 8484 ; 8152 ; 8306 ; 8104 ; 8495 ; 8052 ; 8046 ; 8304 ; 8317 ; 8305 ; 8363 ; 8307 ; 8108 ; 8487 ; 8310 ; 8105 ; 8315 ; 8106 ; 8303 ; 8486 ; 8488 ; 8314 ; 8107 ; 8153 ; 8312 ; 8483 ; 8155 ; 8156 ; 8482 ; 8309 ; 8112 ; 8113 ; 8302 ; 8158 ; 8157 ; 8311 ; 8418 ; 8354 ; 8426 ; 8154 ; 8352 ; 8405 ; 8162 ; 8172 ; 8355 ; 8185 ; 8425 ; 8184 ; 8409 ; 8181 ; 8165 ; 8422 ; 8173 ; 8166 ; 8424 ; 8523 ; 8542 ; 8421 ; 8174 ; 8427 ; 8412 ; 8543 ; 8164 ; 8544 ; 8413 ; 8545 ; 8471 ; 8546 ; 8175 ; 8428 ; 8442 ; 8414 ; 8415 ; 8187 ; 8444 ; 8192 ; 8548 ; 8474 ; 8457 ; 8459 ; 8458 ; 8193 ; 8479 ; 8478 ; 8416 ; 8194 ; 8452 ; 8195 ; 8450 ; 8453 ; 8464 ; 8451 ; 8461 ; 8196 ; 8197 ; 8475 ; 8467 ; 8460 ; 8465 ; 8466 ; 8462 ; 8463 ; 8212 ; 8447 ; 8248 ; 8246 ; 8247 ; 8245
figure 3.7	high (n=11)	8911 ; 8932 ; 8914 ; 8913 ; 8910 ; 8909 ; 8908 ; 8340 ; 8496 ; 8477 ; 8476
	moderate (n=59)	8926 ; 8713 ; 8135 ; 8933 ; 8911 ; 8712 ; 8633 ; 8915 ; 8630 ; 8914 ; 8707 ; 8942 ; 8913 ; 8635 ; 8910 ; 8608 ; 8136 ; 8909 ; 8706 ; 8626 ; 8800 ; 8908 ; 8803 ; 8636 ; 8624 ; 8340 ; 8134 ; 8802 ; 8623 ; 8620 ; 8041 ; 8008 ; 8002 ; 8344 ; 8053 ; 8055 ; 8032 ; 8003 ; 8047 ; 8001 ; 8004 ; 8044 ; 8005 ; 8006 ; 8330 ; 8037 ; 8057 ; 8953 ; 8955 ; 8115 ; 8114 ; 8488 ; 8405 ; 8406 ; 8404 ; 8182 ; 8472 ; 8477 ; 8476

	low (n=131)	8825 ; 8833 ; 8805 ; 8925 ; 8804 ; 8815 ; 8634 ; 8810 ; 8618 ; 8627 ; 8133 ; 8132 ; 8704 ; 8703 ; 8625 ; 8614 ; 8617 ; 8906 ; 8126 ; 8904 ; 8127 ; 8907 ; 8143 ; 8125 ; 8607 ; 8123 ; 8122 ; 8124 ; 8903 ; 8118 ; 8142 ; 8606 ; 8610 ; 8117 ; 8494 ; 8335 ; 8603 ; 8902 ; 8605 ; 8048 ; 8064 ; 8493 ; 8320 ; 8952 ; 8600 ; 8051 ; 8322 ; 8332 ; 8604 ; 8492 ; 8050 ; 8103 ; 8102 ; 8951 ; 8049 ; 8602 ; 8489 ; 8308 ; 8484 ; 8152 ; 8954 ; 8306 ; 8052 ; 8046 ; 8304 ; 8317 ; 8305 ; 8307 ; 8108 ; 8487 ; 8105 ; 8315 ; 8106 ; 8303 ; 8486 ; 8314 ; 8107 ; 8153 ; 8483 ; 8155 ; 8309 ; 8112 ; 8302 ; 8157 ; 8311 ; 8418 ; 8354 ; 8426 ; 8154 ; 8352 ; 8162 ; 8172 ; 8185 ; 8184 ; 8409 ; 8181 ; 8165 ; 8422 ; 8173 ; 8166 ; 8424 ; 8523 ; 8542 ; 8174 ; 8427 ; 8412 ; 8543 ; 8164 ; 8544 ; 8413 ; 8545 ; 8471 ; 8442 ; 8187 ; 8444 ; 8192 ; 8548 ; 8474 ; 8457 ; 8193 ; 8416 ; 8450 ; 8453 ; 8196 ; 8197 ; 8475 ; 8463 ; 8447 ; 8248 ; 8246 ; 8245
figure 3.8	high (n=12)	8910 ; 8041 ; 8038 ; 8045 ; 8055 ; 8142 ; 8003 ; 8047 ; 8048 ; 8064 ; 8400 ; 8180
	moderate (n=46)	8135 ; 8932 ; 8914 ; 8942 ; 8913 ; 8910 ; 8909 ; 8800 ; 8908 ; 8803 ; 8802 ; 8041 ; 8038 ; 8045 ; 8008 ; 8903 ; 8002 ; 8055 ; 8032 ; 8142 ; 8003 ; 8047 ; 8001 ; 8004 ; 8048 ; 8037 ; 8952 ; 8102 ; 8049 ; 8352 ; 8405 ; 8185 ; 8184 ; 8409 ; 8181 ; 8400 ; 8173 ; 8404 ; 8408 ; 8174 ; 8427 ; 8182 ; 8452 ; 8450 ; 8453 ; 8451
	low (n=195)	8825 ; 8833 ; 8824 ; 8926 ; 8805 ; 8925 ; 8816 ; 6340 ; 8934 ; 8713 ; 8820 ; 8933 ; 8714 ; 8804 ; 8815 ; 8712 ; 8633 ; 8634 ; 8915 ; 8708 ; 8630 ; 8810 ; 8637 ; 8632 ; 8707 ; 8618 ; 8635 ; 8627 ; 8608 ; 8706 ; 8133 ; 8626 ; 8342 ; 8132 ; 8704 ; 8703 ; 8636 ; 8624 ; 8625 ; 8614 ; 8340 ; 8617 ; 8906 ; 8126 ; 8616 ; 8623 ; 8904 ; 8127 ; 8498 ; 8907 ; 8620 ; 8143 ; 8497 ; 8125 ; 8345 ; 8607 ; 8331 ; 8123 ; 8122 ; 8124 ; 8121 ; 8344 ; 8118 ; 8615 ; 8496 ; 8606 ; 8610 ; 8117 ; 8044 ; 8494 ; 8335 ; 8603 ; 8902 ; 8006 ; 8605 ; 8493 ; 8330 ; 8499 ; 8320 ; 8057 ; 8600 ; 8051 ; 8322 ; 8332 ; 8604 ; 8492 ; 8050 ; 8951 ; 8602 ; 8489 ; 8308 ; 8484 ; 8953 ; 8152 ; 8954 ; 8306 ; 8104 ; 8495 ; 8052 ; 8046 ; 8955 ; 8304 ; 8317 ; 8305 ; 8363 ; 8307 ; 8108 ; 8115 ; 8114 ; 8487 ; 8310 ; 8105 ; 8315 ; 8106 ; 8303 ; 8486 ; 8488 ; 8314 ; 8107 ; 8153 ; 8312 ; 8483 ; 8155 ; 8156 ; 8309 ; 8112 ; 8113 ; 8302 ; 8158 ; 8157 ; 8311 ; 8418 ; 8354 ; 8426 ; 8154 ; 8162 ; 8172 ; 8355 ; 8425 ; 8165 ; 8422 ; 8166 ; 8424 ; 8523 ; 8542 ; 8421 ; 8412 ; 8543 ; 8164 ; 8544 ; 8413 ; 8472 ; 8545 ; 8471 ; 8546 ; 8175 ; 8428 ; 8442 ; 8414 ; 8415 ; 8187 ; 8444 ; 8192 ; 8548 ; 8474 ; 8457 ; 8459 ; 8458 ; 8193 ; 8479 ; 8478 ; 8416 ; 8194 ; 8195 ; 8525 ; 8464 ; 8461 ; 8196 ; 8197 ; 8468 ; 8475 ; 8467 ; 8460 ; 8465 ; 8466 ; 8477 ; 8462 ; 8476 ; 8463 ; 8212 ; 8447 ; 8248 ; 8246 ; 8247 ; 8245

figure 3.9	high (n=15)	8135 ; 8136 ; 8134 ; 8041 ; 8038 ; 8045 ; 8002 ; 8055 ; 8142 ; 8003 ; 8047 ; 8004 ; 8048 ; 8064 ; 8450
	moderate (n=40)	8135 ; 8708 ; 8910 ; 8136 ; 8800 ; 8704 ; 8703 ; 8803 ; 8134 ; 8126 ; 8041 ; 8038 ; 8702 ; 8143 ; 8008 ; 8002 ; 8055 ; 8032 ; 8003 ; 8001 ; 8006 ; 8048 ; 8064 ; 8037 ; 8952 ; 8057 ; 8102 ; 8049 ; 8405 ; 8406 ; 8184 ; 8409 ; 8400 ; 8173 ; 8404 ; 8408 ; 8180 ; 8442 ; 8459 ; 8463
	low (n=84)	8824 ; 8805 ; 8816 ; 8934 ; 8713 ; 8820 ; 8933 ; 8911 ; 8804 ; 8712 ; 8634 ; 8630 ; 8810 ; 8914 ; 8632 ; 8912 ; 8635 ; 8627 ; 8608 ; 8132 ; 8908 ; 8636 ; 8625 ; 8340 ; 8617 ; 8906 ; 8623 ; 8907 ; 8125 ; 8122 ; 8344 ; 8496 ; 8606 ; 8610 ; 8494 ; 8335 ; 8902 ; 8493 ; 8330 ; 8320 ; 8600 ; 8051 ; 8604 ; 8492 ; 8050 ; 8103 ; 8602 ; 8308 ; 8953 ; 8152 ; 8104 ; 8052 ; 8046 ; 8955 ; 8304 ; 8317 ; 8305 ; 8307 ; 8108 ; 8114 ; 8487 ; 8105 ; 8106 ; 8486 ; 8107 ; 8483 ; 8155 ; 8482 ; 8302 ; 8157 ; 8354 ; 8154 ; 8352 ; 8172 ; 8424 ; 8523 ; 8542 ; 8413 ; 8472 ; 8545 ; 8193 ; 8197 ; 8477 ; 8245

D. Additional Results

Bivariate Choropleth Map

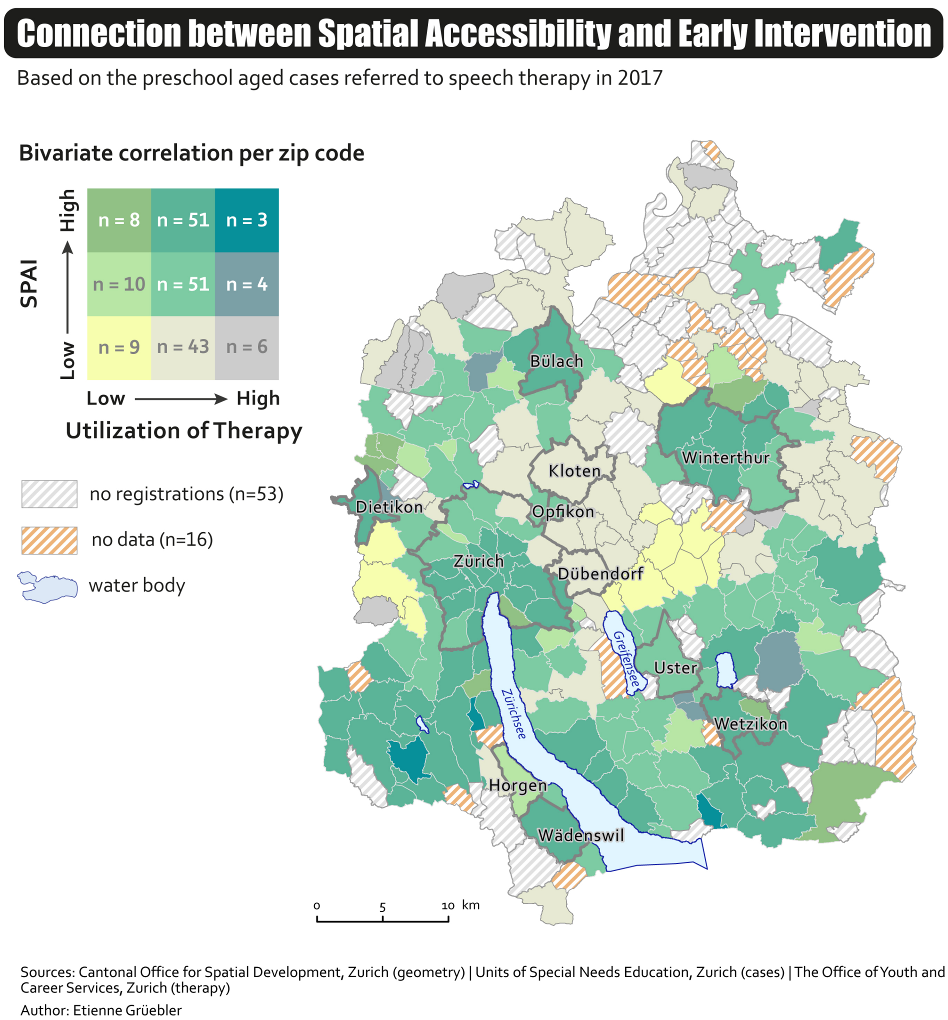

Figure D.1: Bivariate choropleth map representing the connection between spatial accessibility (SPAI values) and early intervention (difference between served and allocated therapy hours) for speech therapy cases. The variables are classified as follows: the spatial accessibility varaible is classified based on the tertiles of the value distribution (thresholds of 0.67 and 1.03), the utilization of therapy is evaluated in percent. Since there are also cases that utilize more hours than originally allocated, a high utilization means the utilization of all allocated hours (100 percent) or more. If less than half of the allocated hours were used (¡50 percent), this refers to low utilization of therapy. Petrol values indicate a positive correlation (high spatial accessibility and high utilization of therapy). Yellow values indicate low spatial accessibility and low utilization of therapy. The correlation with spatial accessibility and utilization of therapy hours, is weak, negative and not significant (r= -0.0135, $p > 0.05$).

MH3SFCA Method

The MH3SFCA method could be another suitable method for this research project. The method offers the following advantages: supply competition is considered by the demand probability according to the Huff model, constant total demand of each population (not dependent on supply quantity) and distance weights are considered not only relatively, but also absolutely through an additional distance weight in the calculation (Jörg et al., 2019). To compare the two methods would have been beyond the scope of this thesis or would have been at the expense of the content discussion. Nevertheless, in order to get a picture of the method, the three maps of potential spatial accessibility are presented below.

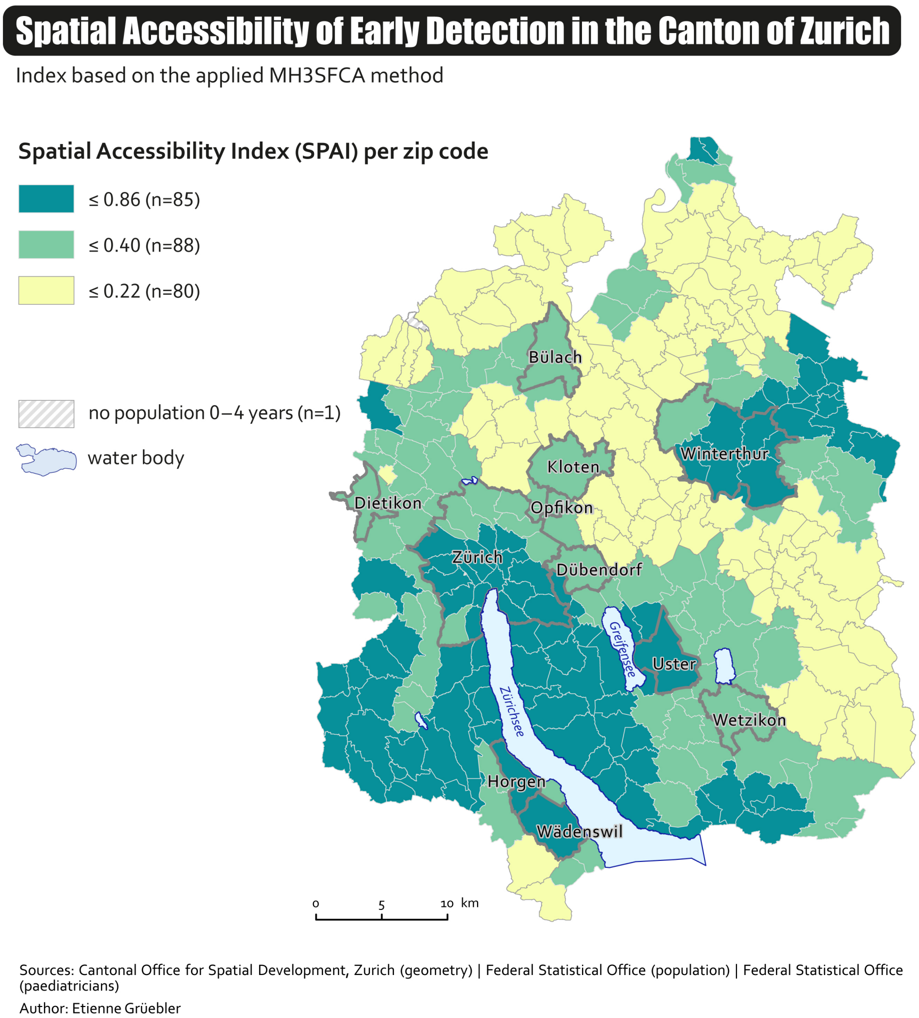

Figure D.2: Spatial Accessibility Index SPAI for total population of preschool aged children (demand) and paediatricians (supply) per zipcode (n = 253), 2017 calculated with the MH3SFCA method. The classification of the values is based on tertiles, since the SPAI values can not be set in relation to the population as in the 3SFCA method and can therefore not be discussed in absolute but in relative terms.

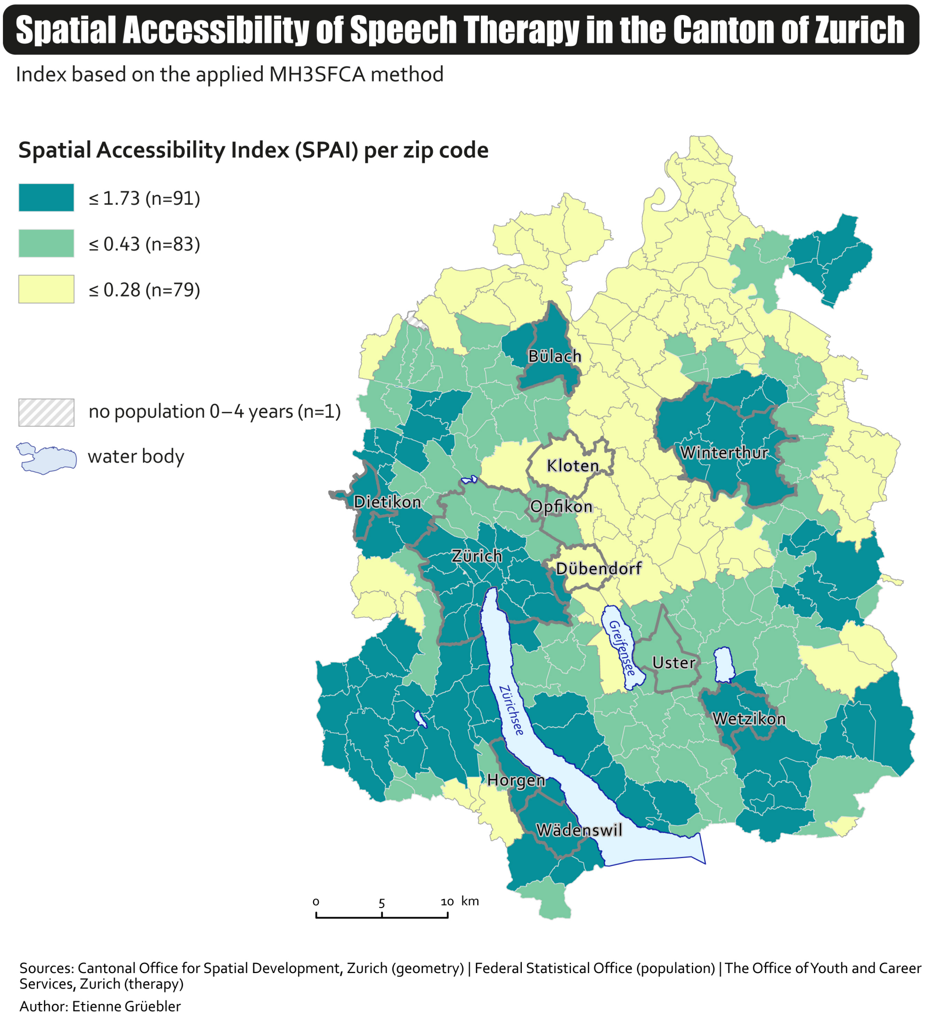

Figure D.3: Spatial Accessibility Index SPAI for total population of preschool aged children (demand) and speech therapy (supply) per zipcode (n = 253), 2017 calculated with the MH3SFCA method. The classification of the values is based on tertiles, since the SPAI values can not be set in relation to the population as in the 3SFCA method and can therefore not be discussed in absolute but in relative terms.

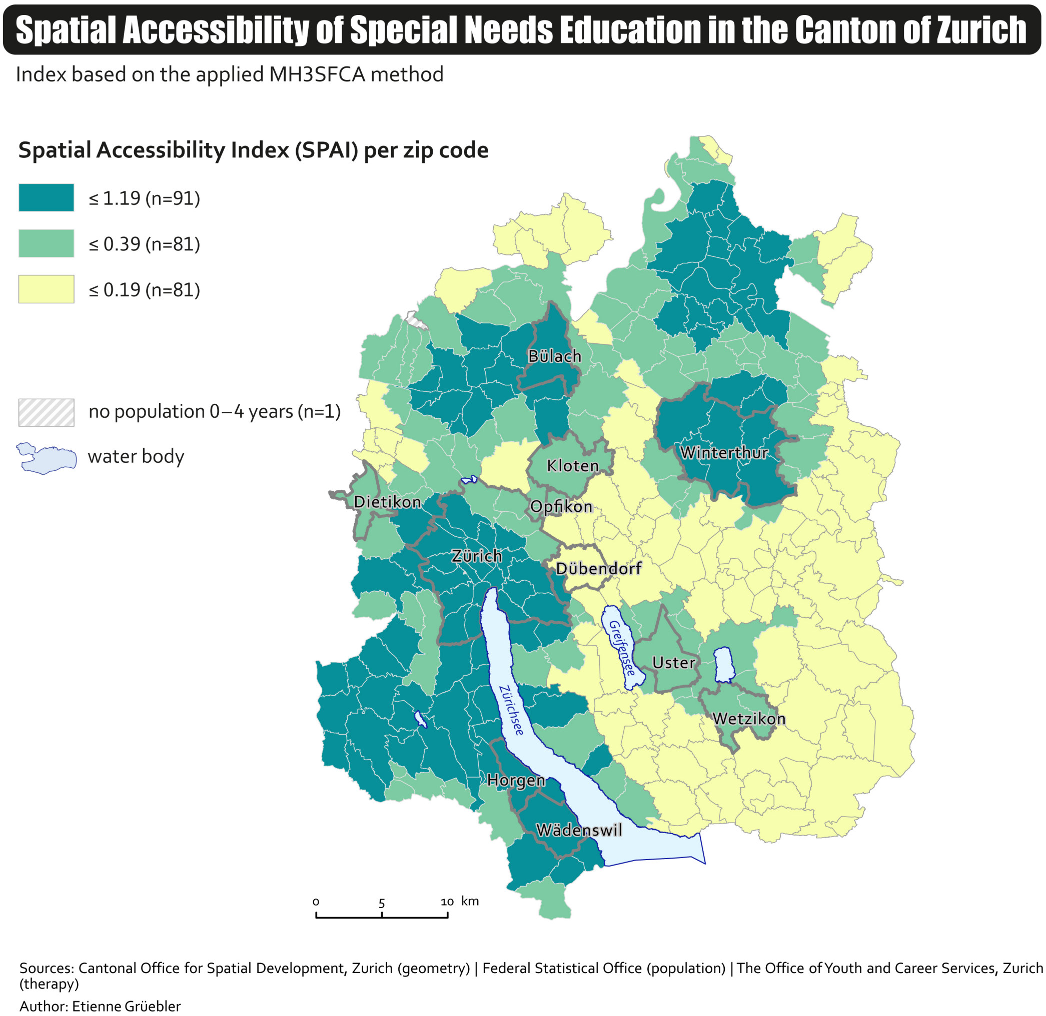

Figure D.4: Spatial Accessibility Index SPAI for total population of preschool aged children (demand) and special needs education (supply) per zipcode (n = 253), 2017 calculated with the MH3SFCA method. The classification of the values is based on tertiles, since the SPAI values can not be set in relation to the population as in the 3SFCA method and can therefore not be discussed in absolute but in relative terms.

Declaration of Authorship

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

Signed: ....