Innovative
Policy Modelling and Governance Tools
for Sustainable Post-Crisis Urban Development

D4.4 Public Services Location Models

Project acronym:	INSIGHT
Project title :	Innovative Policy Modelling and Governance Tools for Sustainable Post-Crisis Urban Development
Grant Agreement number :	611307
Funding Scheme :	Collaborative project
Project start date / Duration:	01 Oct 2013 / 36 months
Call Topic :	FP7.ICT.2013-10
Project web-site :	http://www.insight-fp7.eu/
Deliverable :	D4.4 Public Services Location Models
Issue	1
Date	3/11/2015
Status	Approved
Dissemination Level :	Public

Authoring and Approval

Prepared by		
Name & Affiliation	**Position**	**Date**
Gustavo Romanillos Arroyo	TRANSyT Research Centre. | tGIS research Group | Complutense University of Madrid |Research Associate	28/10/2015
Dra. María Henar Salas Olmedo	TRANSyT Research Centre. | tGIS research Group | Complutense University of Madrid |Research Associate	28/10/2015
Dr. Juan Carlos García Palomares	TRANSyT Research Centre. | tGIS research Group | Complutense University of Madrid |Senior Researcher	28/10/2015
Dr. Javier Gutiérrez Puebla	TRANSyT Research Centre. | tGIS research Group | Complutense University of Madrid |tGIS director	28/10/2015

Reviewed by		
Name & Affiliation	**Position**	**Date**
Dr. Juan Carlos García Palomares	TRANSyT Research Centre. Senior Research Associate	28/10/2015

Approved for submission to the European Commission by		
Name & Affiliation	**Position**	**Date**
Ricardo Herranz (Nommon)	Scientific/Technical Coordinator	3/11/2015
Iris Galloso (UPM)	Management Coordinator	3/11/2015

Record of Revisions

Edition	Date	Description/Changes
Issue 1 Draft 1	30/10/2015	First version of the document
Issue 1	3/11/2015	First version of the document approved for submission to the European Commission

Table of Contents

Executive Summary

This document describes the research developed in the INSIGHT project sub-work *package WP4.4 Public Services Models*, which is framed in the *WP4 Theoretical Modelling* work package. WP4 also includes research on retail models, housing models and housing-retail-public services interaction models.

In the landscape left by the economic crisis, Public Services policies are extremely important but at the same time are dramatically limited. On the one hand, significant negative socio-demographic changes and imbalances, such as the increasing social segregation or the rising economic inequality, must be tackled through policies oriented to fostering public services or improving the existing ones. On the other hand, the economic decline has reduced public resources limiting the launching of these new services and affecting the delivery of the existing ones. In this scenario, the delivery of efficient Public Services is fundamental and the location of public facilities becomes crucial.

The research explores the application of different location models to the four project case studies (Barcelona, London, Madrid and Rotterdam), creating new approaches and methodologies oriented to assisting policy makers and urban planners at some of the *Policy Cycle* stages (defined in the INSIGHT document *D2.2 Urban Planning and governance: current practices and new challenges*), such as the analysis of the current scenario, the definition of policies and measures and the evaluation of future scenarios.

1. Introduction

1.1 Scope and objectives

This research is not focussed on improving existing public service location models but on exploring their application to different case studies in order to create new approaches, tools and methodologies that may be useful to policy makers and urban planners at some of the *Policy Cycle* stages (such as the analysis of the current scenario, the definition of policies and measures and the evaluation of future scenarios) when dealing with public services.

Accordingly, the main objectives are:

- To explore the use of diverse location models in order to analyse the existing public service coverage in the INSIGHT four case studies (Barcelona, London, Madrid and Rotterdam). The analyses have a special focus on the detection of potential social inequalities and spatial imbalances, responding to some of the most important threats over European cities.
- To perform a diagnosis, drawing conclusions from the previous analysis and leading to the adoption of measures.
- To define a set of possible measures oriented to tackle the public service deficiencies or imbalances identified according to the previous diagnosis. These measures will be framed in the current European context, that is to say, they will respond to the austerity policies proper of the European post-crisis scenario.
- To model the application of the defined measures by applying diverse location models.
- To evaluate the impact that the application of these measures would have, estimating the public service coverage of future scenarios.

1.2 Methodology and description of contents

The methodology followed in this research is based on the comparative analysis of the four case studies. They serve as vehicles for exploring new applications of location models in the analysis and modelling of public services and measures.

The content of this report corresponds to the different research objectives:

- Section 2 frames this research in the current European context, describing the important role that location models may play in the delivery of more efficient and balanced public services.
- Section 3 defines the four case studies in detail. It describes the different urban areas and the diverse groups of demand considered. It also introduces the focus on primary education and finally describes the collected data.
- Section 4 analyses the current public service coverage in a comprehensive way. It considers public and private service independently and as a whole, it contemplates the analysis of different urban areas and also the diverse groups of demand previously defined.

- Section 5 evaluates the degree of optimization of current public service coverage in relation to an ideal coverage derived from the optimal location of the existing public facilities. It also reveals to what extent location models may play an important or a modest role in the improvement of the existing service.
- Section 6 defines a set of possible measures to be adopted according to the results obtained from the analyses. The application of these measures is modelled in the four case studies, considering the hypothetical scenario of having to reduce public services and the possible adoption of alternative or complementary measures, such as promoting Public-Private Partnerships (PPPs) or relocating facilities.
- Finally, Section 7 draws some conclusions and highlights the main findings.

2. Public services location models in the current European urban context. Current practices and new approaches

2.1 Public services location models in the current European urban context

In the landscape left by the economic crisis, European cities are currently facing new threats as well as pre-existing problems that have been intensified by the crisis itself or as a consequence of the application of the austerity measures that many countries have adopted in recent years. These problems were identified and described in the INSIGHT document *D2.2 Urban Planning and governance: current practices and new challenges*, being classified into three main threats: a dramatic socio-demographic change (which involves a wide range of problems, from demographic decline to economic polarization and social segregation), an intense economic decline (including problems such as the rising unemployment, the loss of competitiveness or the declining revenues and demand) and an increasing environmental unsustainability (problems such as the depletion of natural resources or the increasing land occupation due to the rapid urban sprawl).

How cities can deal with these problems and threats in this new scenario is a question with no simple responses. On the one hand, important negative socio-demographic changes and imbalances, such as the increasing social segregation or the rising economic inequality, must be tackled through policies and measures aimed at fostering new public services or improving the existing ones. On the other hand, the economic decline has reduced public resources limiting the launching of new services and affecting the delivery of the existing ones. This limitation becomes even more important in European southern countries, where austerity policies have reduced dramatically state budgets and public investments, affecting basic services such as education (Theodoropoulou & Watt, 2011) or health (Brand & Rosenkötter, 2013; Karanikolos et al., 2013), with an increasing number of people unable to access care (McKee, Karanikolos, Belcher, & Stuckler, 2012).

Therefore, it becomes crucial to work on strategies aimed at launching effective public services, adjusting resources. In this sense, planning the optimum location and coverage of public services is one of the most important aspects to consider. It is not only essential in order to define the necessary number of facilities and allocate the corresponding amount of resources. It is also important since the accessibility to public facilities determines the quality of the service or the possibility of choice between different services.

The planning of public services has to deal also with the spatial particularities of cities. In this sense, there are many aspects to take into account that are becoming more and more relevant in order to understand the increasing urban spatial complexity. The rising social polarization is being crystalized in a growing spatial segregation (European Commission, 2010), evidenced in the formation of ghettos by the different immigrants communities, the formation of new gated communities (Colini, Czischke, Güntner, Tosics, & Ramsden, 2013) or in the gentrification processes wide spread across many European cites (Hamnett, 2003). Beside this, other processes, such as ageing population, are also being concentrated in certain urban areas.

Finally, the planning of public services has to tackle an additional problem: the increasing urban sprawl. Since the mid-1950s cities have expanded on average by 78%, whereas the population has grown by only 33% (European Environment Agency, 2006). Urban sprawl affects dramatically the quality of public services since, with a limited budget and a limited number of facilities, the coverage of population within a reasonable distance is not economically viable.

2.2 Location models: current practices and new approaches

Current location models have their origins in the variety of methods of analysis, optimization techniques and mathematical models developed in the1960s and 1970s (Cooper, 1963; Hakimi, 1964, 1965; Rushton, 1979). First location models where classified into two major categories: *location on a plane* and *location on a network* models (Revelle, Marks, & Liebman, 1970). The first category considers an infinite number of solutions in the space and mainly Euclidean distance, the second one just contemplates a number of finite points on a network (nodes and points on the arcs) and distance or time measurement along the network. Although this is still the main classification (together with the similar one that distinguishes between *continuous* or *discrete* models depending on whether the facilities can be located anywhere on the plane or at some points on the plane that are specified in advance), in practical applications, policy makers and planners often rely on discrete-location models instead of continuous ones (García-Palomares, Gutiérrez, & Latorre, 2012; Joao C Teixeira & Antunes, 2008; Yeh & Chow, 1996). Since then, many different classifications have been proposed according to different criteria (Klose & Drexl, 2005). In relation to the solutions, we can distinguish between efficient and equity oriented models (Murray, 2010). The most common model is oriented to solve the so called *p-median problem* (Hakimi, 1965), minimizing the total demand-weighted travel to service facilities. Another approach focusses on solving the *p-centre problem*, with the intent of locating p facilities to minimize the maximum distance from a demand point to its closest facility (Hakimi, 1964, 1965). Another important location model is the so-called *set covering problem* (LSCP), developed by Toregas, Swain, ReVelle, & Bergman, (1971). The model finds the minimum number and location of facilities that guarantee either a standard of service coverage or a range in the context of central place theory, so a minimal set of facilities is proposed such that demand points are responded to or served within a maximum travel time/distance. Shortly after, Church & Velle (1974) improved this model by formulating the maximal coverage location problem (MCLP), in which p facilities are to be sited to maximize demand served within the stipulated standard.

The scope of facility location models rapidly covered both private and public sectors. They share the objective of maximizing some measure of utility while at the same time they must satisfy constraints on demand and other conditions (Revelle et al., 1970) and the main difference is just the way in which the objectives and constraints are articulated. Since the 1990s, but especially in the last 15 years, Geographic Information Systems (GIS) started to integrate some location-allocation models that were widely applied in a range of public and private sector contexts (see Church, 1999, 2002; Hamacher & Drezner, 2002; or review by Murray, 2010). Regarding the public sector, these models have been applied to fire stations (Liu, Huang, & Chandramouli, 2006; Murray & Tong, 2009; ReVelle, 1991), schools (João C. Teixeira, Antunes, & Peeters, 2007), health care facilities (Murawski & Church, 2009; Verter & Lapierre, 2002), recycling depot planning (Valeo, Baetz, & Tsanis, 1998), incinerators (Alçada-Almeida, Coutinho-Rodrigues, & Current, 2009), waste infrastructure (List & Mirchandani, 1991), conservation-reserve planning (Gerrard, Church, Stoms, & Davis, 1997), etc. When it comes to the private sector, location models have been frequently applied in franchise establishments, banking (Min & Melachrinoudis, 2001), the place of cellular tower or wireless infrastructure (Grubesic & Murray, 2002), etc.

These and other applications of location models in different fields have been constantly growing over the last years offering a wide range of solutions to location problems (Hillier, 2010). However, the scope of most of these applications is narrowed to solve a specific location problem. The purpose of this research is to extend this perspective and explore the application of different location models to different case studies and at different stages of the *Policy Cycle* (such as the analysis of the current scenario, the definition of policies and measures and the evaluation of future scenarios) so that they can become useful tools for policy makers and urban planners.

3. Definition of the case studies

3.1 Introduction to the four case studies: Barcelona, London, Madrid and Rotterdam

INSIGHT works on four case studies: the cities of Barcelona, London, Madrid and Rotterdam. They have been chosen not only because they are major cities of the partners' corresponding countries but also because they are complex and diverse enough to make possible the variety of analysis and model tests needed in this project. These four cities are significantly different in terms of population, extension and density. Their urban fabric is also diverse and rich, with important historical centres, expansion districts and a spread peripheral development. They also present different socio-demographic profiles and they vary in terms of economic activity, which affects important aspects such as the distribution of land use and the transport patterns.

In the context of this research, this variety makes it possible to explore a wide range of aspects and draw conclusions by comparing the results. For instance, what would be the different consequences of applying the same policy in the different cities? What would be the resulting accessibility to a specific public service when reducing the number of facilities by a 10%, in each of the four cities? How would this affect the population living in the city centres or the one living in the periphery? Would the different groups of demand be equally covered?

3.2 Definition of the study urban areas

When trying to carry out comparative analysis between cities, one of the first issues to come up is the spatial delimitation of the urban areas. Changing their boundaries has a direct impact on the results (Goodchild, 2009) and these boundaries have become completely blurred and diverge according to different criteria. This issue is part of the well-known *Modifiable Areal Unit Problem* (MAUP), defined by Kendall (1939) and discussed in-depth in the 90s (Bivand, 1998; Griffith, 1992).

The difficulties to set a clear definition of what is an urban area led to a growing concern on reaching a common agreement within the research arena. Whilst population thresholds have been frequently suggested as a proxy to define urban areas, they are far from being able to synthesize what an urban area comprises in terms of land use mix and complex relationships. Even when an agreement on population thresholds has been set to categorize cities, this is only valid for a certain spatial framework since the size of what it is considered a metropolitan area or a city varies across space depending on the size of the other settlements of the urban network.

In order to overcome this problem and guarantee as much as possible the comparability of the results, INSIGHT has adopted some of the urban areas already defined by different institutions in the European framework, currently in use since they are the result of sound studies and expertise. These institutions are the largest European-wide public geo-referenced data providers: the Geographic Information System at the Commission (GISCO), the European Environment Agency (EEA) and the European Observation Network, Territorial Development and Cohesion (ESPON).

GISCO, the geographic extension of EUROSTAT, contains the geographic data of reference for geo-referencing official statistics, thus enabling spatial analysis. In addition to the administrative boundaries and transport networks, there are a few thematic datasets which include data related to urban areas. Among them, there are two versions of the Urban Audit definition of urban areas (2001 and 2004). Urban Audit is a data collection system that provides information of a selection of European cities from different institutions. The spatial definition of these cities includes the core area (i.e. the central municipality or equivalent LAU2 administrative unit) and the *Large Urban Zone* (LUZ), comprising the functional urban area. The latter includes the commuting area within each metropolitan area.

The EEA provides spatial datasets that are of interest for environmental issues, for which urban areas are of particular concern. For this reason, its data repository includes land use cartography of urban areas at a larger scale than the seamless land use / land cover databases. There are two datasets of this type. On the one hand, the *Urban Morphological Zones* (UMZ) consists on the delimitation of urban areas. These polygons were built upon the categories of artificial land cover in the Corine Land Cover dataset when a set of urban areas lay less than 200m apart. On the other hand, the EEA also contains the Urban Atlas, which provides land use and land cover data *for Large Urban Zones* (LUZ) over 100,000 inhabitants, as defined by Urban Audit.

Finally, the ESPON provides extensive territorial data and information built from in-depth research projects. The ESPON 2013 Database contains a) the cartography and some basic indicators of the above-mentioned *Urban Morphological Zones* (UMZ) over 10,000 inhabitants; b) the cartography and population of the *Morphological Urban Areas* (MUA) over 20,000 inhabitants and their corresponding labour basins (*Functional Urban Areas* (FUA), and c) a report on Urban Audit's *Large Urban Zones* (LUZ).

INSIGHT aims at analysing and modelling urban patterns that happen in different parts of metropolitan areas with the use of a mixture of traditional statistics and new available data (i.e. big data). This poses an issue on the typical trade-off between the desired spatial coverage and its resolution, since usually the larger the spatial coverage, the smaller and less homogeneous the data available.

Both the UMZ and MUA delimitate areas that are tighter to the city centre, in some cases appearing several of these units within a single LUZ or FUA. The MUZ are strictly based on continuous artificial land use in the moment to which they refer, which makes boundaries extremely linked to the physical layout. On the contrary, MUAs are defined in terms of population density and have smoother and more constant boundaries.

In most cases, the LUZ and FUA spatial datasets cover the whole metropolitan area extensively, with the inclusion of marked rural areas in some cases, like in Madrid. The main difference between them is that whilst the criteria for the spatial definition of each LUZ was slightly adapted to each city, the ESPON DB project applied a common criteria to define all the FUAs, thus minimizing the comparability issues of the LUZs. Other factors to be taken into account are the usually largest size of each FUA and the widespread use of LUZs within different institutions.

The decision on the optimal spatial delimitation of the study areas has been discussed and agreed among all INSIGHT partners. Considering a trade-off between the objectives of the project, comparability, data availability, and the computation requirements needs to be reached, our general proposal is to use the LUZ for Madrid and London, and the FUA for Rotterdam and Barcelona. This choice ensures comparability within INSIGHT study areas (between the capital cities and between the second-tier cities separately), and also with previous and further research in the European framework. In any case, we agreed that this decision could be revised according to the specific characteristics of each research conducted in the project.

Actually, in the specific context of this research, the adopted urban area for the four study cases has been the *Multifunctional Urban Area* (MUA), which defines a dense and coherent morphological whole that fulfil the criteria of 20,000 inhabitants and a minimum density of 650 inhabitants/km^2. The main reason was the availability of data at the level of disaggregation we considered necessary. In the four study cases, the extension of the FUA and the LUZ areas did not allow us to obtain the location of public facilities at a point level (X,Y coordinates) and reduced considerably the level of disaggregation of socio-demographic data.

Apart from the MUA, we have considered the analysis of the municipal areas (the NUTS-5 level according to the ESPON database) in order to perform additional and independent analysis for this central area and for the peripheral one within the MUA. This supplementary analysis may reveal important information about the different accessibility to public services in such areas. The cause of these potential differences is part of the goals of this research.

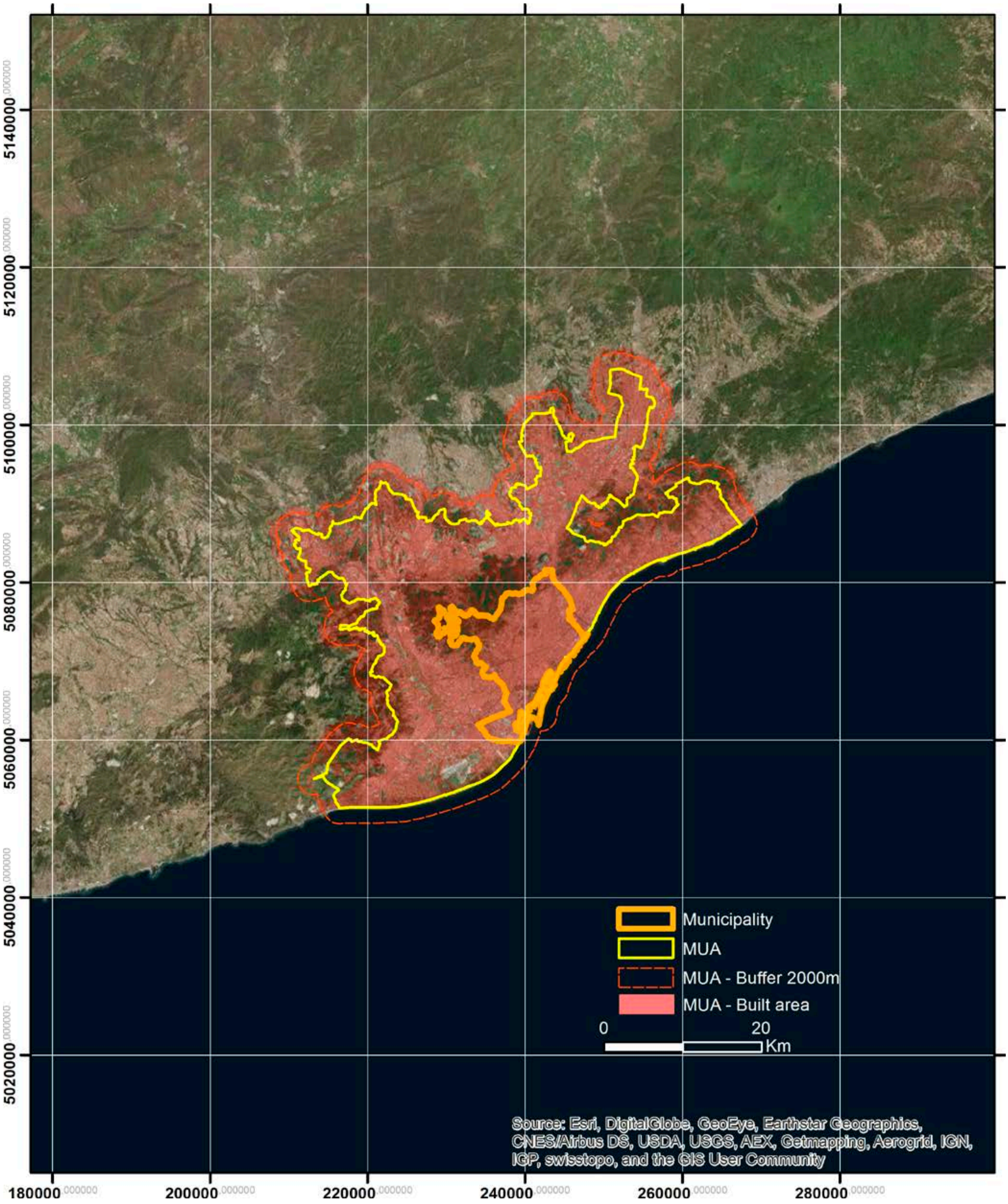
Finally, another area has been defined as a 2,000 m buffer of the MUA. This area corresponds to the extent of the road network defined for running the different analysis, avoiding errors in the peripheral areas of the MUA when calculating network distances.

The next table shows some basic information (population, area and population density) related to the different urban areas considered, according to different data sources that will be described in detail in the next section. Then, different maps are provided with the aim of illustrating the extent of the different areas for the four case studies at the same scale.

Table 3.1. Population, area and population density of the case studies according to the different urban areas

Data description	Barcelona	London	Madrid	Rotterdam
Population MUA	3,686,816	9,410,522	5,734,288	1,050,890
Area MUA (km^2)	1,227	6,001	3,500	1,157
Density MUA (Pop/ km^2)	3,004	1,568	1,638	908
Population Municipality	1,636,270	8,136,261	3,268,346	620,195
Area Municipality	176	4,110	1,046	856
Density Municipality (Pop/ km^2)	9,284	1,979	3,124	725
Population MUA - Periphery	2,050,546	1,274,261	2,465,942	430,695
Area MUA - Periphery	1,051	1,891	2,454	302
Density MUA - Periphery (Pop/ km^2)	1,951	674	1,005	1,428

Figure 3.1. Barcelona case study urban areas



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3.2. London case study urban areas

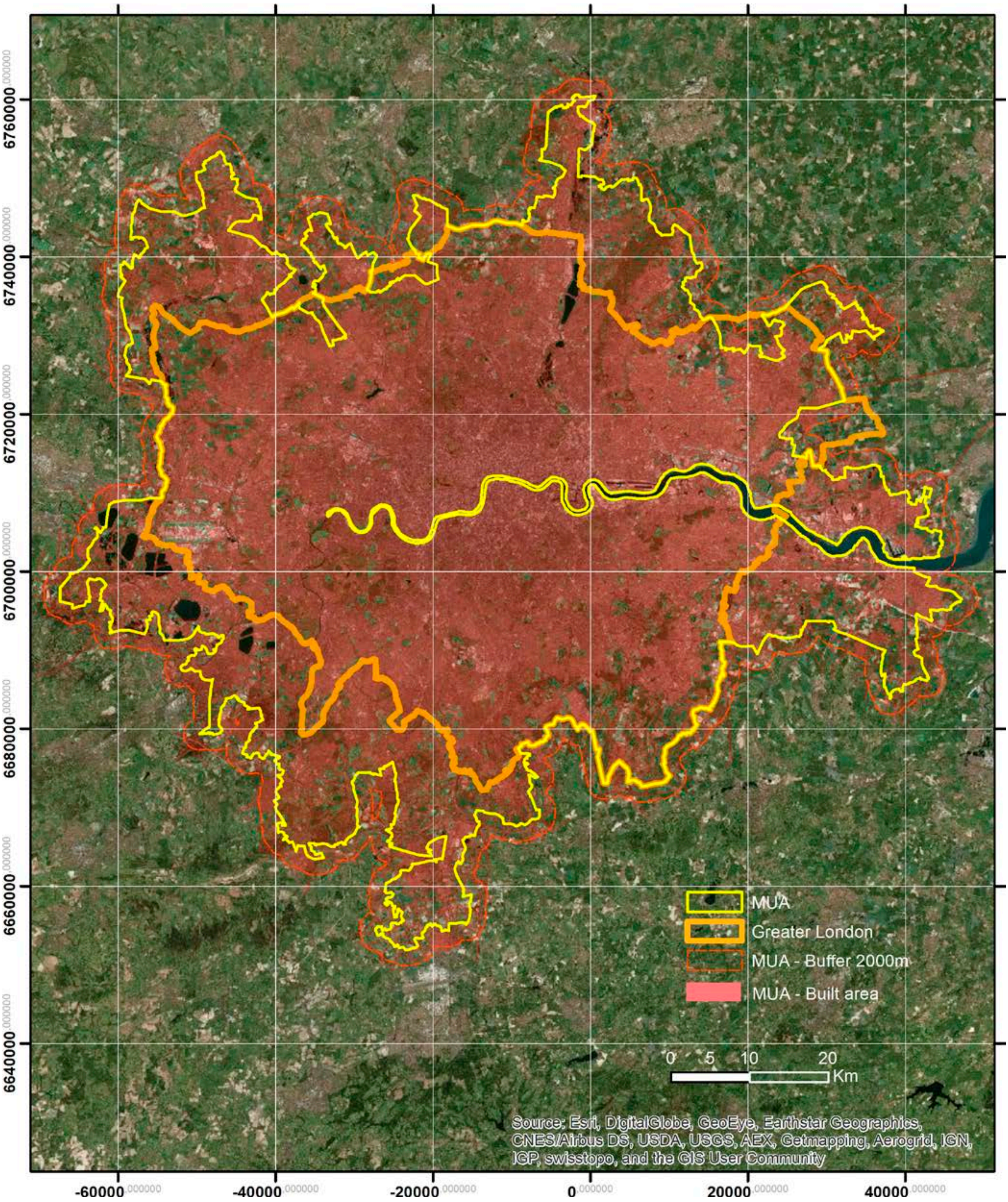
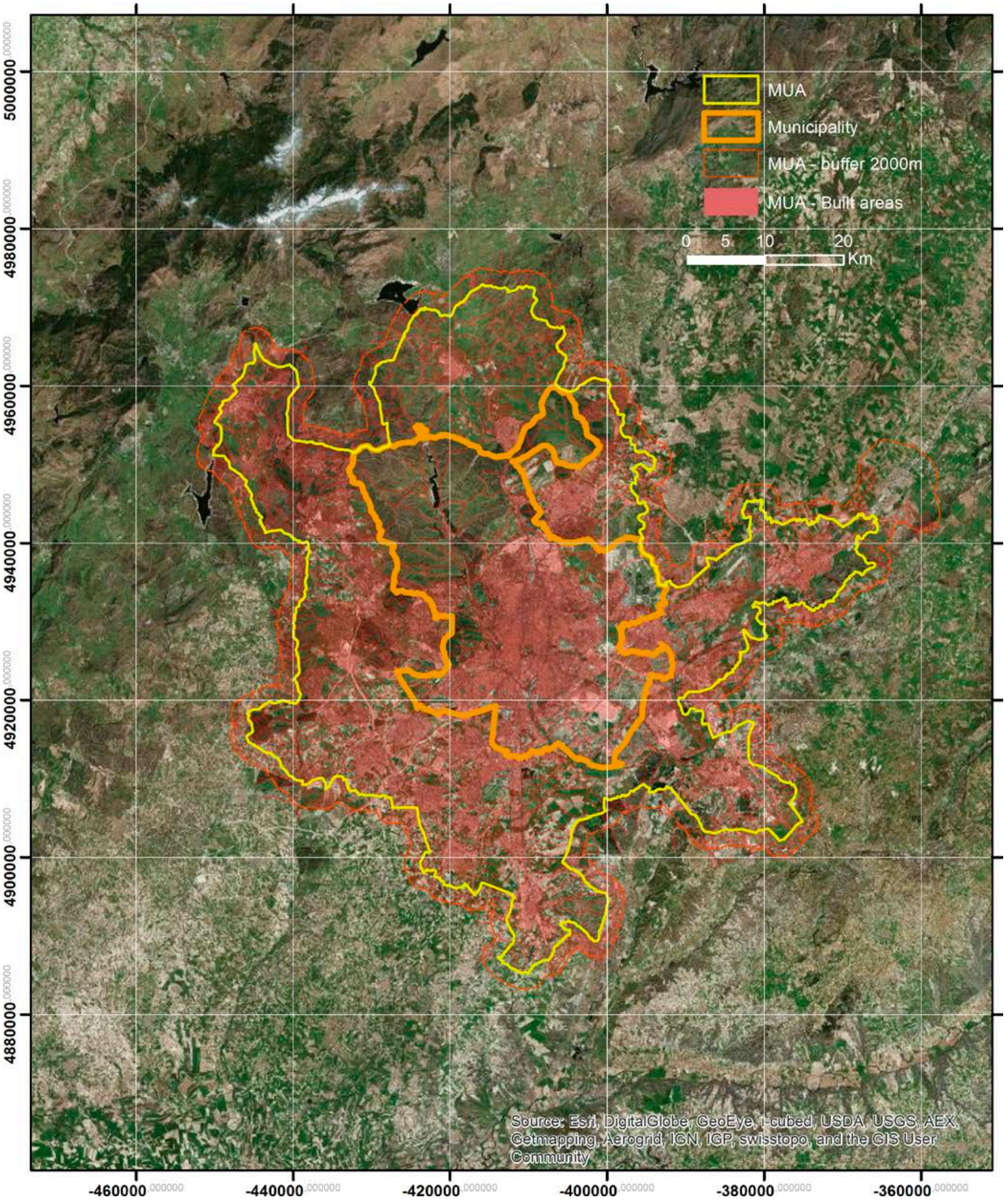
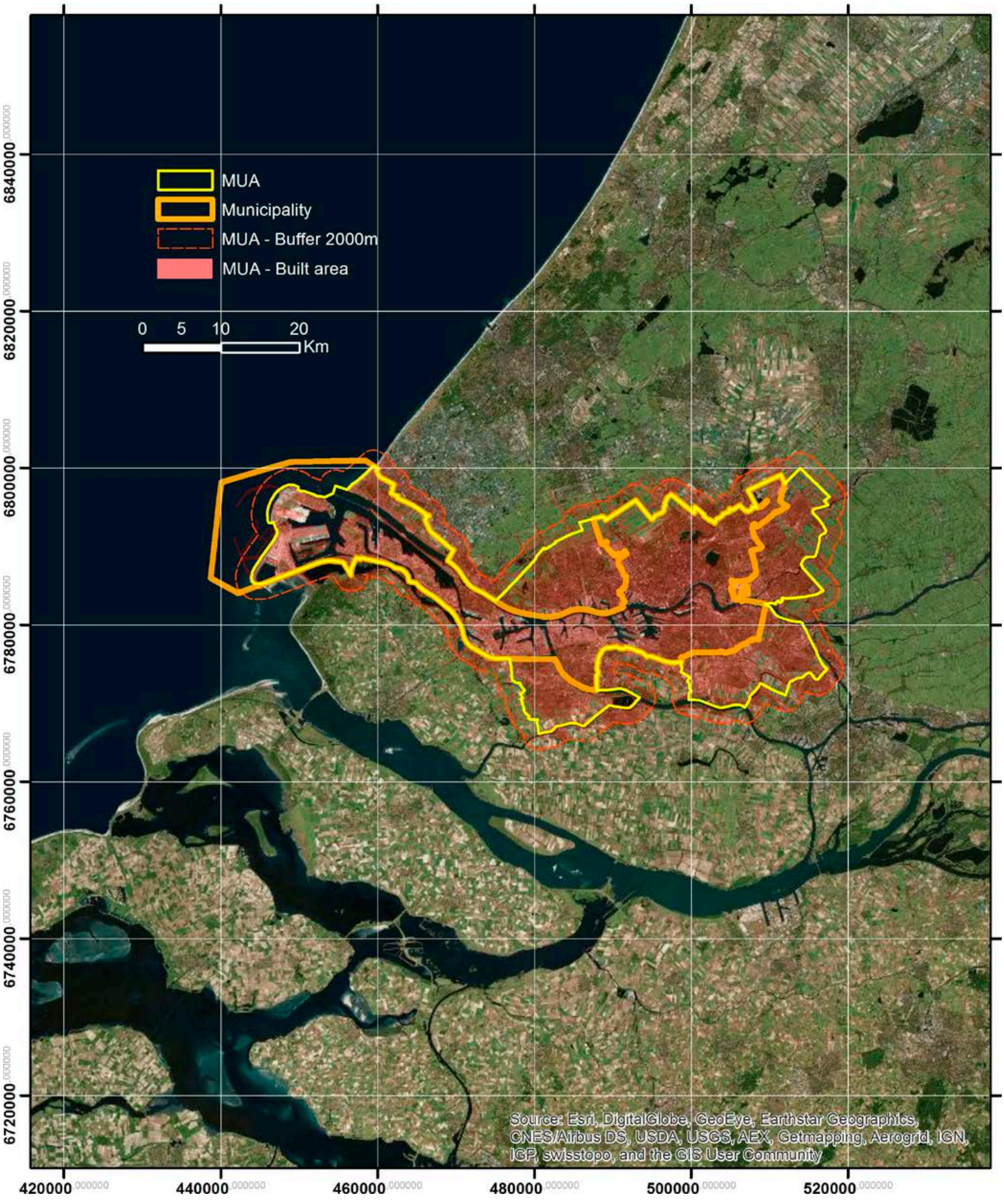


Figure 3.3. Madrid case study urban areas



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3.4. Rotterdam case study urban areas



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

3.3 Definition of the four specific case studies

3.3.1 Focussing on a public service: Education and the location of primary schools

As mentioned in Section 2, the location of facilities is one of the most important aspects that determine the quality of public services. It is crucial not only because it defines the service coverage but also because the way these services cover the different groups of demand can affect existing negative trends related to the major urban threats and problems previously identified, such as social cohesion or economic polarization.

This research is focused on just one public service that is relevant in the current urban context considered in INSIGHT and suitable for the kind of analysis and methodologies we would like to carry out with the aim of transferring them to other public services. Considering this, we have decided to focus on public education, more specifically on primary schools, for different reasons.

First, education is not only one of the fundamental public services (as well as health), but it also has a big impact on public budgets, which makes it vulnerable and questioned in times of economic crisis (Bedi & Garg, 2000).

Second, we looked for a public service representative of the ones that affect and are currently affected by the different major identified threats, feeding a circular dynamics. In many countries the economic decline led to cutting the budget of public education and this fact can definitely reduce the quality of public schools, affecting specially the groups of population that cannot afford private education, reducing their future opportunities in the labour market. This fact will directly increase even more the current social imbalance, which is another of the major existing urban threats. This example was already studied and documented more than two decades ago (Brewer, Eide, & Ehrenberg, 1999) and also recently. For instance, according to Ashley, Duberley, Sommerlad, & Scholarios (2015), the most top rated jobs in the United Kingdom still remain mainly accessible to the minor wealthy class that has studied in private schools, and the same trend is supposed to occur in a more dramatic way in other countries that have been more affected by the economic crisis.

Finally, this research focuses on the study of public services location, and the optimal spatial distribution of primary schools is fundamental in order to guarantee the quality of the service. Children go to school every working day (with the corresponding impact on urban mobility) and more and more cities are planning the construction of public schools so that they can be reached by walking a reasonable distance (McDonald, 2008). Actually, distance to school is one of the parent’s determining criteria when selecting a school, together with the academic performance (Ibrahim, Osman, & Bachok, 2014). In contrast, location and the distance criterion are not that important when selecting other less frequented public facilities, such as hospitals or health centres.

3.3.2 Analysing the coverage of public and private schools

This research aims at analysing public services locations in a comprehensive way, looking into the way a specific distribution of public facilities may affect some existing major problems. One of these problems is the increasing economic imbalance and the growing social segregation. Because of this, this study extends the analysis of public schools to private ones, in order to guarantee a more complete understanding of the existing educational coverage.

Analysing the different coverage of public and private schools may reveal important information. The study of the public/private ratio may inform about the level of dependency on the public system while the analysis of public/private schools location may confirm a spatial segregation, or may simply reveal the private coverage or certain areas that seemed to be uncovered. Apart from this, the number and location of private schools will be also important when modelling future possible scenarios, since we will analyse the possibility of promoting Public-Private Partnerships (PPPs) and its consequences (Section 6).

In any case, some caveats must be considered when classifying schools in diverse countries. The education systems in the Netherlands, the United Kingdom and Spain are different when distinguishing public and private centres, so it is necessary to highlight the main dissimilarities in order to better understand the results of the analysis contemplated in the following sections:

- In Spain there are basically three types of primary schools: public, private and other privately managed schools that receive public funds ("escuelas concertadas" or "concerted schools"). Although these concerted schools are not free, the tuition fees are not high compared to the private schools average. In any case, they are considered as private in this research, since the database from the regional department of education did not make any difference between private and concerted schools.

- The UK distinguishes many more types (Private-Independent schools, free schools, community schools, Voluntary Aided schools, Voluntary Controlled schools, Foundation Schools and Academy schools). The UK Department for Education database used in this study finally simplifies this classification, but the significantly low number of private schools considered in London is probably due to this simplification of its more complex classification.

- Finally, although all primary schools in Netherlands ("basisschool") are funded by the government, only approximately one third of them are run under the authority of the municipality and are not based on any particular religion or conviction ("openbare" schools). The remaining two thirds of the schools are "denominatie" schools, related to a particular religion or conviction (such as Roman Catholic, Protestant, Muslims, etc.). Because of this, the analysis of Rotterdam will be based on this distinction and not on the public-private one, considering that, in any case, it may be relevant in terms of social segregation (religion-based instead of capital based in this case).

The next table shows the basic figures of public and private schools for each of the four cities.

Table 3.2. Basic figures on public and private primary schools in the four case studies

Data description	Barcelona	London	Madrid	Rotterdam
Public schools / Openbare schools*	505	2.094	635	114*
Private schools / Denominatie schools*	325	507	454	193*
Total number of schools	830	2.601	1.089	307
Public schools (% over total)	60.84%	80.51%	58.31%	37.13%*
Private schools (% over total)	39.16%	19.49%	41.69%	62.87%*

3.3.3 Defining different groups of demand

The location of demand is the most important variable when planning the distribution of any kind of facility. Since different public services are required by diverse groups of population, the characterization of demand is crucial when planning the location of the different facilities and estimating their corresponding specific demand.

Though the definition of target groups of demand has been traditionally more considered in the private sector than in the public one (Deacon, 1978), location models for both sectors have already been improved by the introduction of different groups of demand (Berman, Drezner, & Wesolowsky, 2001).

In the context of this research, we have distinguished three different groups of demand:

1. **Total population (P_P)**: this group of demand corresponds to the total population regardless their age, gender or whatever socio-economic condition.

2. **Target population (P_T)**: this group of demand is defined by a target population according to their age, selecting only children within the range of age that corresponds to primary school. This range of age varies in the three different countries: in Spain primary students are aged between 6 and 12, in the Netherlands between 4 and 12, and in the United Kingdom between 5 and 11.

3. **Vulnerable population (P_V)**: this group of demand corresponds to the most vulnerable population in socio-economic terms. With the aim of making the analysis of the four cities as much comparable as possible, our intention was to define the vulnerable population according to the same set of criteria for each city. However, the availability of socio-economic data at the level of disaggregation needed for the analysis, made us to simplify the characterization and use just one single criterion: the unemployment rate, with the exception of Rotterdam, where this data was not available. In this case we selected the vulnerable population according to an economic criterion: the average price of housing.

   Since unemployment rates vary significantly in the four cities, the ‘vulnerability threshold’ was not the same for each of them. Vulnerable people were defined as the 25% of population with higher rate of unemployment. Thus, in Barcelona, vulnerable population was defined as the one whose unemployment rate was over 28.0%, in the case of London over a 10.2% and finally, in the case of Madrid over a 15.1%. In the case of Rotterdam, vulnerable people was defined as the one with the 25% lowest housing value, resulting in those whose house’s price was under 143,251 euros.

A better characterization of demand would result in more accurate outputs from the analysis, but major differences are not expected, since we think the selected criteria are significant enough. Anyway, one of the purposes of INSIGHT is dealing with new and non-conventional data sources, so further analysis could incorporate other data with enough spatial resolution. At the moment of this research, the exploration of these new data from different sources such as Twitter, Panoramio or credit card transactions data from the BBVA bank, is not revealing significant information for the particular characterization of primary school demand.

The next table shows the total and target demand that correspond to public and private primary schools. Vulnerable demand is not included, since it has been simply defined as a % of the total population.

Table 3.3. Total and target demand by public and private primary school in the four case studies

Data description	Barcelona	London	Madrid	Rotterdam
Public schools	505	2.094	635	114
Private schools	325	507	454	193
Total number of schools	830	2.601	1.089	307
Population MUA	3,686,816	9,410,522	5,734,288	1,050,890
Population by public school	7,301	4,494	9,030	9,218
Population by private school	11,344	18,561	12,631	5,445
Population by school	4,442	3,618	5,266	3,423
Target population MUA	242,506	769,318	349,675	81,637
Target population/total population	6.58%	8.18%	6.10%	7.77%
Target population by public school	480	367	551	716
Target population by private school	746	1.517	770	423
Target population by school	292	296	321	266

3.4 Data collection

In order to carry out different comparative analysis between case studies and run models on different cities, we have created a common database for the project INSIGHT. Described in the deliverable *D3.1 INSIGHT Integrated Database*, the database works as a repository in which different data from the four case study cities have been uploaded to an online platform, making it available to the different partners. The database includes some basic cartographic data (transport networks, built environment, land use, etc.) as well as other socio-demographic and economic data.

Additionally, this research required the collection of more complementary data from different European, national and local sources, in order to have the level of detail and disaggregation needed for the specific analysis carried out here.

The next tables provide a description of the different data collected for each case study, identifying the corresponding data sources, type of data and level of disaggregation. Finally, Figure 3.5 provides an example of the collected data, by illustrating the population data in London, over 30,000 population points, which gives an idea of the level of disaggregation required for the analyses carried out.

Table 3.4. Description of Barcelona data

Description of data	Source	Year	Level of disaggregation	Type
Population by age and gender	Regional census / Statistical Institute of Catalonia	2011	Census areas	Table
Active population by age and gender	Regional census / Statistical Institute of Catalonia	2011	Census areas	Table
Unemployment by age and gender	Regional census / Statistical Institute of Catalonia	2011	Census areas	Table
Census areas	Statistical Institute of Spain (INE)	2011	Census areas	Shapefile
Road network	Cartociudad initiative / The Ministry of Public Works and Transport, Spain	2012	Continuous data	Shapefile
Primary Schools: Public and private	Idescat / Statistical Institute of Catalonia	2012	Point data (x,y coordinates)	KML
MUA boundary	ESPON	2007	-	Shapefile
Municipal boundary	ESPON	2007	-	Shapefile

Table 3.5. Description of London data

Description of data	Source	Year	Level of disaggregation	Type
Population by age and gender	National Census/ England and Wales	2011	Output census areas (OA)	Table
Active population by age and gender	National Census/ England and Wales	2011	Output census areas (OA)	Table
Unemployment by age and gender	National Census/ England and Wales	2011	Output census areas (OA)	Table
Census areas	National Census/ England and Wales	2011	Output census areas (OA)	Shapefile
Road network	Open Street Map	2015	Continuous data	Shapefile
Primary Schools: Public and private	Department for Education / UK	2012	Point data (x,y coordinates)	KML
MUA boundary	ESPON	2007	-	Shapefile
Municipal boundary	ESPON	2007	-	Shapefile

Table 3.6. Description of Madrid data

Description of data	Source	Year	Level of disaggregation	Type
Population by age and gender	Regional census / Statistical Institute of Madrid	2011	Census areas	Table
Population by age and gender	Register of inhabitants / Statistical Institute of Spain (INE)	2013	Census areas	Table
Active population by age and gender	Register of inhabitants / Statistical Institute of Spain (INE)	2013	Census areas	Table
Unemployment by age and gender	Register of inhabitants / Statistical Institute of Spain (INE)	2013	Census areas	Table
Census areas	Statistical Institute of Spain (INE)	2011	Census areas	Shapefile
Road network	Cartociudad initiative / The Ministry of Public Works and Transport, Spain	2012	Continuous data	Shapefile
Primary Schools: Public and private	Nomecalles initiative / Statistical Institute of Madrid	2013	Point data (x,y coordinates)	KML
MUA boundary	ESPON	2007	-	Shapefile
Municipal boundary	ESPON	2007	-	Shapefile

Table 3.7. Description of Rotterdam data

Description of data	Source	Year	Level of disaggregation	Type
Population by age and gender	Centraal Bureau voor de Statistiek (CBS)	2014	Grid 100x100m	Shapefile
Population by age and gender	Centraal Bureau voor de Statistiek (CBS)	2014	Postcode 4 level	Table
Postcode areas	Centraal Bureau voor de Statistiek (CBS)	2014	Postcode 4 level	Shapefile
Average value of dwellings in euros	Basisregistraties Adressen en Gebouwen	2014	Census areas	Shapefile
Road network	Open Street Map	2015	Continuous data	Shapefile
Primary Schools: Public and private	Dienst Uitvoering Onderwijs / Ministerie van Onderwijs, Cultuur en Wetenchap	2015	Point data (x,y coordinates)	Table
MUA boundary	ESPON	2007	-	Shapefile
Municipal boundary	ESPON	2007	-	Shapefile

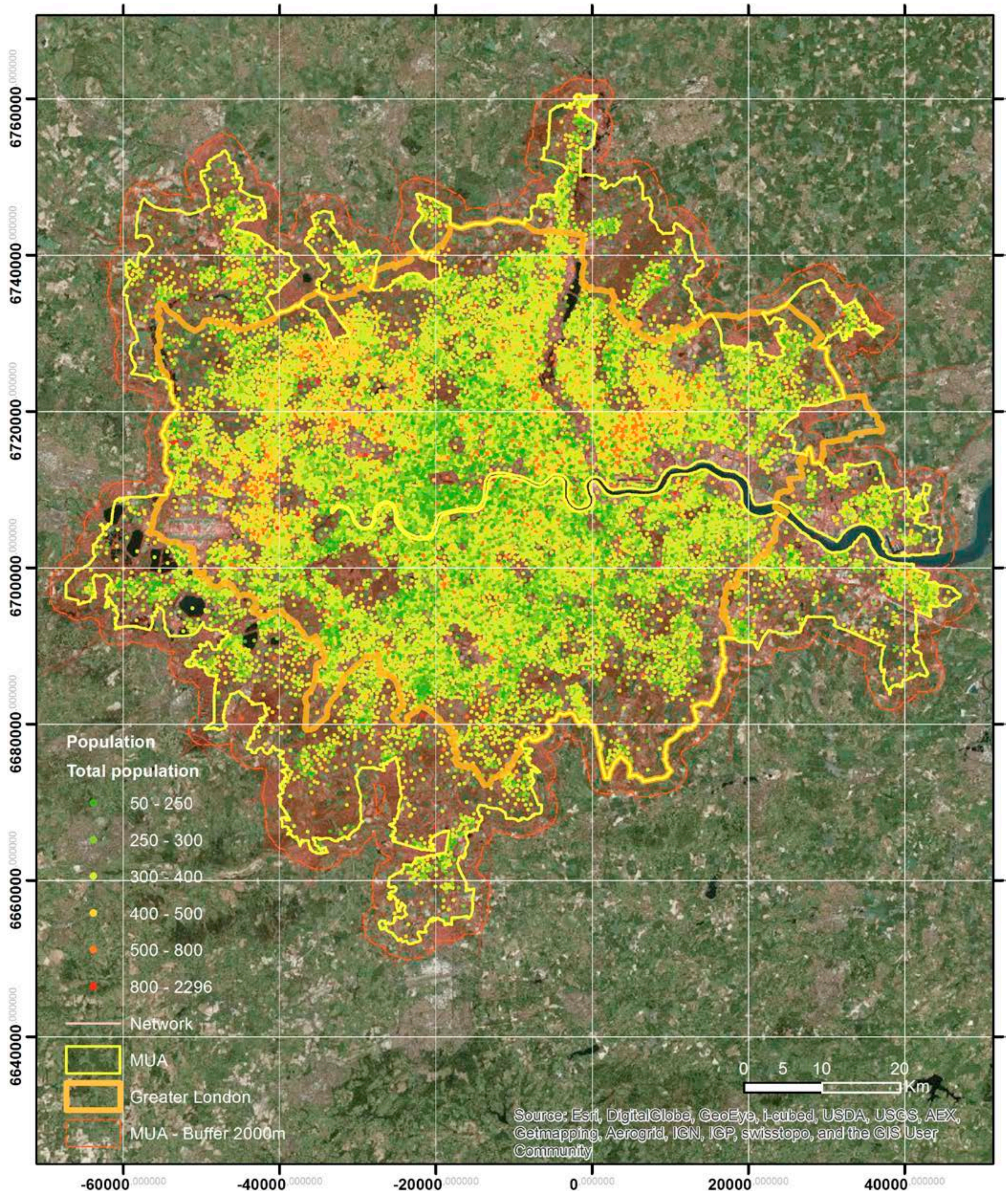


Figure 3.5. Example of data collection: Population point data in London

4. Analysis of existing public services coverage

4.1 Analysing public services coverage

The goal of public services location models is to estimate the best distribution of public facilities, that is to say, the one that provides the best possible spatial coverage with a specific number of facilities. Since in most of the cases, location models are applied to existing urban scenarios, they aim at improving the present service coverage. The analysis of this existing service coverage becomes then crucial in order to find possible deficiencies or imbalances, the ones than will have to be considered and tackled by the location models. The absence of a comprehensive analysis may lead to define policies that probably will not tackle the real problems in the best possible way. The definition of a general policy (for instance, reducing the budget, closing or privatizing 10% of public schools) would affect diverse groups of population in a very different way, or it can have different consequences in certain urban areas. Only an analysis as comprehensive as possible can guarantee that the location of public services and resources is the optimum to face possible existing negative trends.

This section aims at analysing the existing coverage of primary schools in the four case studies with three different objectives. The first one is to evaluate the quality of service in relation to service closeness and choice. The second objective is to find the mentioned possible deficiencies or inequalities. For this reason, the analysis is extended to the coverage of public and private schools, the coverage of different urban areas and the coverage of different groups of population. Finally, the third objective is to compare the results of the four cities, and analyse the similarities and disparities considering their different nature in size, population, density, urban fabric and resources.

The existing service coverage is analysed by measuring the accessibility of the different groups of demand to the existing facilities. We have estimated the population minimum distance to the service, which has been calculated as the network distance to the closest facility by using the *Find Closest Facility* tool within the *Network Analyst* extension of the software ArcMap 10.3 (ESRI). This tool uses the well-known Dijkstra's algorithm for finding shortest paths (Dijkstra, 1959). We have built the network considering just pedestrian mobility, excluding non-pedestrian roads such as highways, and introducing as impedance the street length (metres). Finally, in order to avoid border effect errors in the calculations of the peripheral areas (real shortest paths missing because of network discontinuities), the network has been extended 2,000m out of the MUA.

Different graphs illustrate the accumulated population by distance, instead of population by distance, since they provide the information commonly managed in location policies (number of total people covered in a certain distance). Apart from the graphs, average distance to primary schools and different indexes are calculated, so that a quantitative comparison regarding the different degrees of coverage is provided. Specific distances and indexes are calculated regarding the coverage of public and private schools, the coverage of different urban areas and the coverage of different groups of population. The different indexes are described in the next sections.

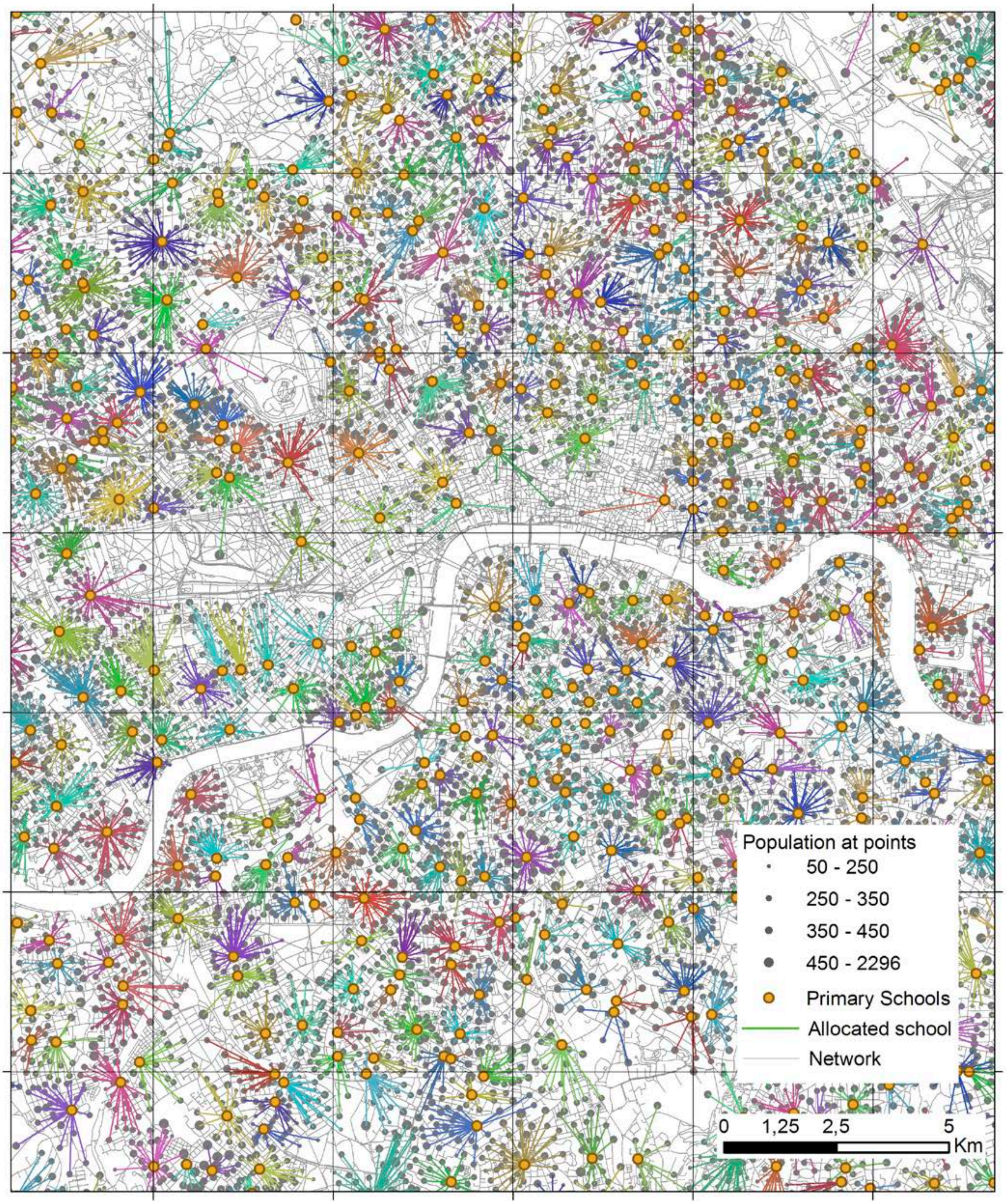


Figure 4.1. Existing location of primary schools in central London and allocated demand

4.2 Analysis of public and private schools coverage

This section analyses the coverage of public and private primary schools through different graphs and by calculating the next indexes:

- δ_{Pu}: Average distance to a public primary school, estimated as:

$$\delta_{Pu} = \frac{\sum_i \mathrm{P}_{Pi} \, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- δ_{Pr}: Average distance to a private primary school, estimated as:

$$\delta_{Pr} = \frac{\sum_i \mathrm{P}_{Pi} \, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- δ_{S}: Average distance to a primary school, estimated as:

$$\delta_{S} = \frac{\sum_i \mathrm{P}_{Pi} \, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- I_{SP}: Index of primary schools coverage in relation to public primary school coverage. This index compares the different distances to the closest primary schools between the population who can afford private education and the one that depends on the public one, reflecting possible imbalances. The smaller the value is, the greater the coverage imbalance. The maximum value would be 1 in the case of the absence of private facilities. The index is estimated as:

$$I_{SP} = \frac{\delta_S}{\delta_{Pu}}$$

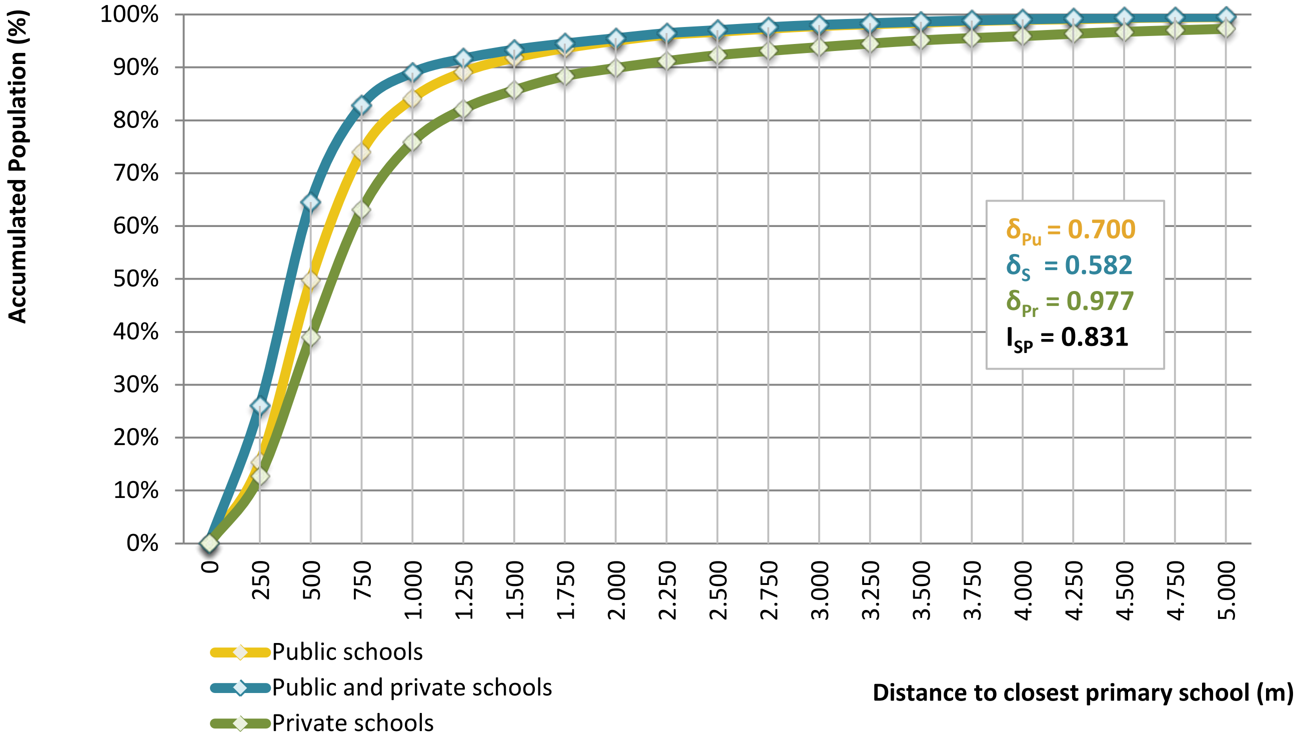
Considering:

P_{Pi}: Total population (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j) in the MUA.

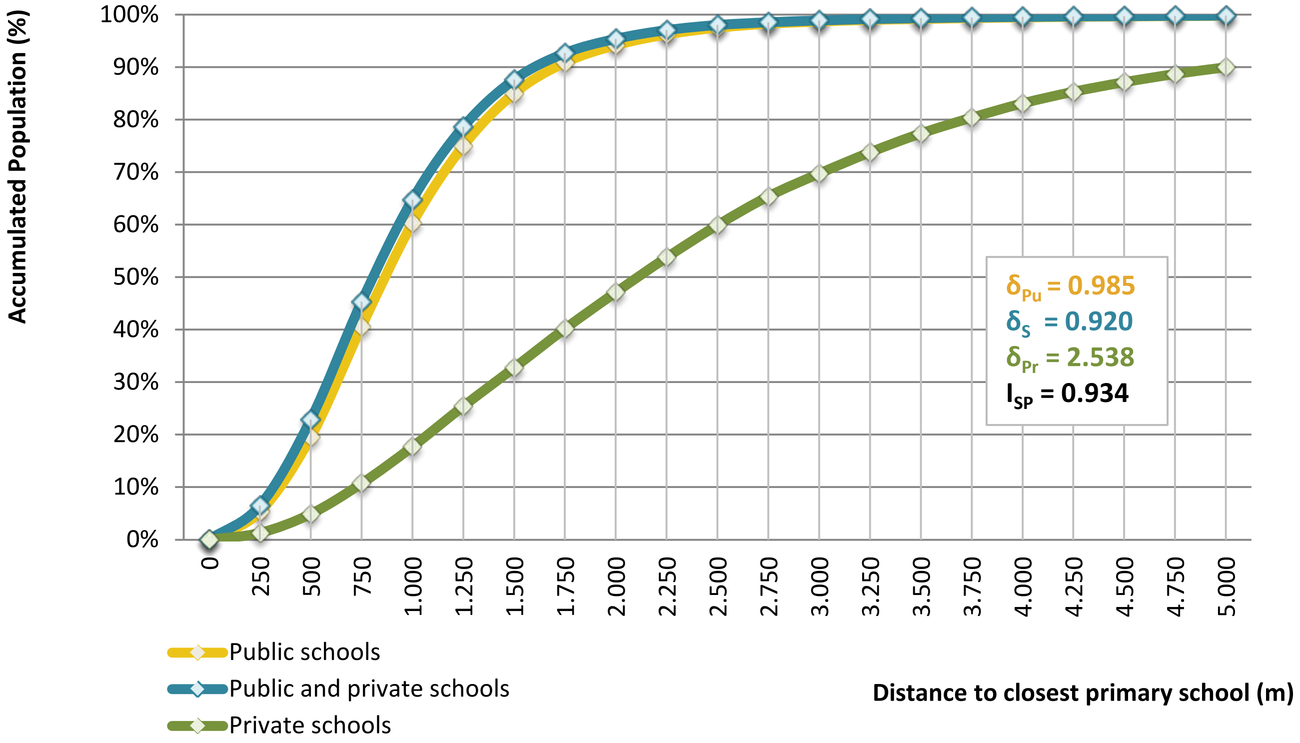
C_{ij}: Cost between the demand points (i) and their corresponding closest facility (j): Public primary schools in the case of δ_{Pu}, private primary schools in the case of δ_{Pr} and any primary school in the case of δ_{Pr}. For the analysis of this research, the considered cost is always the network pedestrian distance, classified in ranges from 0.25 to 10 km.

Graphs and indexes for each of the four case studies are provided next. Then, the four cities are compared through additional graphs and indexes. Finally, we include some comments highlighting the main findings.

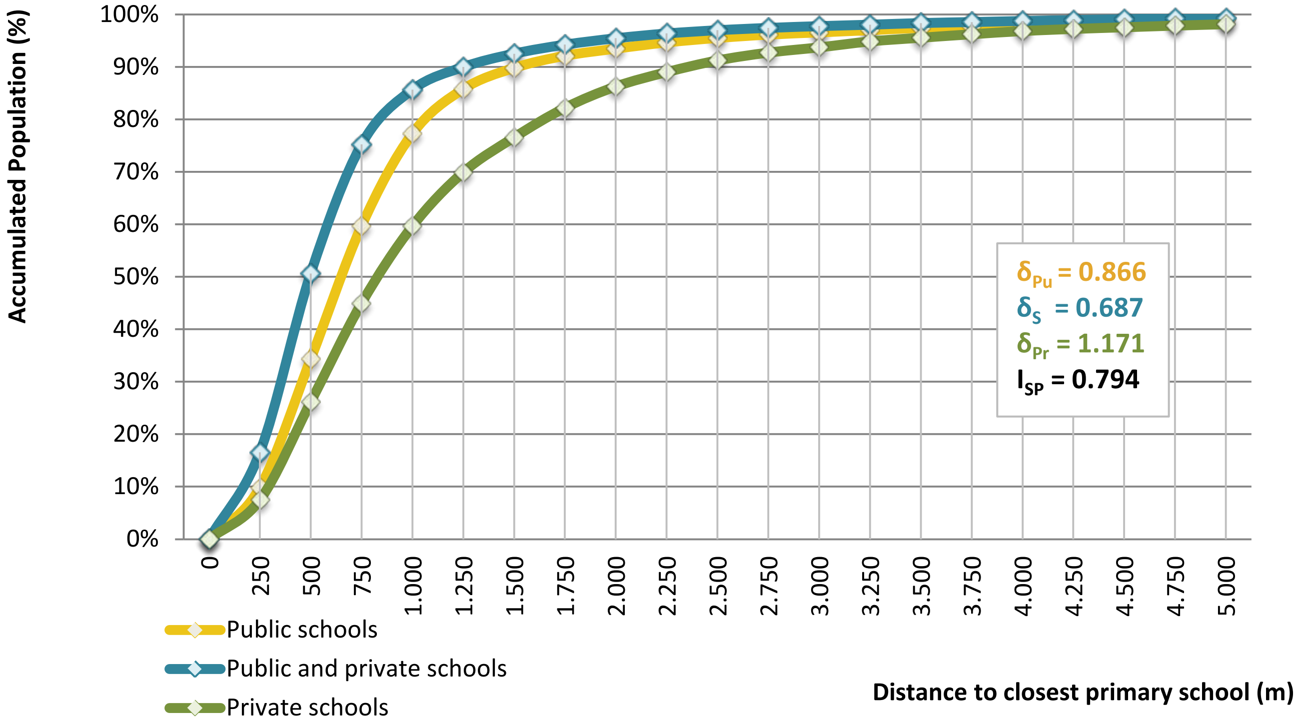
Graphic 4.1: Population by distance to closest primary school in Barcelona



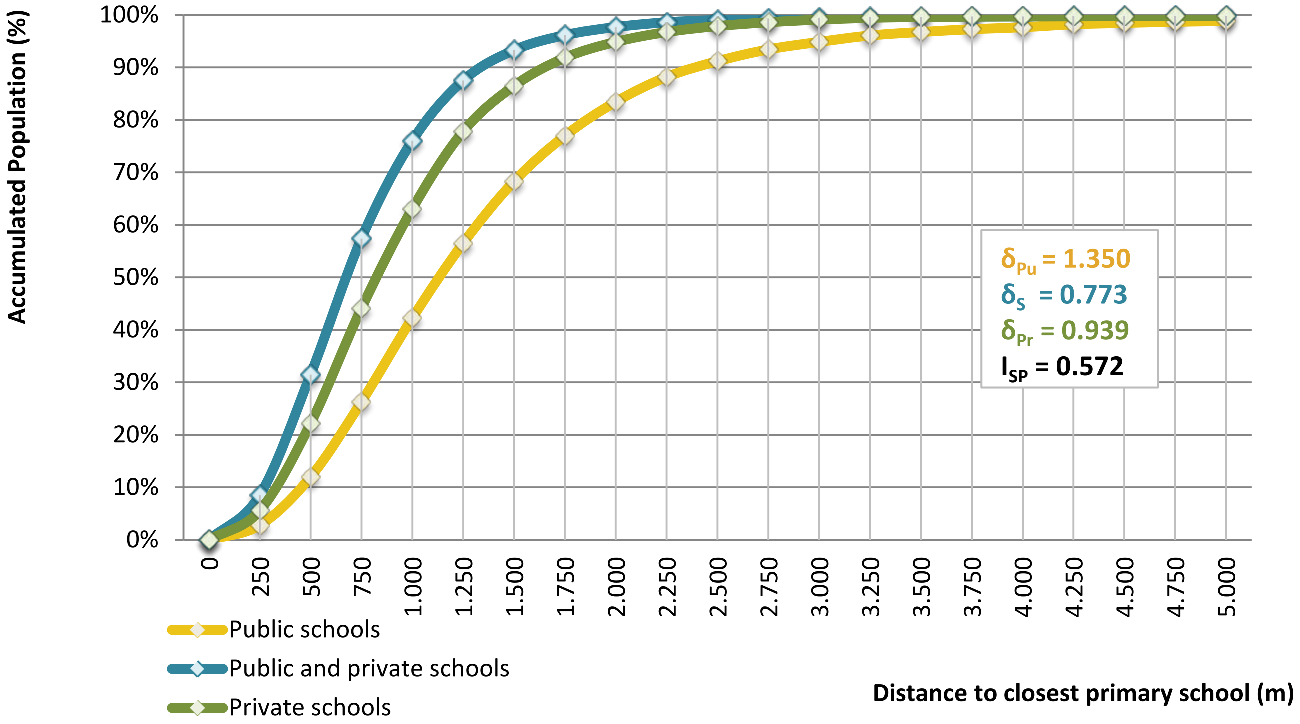
Graphic 4.2: Population by distance to closest primary school in London



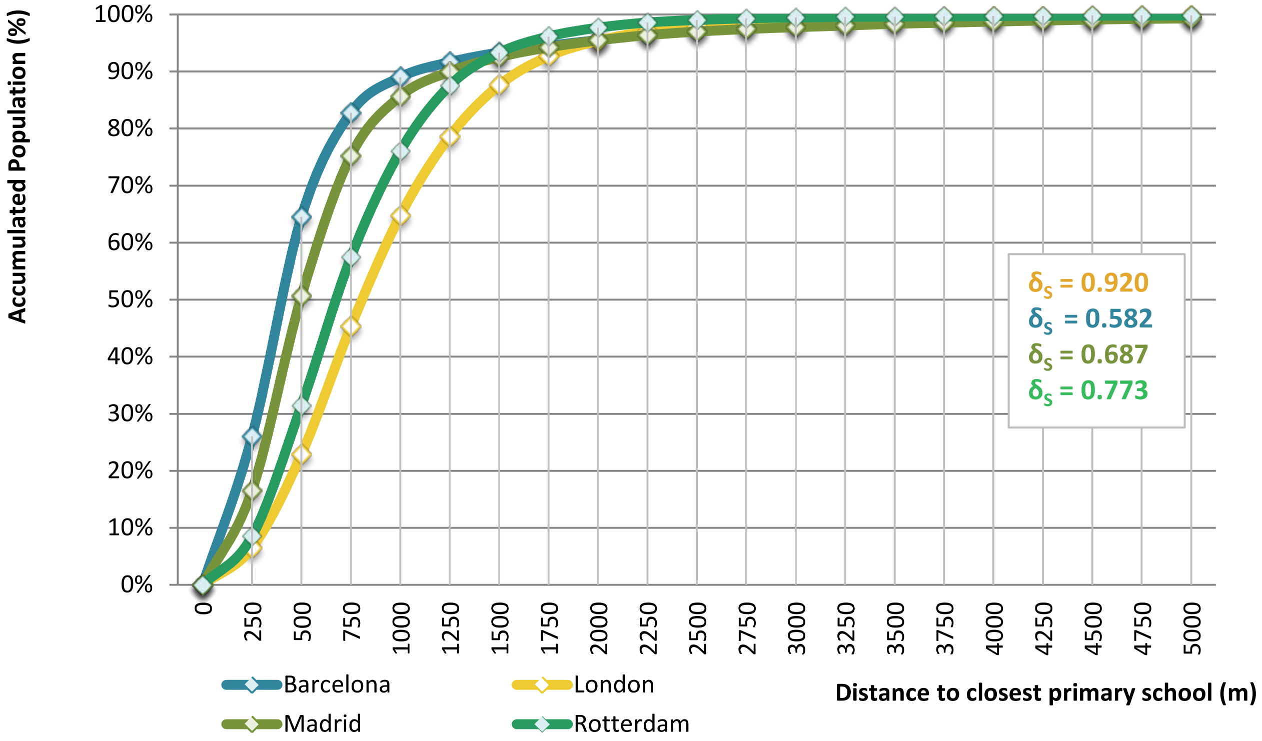
Graph 4.3: Population by distance to closest primary school in Madrid



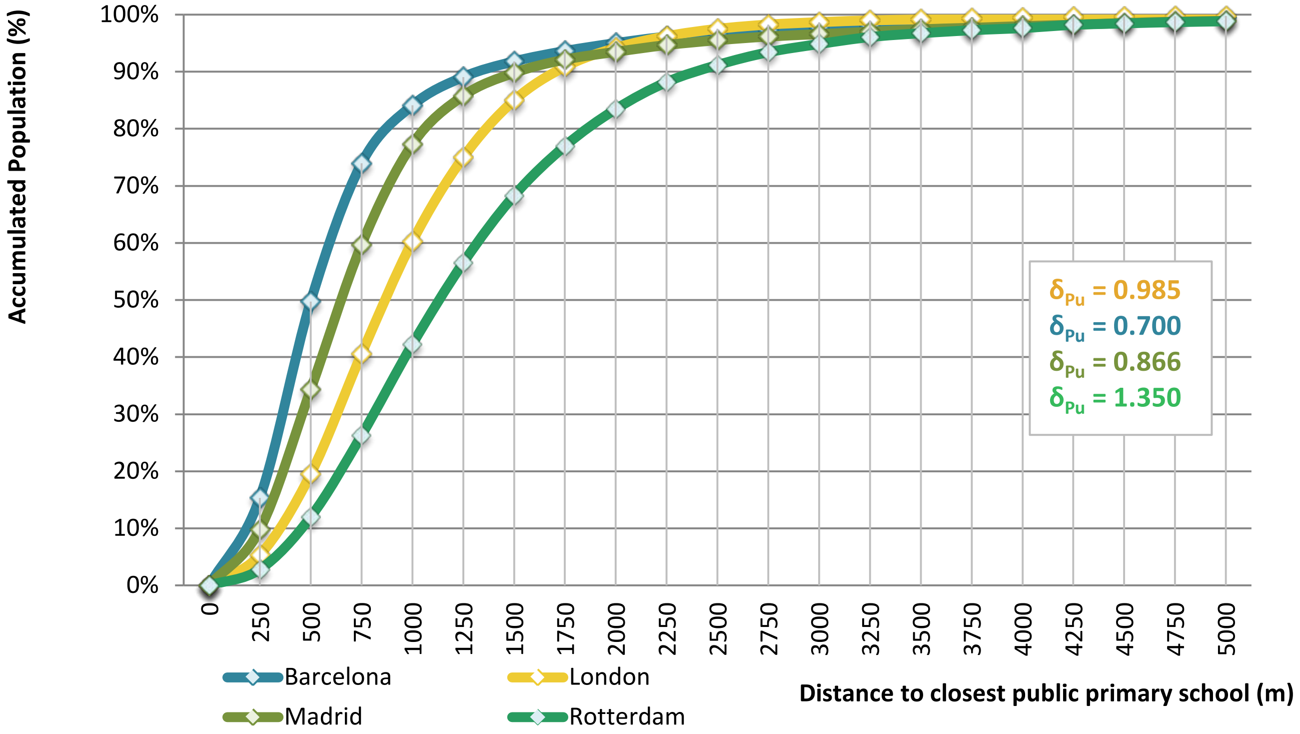
Graph 4.4: Population by distance to closest primary school in Rotterdam



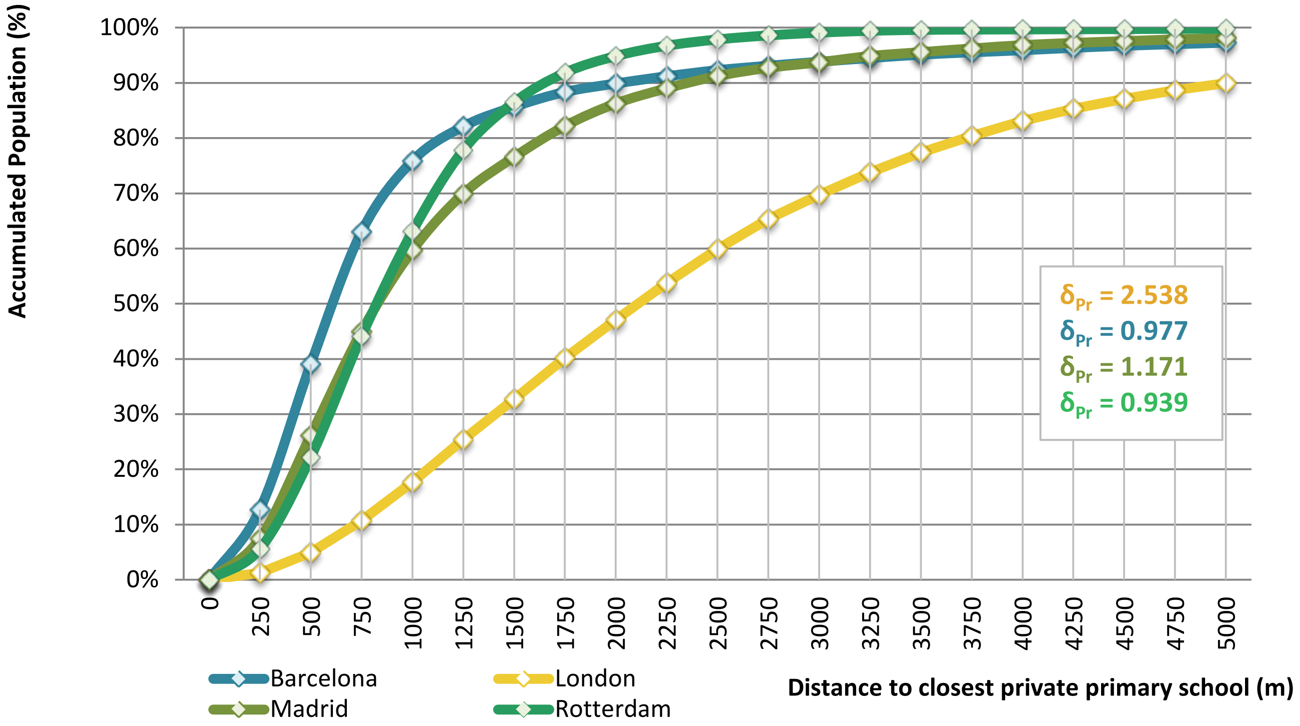
Graph 4.5: Population by distance to closest primary school in the 4 cites



Graph 4.6: Population by distance to closest public primary school



Graph 4.7: Population by distance to closest private primary school (*denominatie* schools in the case of Rotterdam).



The existing schools coverage in the four cities depends on the distribution of a specific number of facilities and other variables such as the population density or the urban fabric. This is very important when analysing the obtained results. For instance, one of the most striking findings is that the coverage of public primary schools in Barcelona and Madrid is better than in London, even if London has many more schools in proportion to the population (more than the double in the case of Madrid (Table 3.3)). The reasons behind this fact may be diverse, but the remarkable difference between these cities in terms of population density (Table 3.1) may be one of the most determinants. At the same time, this may partially explain the fact that the coverage of public primary schools in Rotterdam, the city with a lower population density (Table 3.1), is the worst one while its number of schools in proportion to population is similar to the one in Madrid (Table 3.3). Section 4 will explore to what extent the poorer coverage is also determined by a lack of optimization in the facility distribution by comparing the existing coverage to the optimal one with the same amount of facilities.

The analyses reveal other remarkable findings regarding the different public/private schools coverage. On the one hand, in three out of the four cases (with the exception of Rotterdam), public school coverage is significantly better than the private schools' one. This is even more remarkable in the case of London, since private centres in this city correspond to less than the 20% of the total ones. Barcelona and Madrid have a very similar coverage and a very similar proportion of public/private centres (around 60% and 40% respectively). On the other hand, Rotterdam presents a different scheme that has to be analysed considering that its school classification does not correspond to public / private but to *Openbare* / *Denominatie* schools, as it is explained in Section 3.3.2. *Denominatie* school coverage is significantly greater than Openbare one, due to the imbalanced proportion of centres (around 60% and 40% respectively according to the Table 3.2). This makes that, as the Graph 4.5 illustrates, the overall primary schools coverage in Rotterdam is not the worst anymore, though the difference between the accessibility to primary education is dramatically lower in the case of people who do not want to receive a segregated religious education (I_{SP}=0.572).

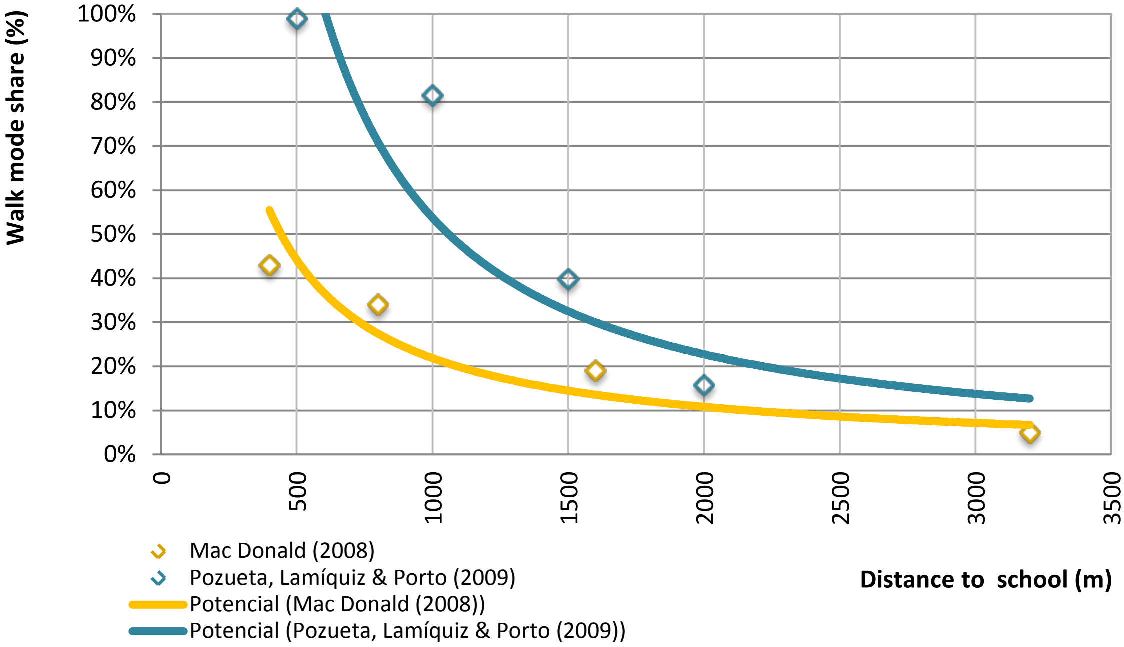
4.2.1 Evaluating distance to school: how far is too far?

Apart from the comparative analysis of the existing accessibility to public and private schools, it is also important to analyse the estimated average distances to school per se with the aim of providing an evaluation: how far is too far? There is not a simple response to this question. While establishing a maximum distance for certain public facilities such as fire stations or other emergency facilities can be more objective and clear, the evaluation of distances to primary schools must be done in accordance with a predefined urban model and specific planning objectives related to this model. In this sense, one of the most important and common urban planning goals regarding the accessibility to primary education is promoting walking as the main transport mode for the school trip. In order to reach this objective, some countries or cities define or recommend different distances to school that in most cases range from 0.4 to 0.8 km (Ibrahim et al., 2014). Beside these standards or guidelines, diverse studies have analysed the distance factor in children's mode choice. The research conducted by McDonald (2008) estimates the walk mode share that corresponds to different distances to school (see Graph 4.8) by analysing the data from the United States Department of Transportation's 2001 national survey. The results differ significantly from the obtained by Pozueta, Lamíquiz, & Porto (2009) in a research conducted in Madrid (see Graph 4.8), evidencing that mode choice to school differs from one place to another, a fact already studied by Ewing, Schroeer, & Greene (2004). However, both studies revealed that the maximum walk mode share is approximately reduced by a 50% when distance to school reaches 1km. Following the recommendation established by Ibrahim et al. (2014) of an average distance to school of 0.8 km and supposing that the goal of the four cities is to reach the walk mode share that corresponds to this distance, we will consider this distance as a threshold that may help us to evaluate the consequences of the estimated average distances in the four cities.

For the evaluation of these four case studies, we have distinguished between the average distance of population to public schools and to both public and private schools. In the first case, only Barcelona (0.700 km) is within the range of 0.4-0.8 km. Madrid is close to these values (0.866 km), London surpassed them (0.985 km) and Rotterdam is clearly out of the range with 1.350 km, a figure that could clearly implicate a dramatic reduction of walk mode-share for the school trip according to the mentioned studies. In relation to the average distance to both public and private centres, the offer of private centres in Rotterdam lead the four cities to present acceptable results, with the exception of London, which is still out of the 0.4-0.8 km range of distances.

Beside this mode-choice criterion, it is important to consider another one: the role of trip distance in the selection of the school. According to Ibrahim et al. (2014), after academic performance, location is the most influential factor. A bad distribution of public schools will stimulate the emergence of private centres that may reach demand levels unexpected in other circumstances.

Graphic 4.8: Walk mode share according to distance to school



4.3 Analysis of public schools coverage in different urban areas

4.3.1 Analysis of the MUA central and peripheral areas

This section analyses the coverage of public primary schools in the different urban areas defined for the four case studies (in Section 3.2) through different graphs and by calculating the next indexes:

- δ_{Pu}: Average distance to a public primary school in the MUA, estimated as:

$$\delta_{Pu} = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- δ_M: Average distance to a public primary school in the municipal area, estimated as:

$$\delta_M = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- δ_{Pe}: Average distance to a public primary school in the peripheral area, estimated as:

$$\delta_{Pe} = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- I_{PM}: Index of public primary schools coverage in the peripheral area in relation to public primary school coverage in the municipal area. This index compares the different distances to the closest primary schools between the population living in the central area and the population living in its peripheral ring within the MUA, reflecting possible imbalances. The index is estimated as:

$$I_{PM} = \frac{\delta_{Pe}}{\delta_M}$$

Considering:

P_{Pi}: Total population (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j), considering the MUA population in the case of δ_{Pu}, the population of the municipal area in the case of δ_M and the population of the peripheral are in the case of δ_{Pe}.

C_{ij}: Cost between the demand points (i) and their corresponding closest public school (j). For the analysis of this research, the considered cost is always the network pedestrian distance, classified in ranges from 0.25 to 10 km.

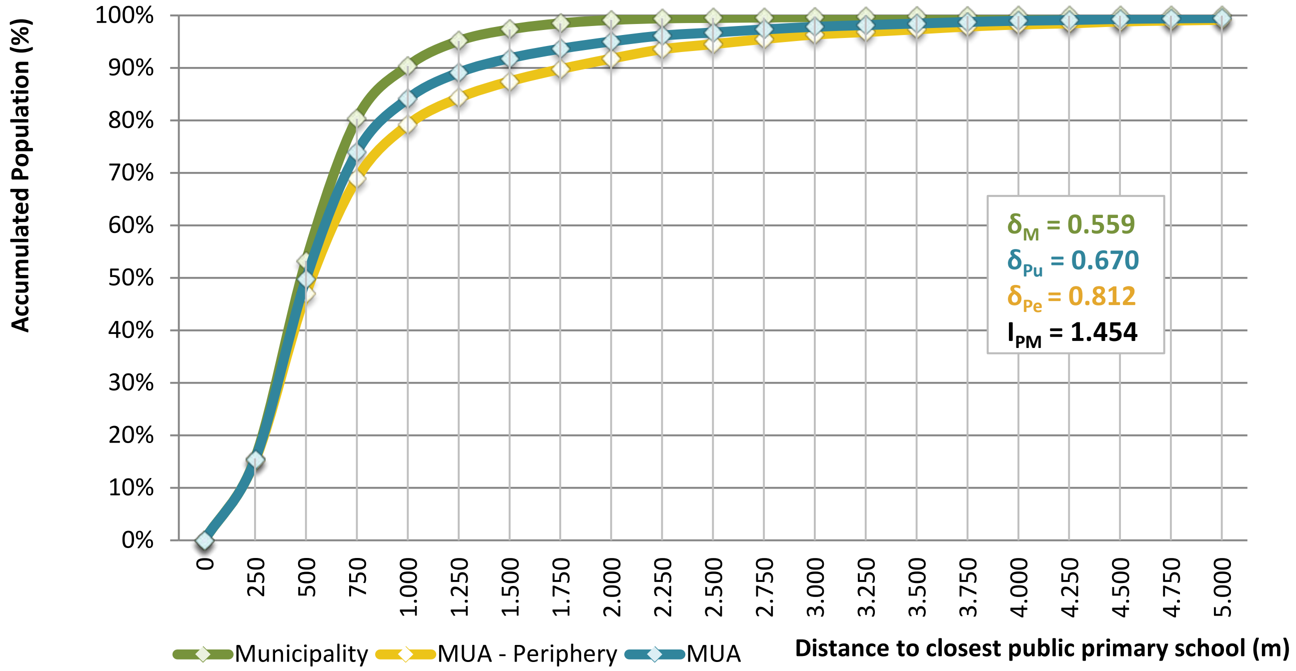
Graphs and indexes for each of the four case studies are provided next, after some comments highlighting the main findings.

Three out of the four cities (again with the exception of Rotterdam) present certain similarities when comparing the public schools coverage in the different urban areas. In these cases, the coverage of the municipal area is better than the one in the periphery, though in the case of London, this difference is significantly greater (I_{PM} = 1.643) than in the cases of Barcelona and Madrid (I_{PM} = 1.454 and I_{PM} = 1.304 respectively). This means that London presents the greater imbalance in the accessibility to public primary education: while the average distance to a school is 985 m in the case of the population living in the municipal area, this distance raises to 1,489 m for the population living in the periphery of the MUA. It is remarkable too that the same distance in the case of Barcelona and Madrid is 812 m and 999 m respectively.

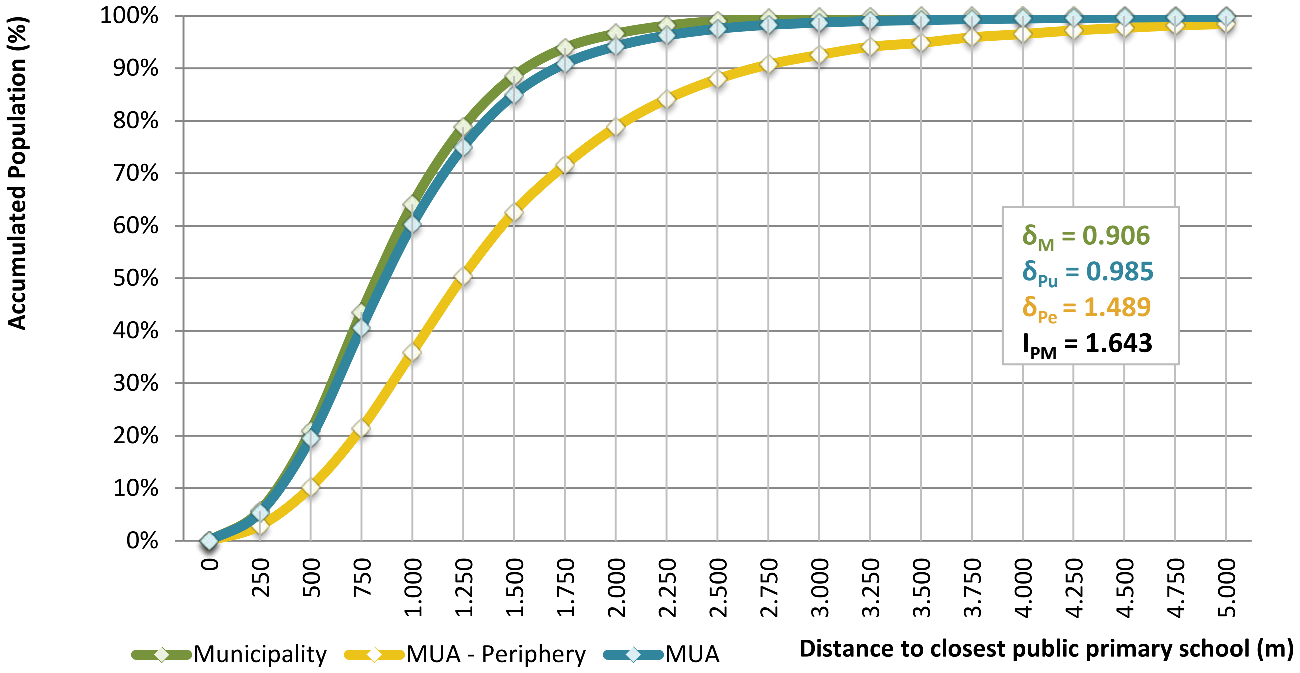
Again, these differences of service coverage regarding the different urban areas in the three cases could be related to possible disparities in the population density, however the figures are similar in London and Madrid and the variation is greater in Barcelona (population density in the peripheral area of the London MUA is 35% of the average population in the municipal area (the Greater London area), while in Madrid is 32% and in Barcelona 21%). The different coverage may then be explained by other factors, like the number of facilities per capita and the degree of optimization in the distribution of these facilities across the peripheral areas. Section 5 will analyse these factors in detail.

The case of Rotterdam presents a different scheme, with similar school coverage in the periphery and the municipal area (I_{PM} = 0.938). Considering that the population density in the MUA peripheral area is around the double (1.96) of the one of the municipal area, again the coverage must be explained by the factors previously mentioned, that will be analysed in Section 5.

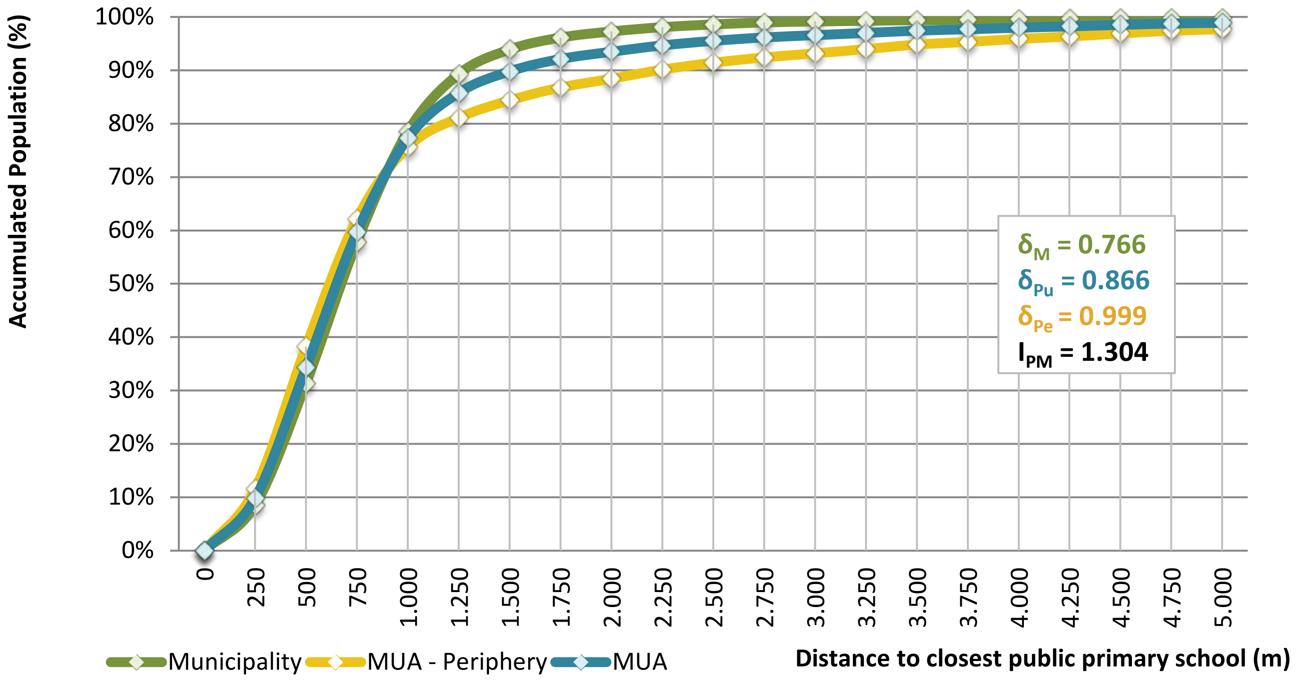
Graph 4.9: Population by distance to closest public primary school according to different urban areas in Barcelona



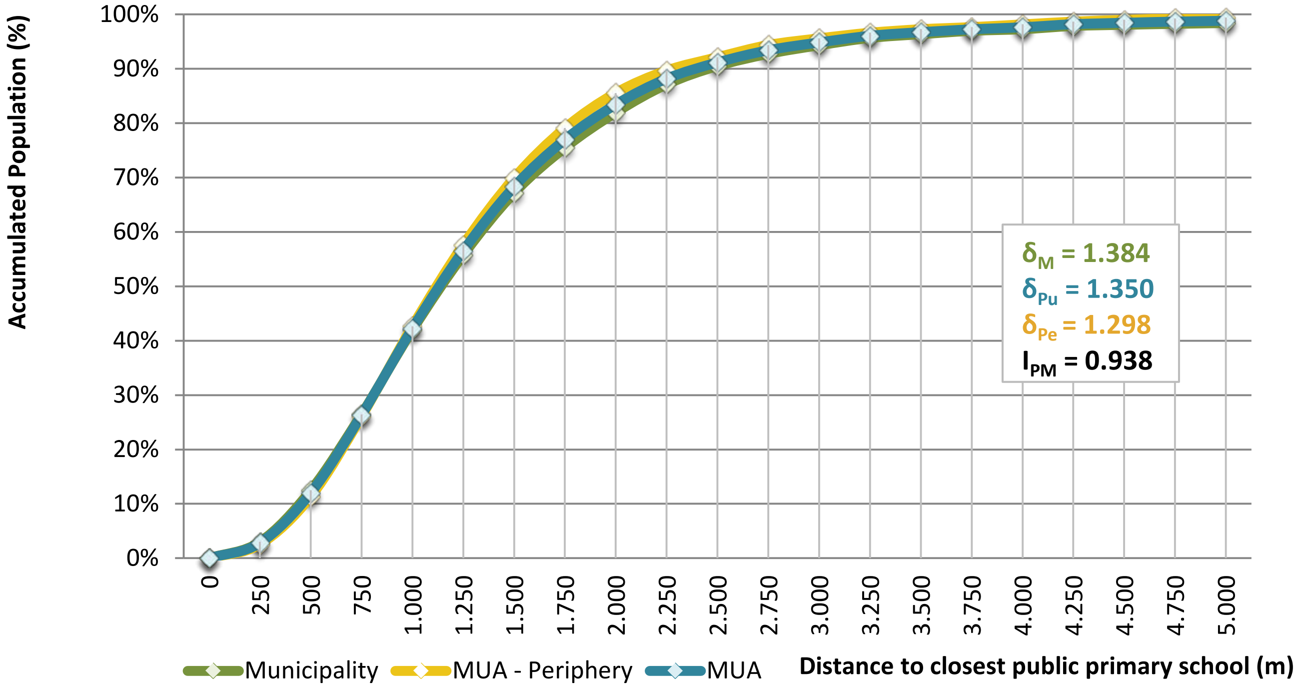
Graph 4.10: Population by distance to closest public primary school according to different urban areas in London



Graph 4.11: Population by distance to closest public primary school according to different urban areas in Madrid



Graph 4.12: Population by distance to closest public primary school according to different urban areas in Rotterdam



4.3.2 Local analysis of the public service coverage and the influence of population density

Section 4.3.1 analyses the service coverage in three defined urban areas. This is useful in order to get an overall view but it may not uncover possible local imbalances. This section performs a more disaggregated and detailed spatial analysis of the public service coverage for the London case study. It also studies the influence of population density on the accessibility to public services, by performing firstly a global Ordinary Least Squares (OLS) linear regression analysis and finally a Geographically Weighted Regression (GWR) analysis, considering both variables.

Firstly, the results obtained from the location model previously applied (at point level, contemplating around 30,000 points in the case of London) have been aggregated in hexagonal cells with 2000 m of diameter. The figures 4.3.2.1 and 4.3.2.2 represent the average distance to closest public primary school and the population respectively, according to this level of aggregation. The first figure shows the significant differences between the MUA central and the peripheral areas, but also evidences the importance of the analysis at this level of disaggregation, since there are relevant variations all across the MUA. Then, a simple visual comparison between the two figures evidences that both variables are strongly correlated.

Figure 4.2: Average distance to closest public primary school in London MUA

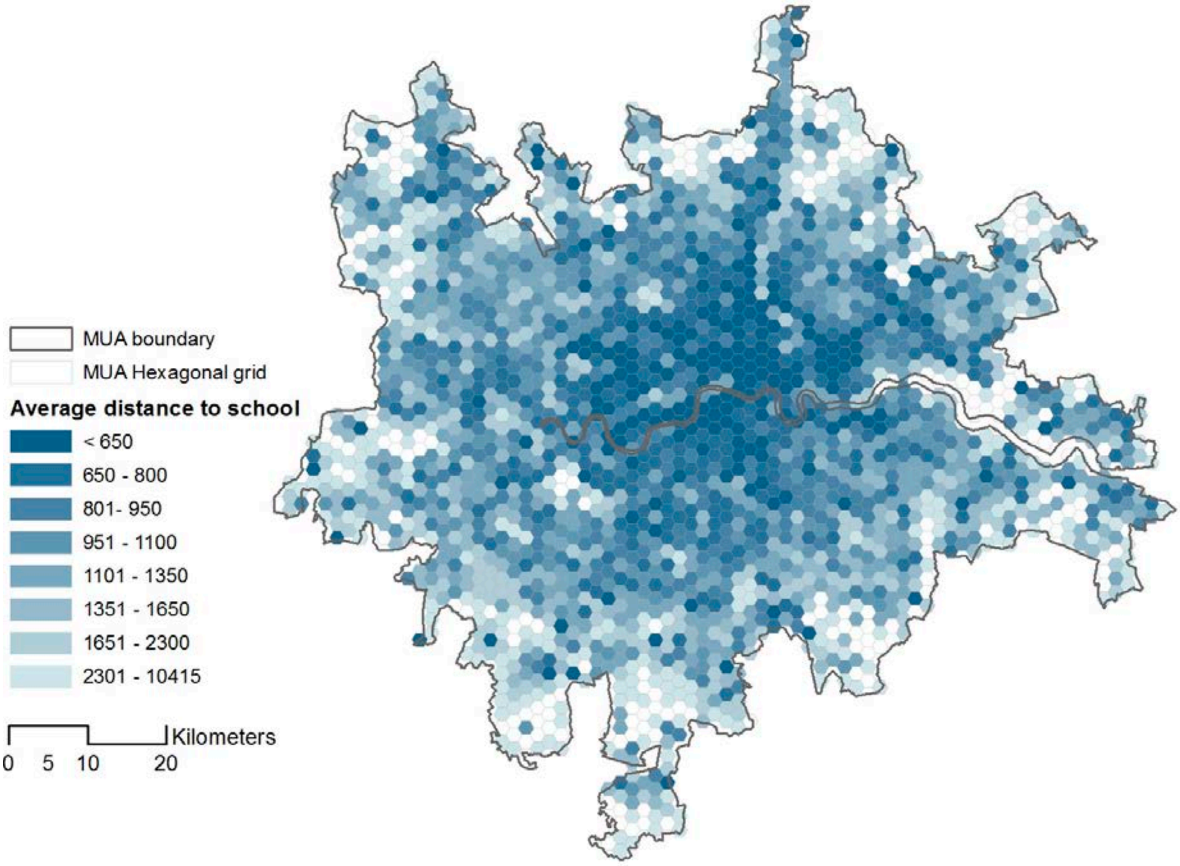
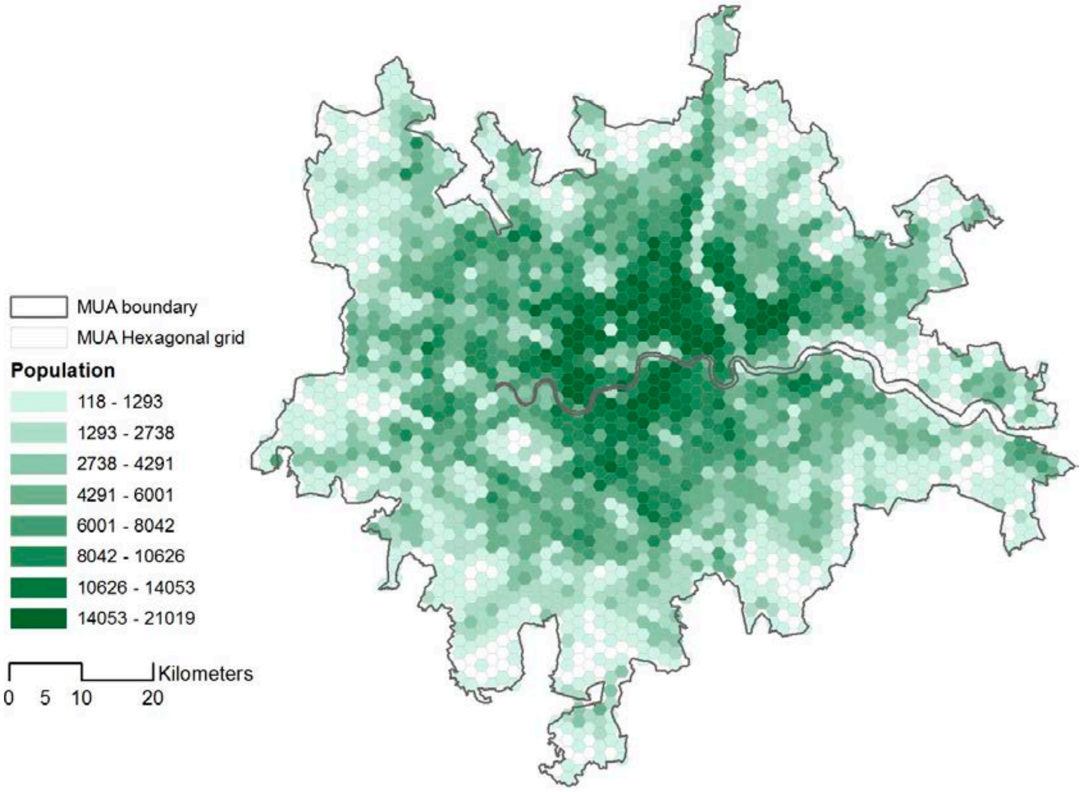


Figure 4.3: Population in London MUA (hexagonal cells of 2 km diameter and 2.60 km^2 area)



In order to know to what extent population density is determining the estimated service coverage of primary schools, a global Ordinary Least Squares (OLS) linear regression was performed. The results showed that the model did not fit well since the obtained adjusted R-Squared = 0.27 (estimated values illustrated in Figure 4.4) but the visual exploration of the map illustrating the OLS residuals pointed out that they could be spatially autocorrelated.

Global Moran's I statistic was calculated in order to measure the spatial autocorrelation of the average distance to school values, obtaining a Moran's Index = 0.2947, a z-score = 29.9265 and a p-value = 0.0000. These values confirmed the spatial autocorrelation so we decided to perform a Geographically Weighted Regression (GWR) analysis (Brunsdon, Fotheringham, & Charlton, 1998). The GWR fitted significantly better with the existing values. The obtained adjusted R-Squared was 0.664 with a bandwidth of 3,000m. The predicted values (distance to closest primary school) are shown in Figure 4.6.

The determinant role of population density in the accessibility to public services is well known (McDonald, 2008), but these results evidence its specific impact in the case of London. This analysis may also be of interest in the detection of areas in which a better public service coverage should be expected (see the GWR residuals map, Figure 4.7), since the bad accessibility in these areas do not respond to the population density factor but may have to do with a bad distribution of facilities or a bad network connectivity.

Figure 4.4: Estimated values (distance to school) by the Ordinary Least Squares (OLS) linear regression

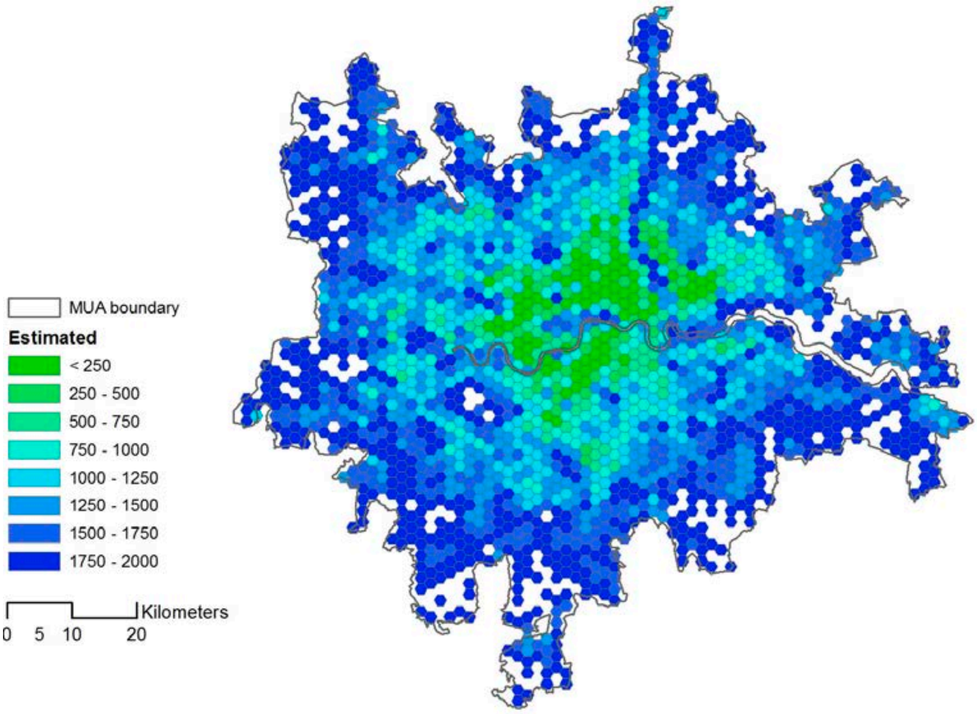


Figure 4.5: Ordinary Least Squares (OLS) linear regression residuals

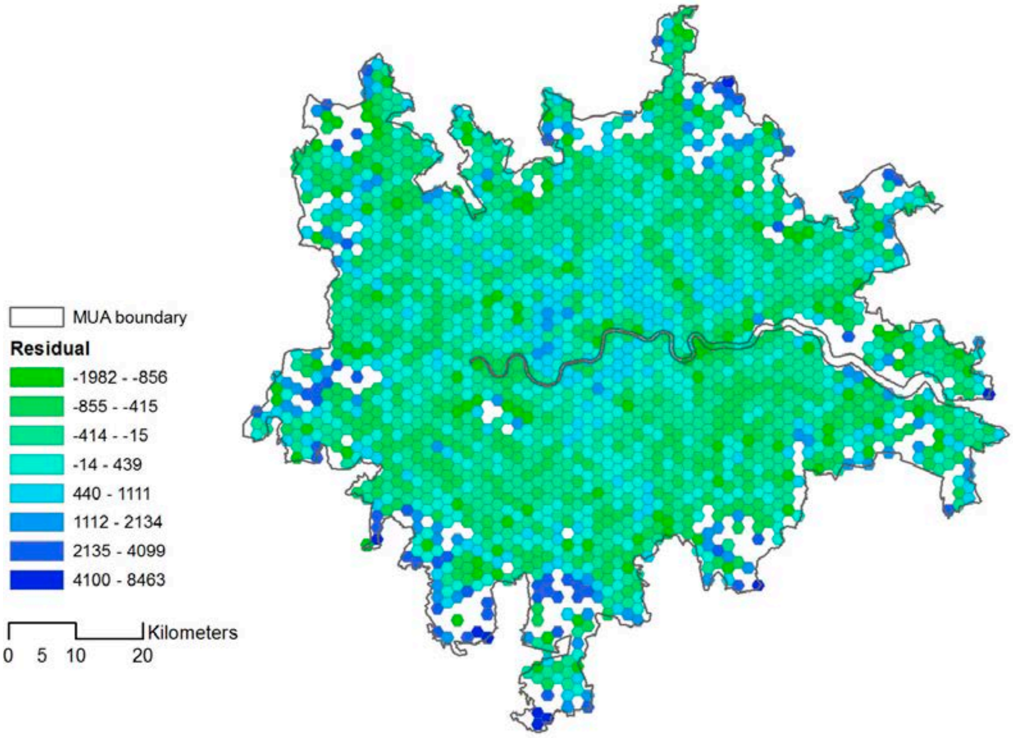


Figure 4.6: Predicted values (distance to school) by the Geographically Weighted Regression

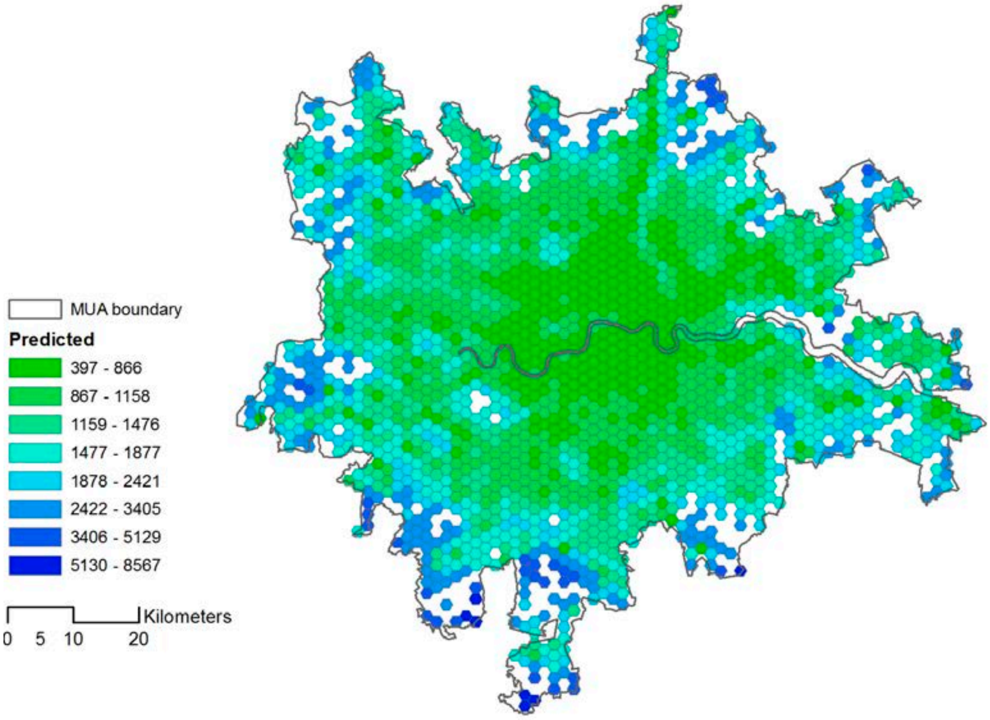
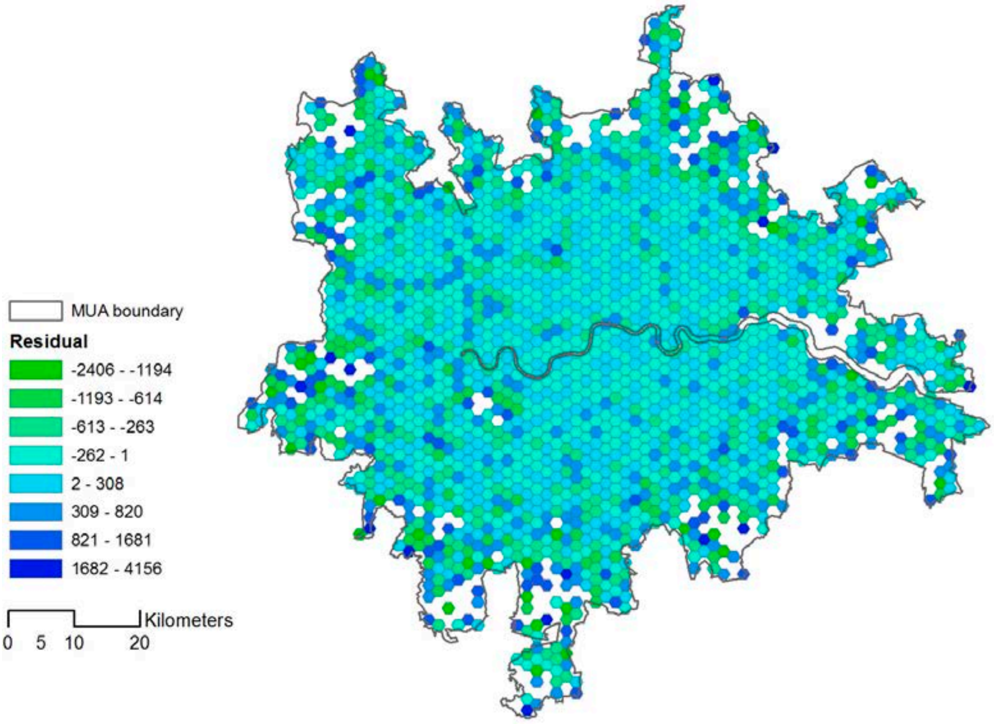


Figure 4.7: Geographically Weighted Regression residuals



4.4 Analysis of primary schools coverage according to different groups of demand

This section analyses the coverage of public primary schools according to the different groups of demand defined in Section 3.3.3, through different graphs and by calculating the next indexes:

- δ_{Pu}: Index of public primary schools coverage of *Total population*, estimated as:

$$\delta_{Pu} = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- δ_{T}: Index of public primary schools coverage of *Target population*, estimated as:

$$\delta_{T} = \frac{\sum_i \mathrm{P}_{Ti}\, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Ti}}$$

- δ_{V}: Index of public primary schools coverage of *Vulnerable population*, estimated as:

$$\delta_{V} = \frac{\sum_i \mathrm{P}_{Vi}\, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Vi}}$$

- I_{TP}: Index of public primary schools coverage of Target population in relation to public primary school coverage of Total population. This index compares the difference of accessibility to primary schools between these two groups of demand, reflecting possible imbalances. The index is estimated as:

$$I_{TP} = \frac{\delta_T}{\delta_{Pu}}$$

- I_{VP}: Index of public primary schools coverage of *Vulnerable population* in relation to public primary school coverage of *Total population*. This index compares the difference of accessibility to primary schools between these two groups of demand, reflecting possible imbalances. The index is estimated as:

$$I_{VP} = \frac{\delta_V}{\delta_{Pu}}$$

Considering:

P_{Pi} : Total population (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j) in the MUA.

P_{Ti} : Target population (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j) in the MUA.

P_{Vi} : Vulnerable population (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j) in the MUA.

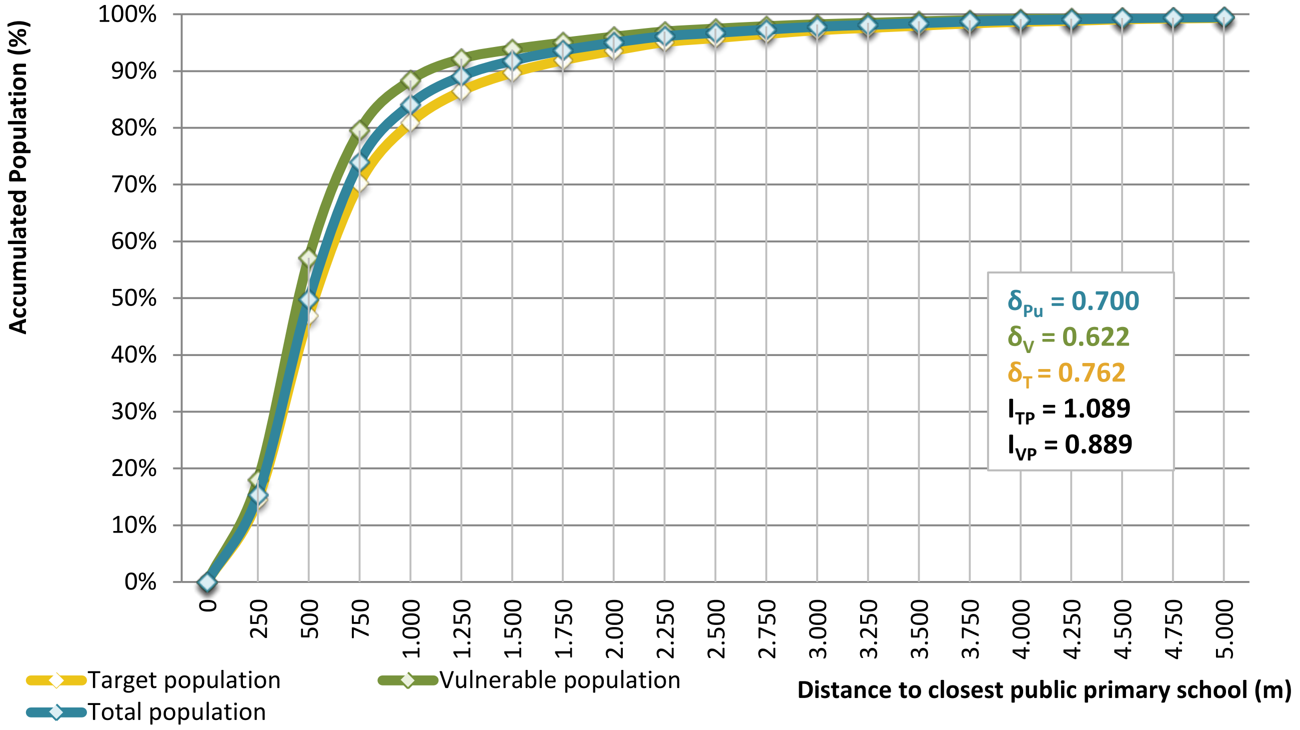
C_{ij}: Cost between the demand points (i) and their corresponding closest public school (j). For the analysis of this research, the considered cost is always the network pedestrian distance, classified in ranges from 0.25 to 10 km.

Graphs and indexes for each of the four case studies are provided at the end of this section.

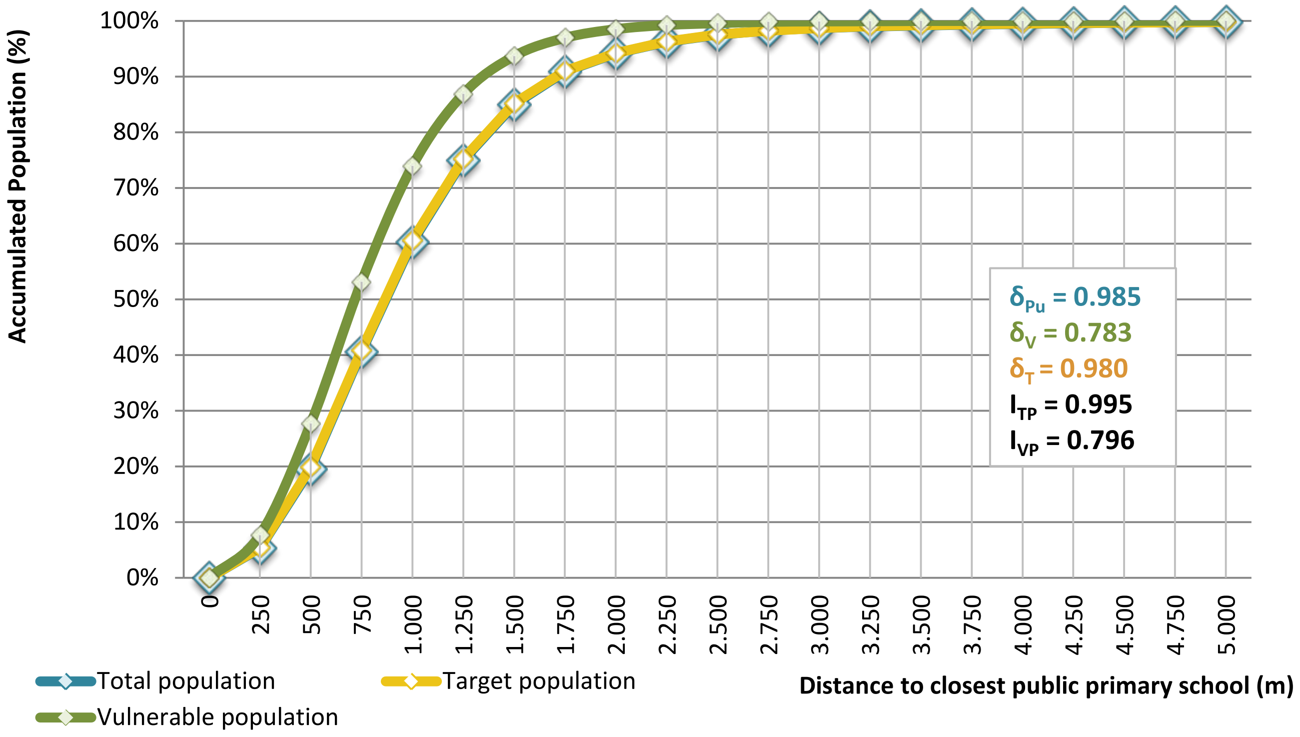
The main finding is that, in the four case studies, the public primary schools coverage of the *Vulnerable population* group of demand is greater than the *Total population* one or the *Target population* one. In the case of London and Madrid the average distances of *Vulnerable population* to the closest facility are around 80% of the ones of *Total population* (I_{VP} = 0.796 and I_{VP} = 0.795 respectively). Taking into account this group of demand is more dependant on public service, this is a positive finding, and these values may reveal that local policies are taking these groups into account when locating public schools. In the case of Barcelona, the difference is lower (I_{VP} =0.889) and in Rotterdam is not really significant (I_{VP} = 0.929).

When it comes to the *Target population* group of demand, the obtained results barely diverge in the four case studies. In Barcelona, London and Rotterdam this difference is actually not significant (I_{TP} = 1.089, I_{TP}= 0.995 and I_{TP} = 1.016 respectively), though in the case of Madrid the difference is slightly greater (I_{TP} = 1.113). Since the same facility distributions offer similar coverages in the four cases, what these results reveal is basically the inexistence of significant imbalance in the target population distribution across the city.

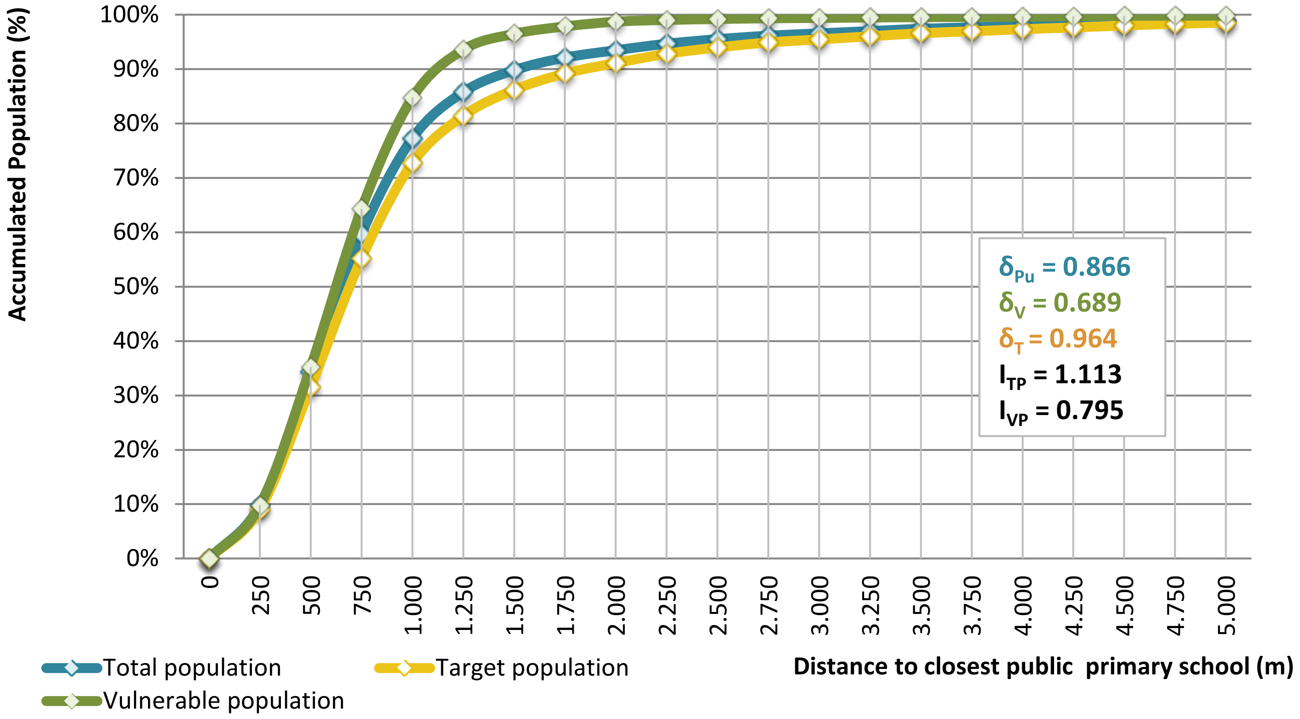
Graph 4.13: Population by distance to closest primary school according to different groups of demand in Barcelona



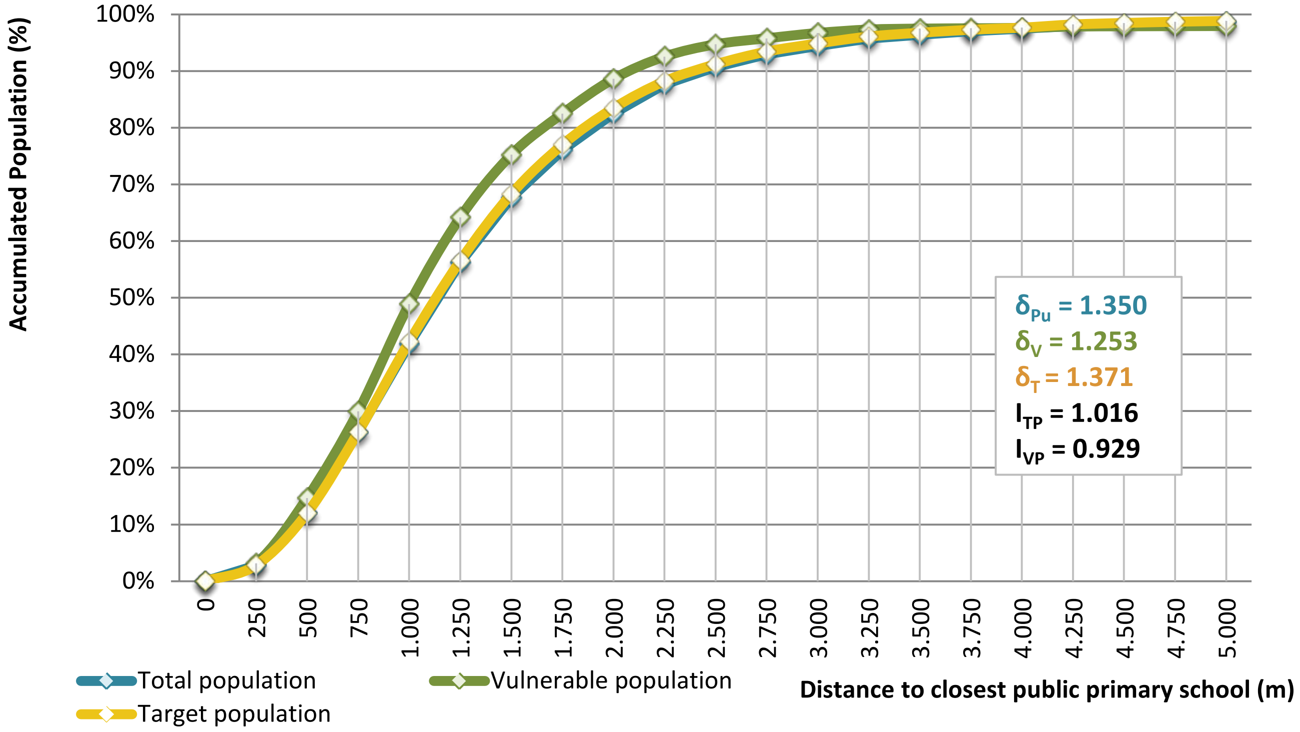
Graph 4.14: Accumulated Population by distance to closest primary school according to different groups of demand in London



Graph4.15: Population by distance to closest primary school accroding to different groups of demand in Madrid



Graph 4.16: Accumulated Population by distance to closest public primary school according to different groups of demand in Rotterdam



4.5 Analysing service choice

Many European cities aim at improving public service choice for two different reasons. The first one is that people demand more personalised public services “which respond to individual choices and people’s real life complex needs” (*Open Public Services*, 2014). This is a growing demand in sectors like transport, health care or education, since people claim for more and more diverse public transport modes (with an increasing demand of public bike share systems, for instance), they aim at choosing between different health centres or doctors, or public schools according to different educational programmes, facilities, etc.

The second reason is that choice improves the public sector by introducing competition. As Orr (2014) stated: *“For 35 years now, “choice” has been the banner under which public services have been reformed. Choice means competition and competition means efficiency”*. More specifically, in the field of education, this statement has been supported by different research studies that have also introduced the idea that the proximity of private and public schools has a positive impact by improving the quality of the public ones (Dee, 1998) and because competition leads private schools to give tuition discounts giving rise to more social cohesion (Epple, Figlio, & Romano, 2004).

The objective of this section is to evaluate the school choice in the four case studies by comparing the average distance to the closest facility to the average distance to a number of facilities that has been set to three. In order to do so, the next distances and indexes have been calculated:

- δ_{Pu3}: Average distance to the three closest public primary schools in the MUA, estimated as:

$$\delta_{Pu3} = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- δ_{S3}: Average distance to the three closest primary schools in the MUA, estimated as:

$$\delta_{S3} = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- I_{PuCH}: Index of relative public service choice. This index compares the average distance to the closest public primary school to the average distance to the three closest public primary schools. The values range between 0 and 1. The closest the value is to 1, the more balanced is the distribution is the possibility of public service choice. The index is estimated as:

$$I_{PuCH} = \frac{\delta_{Pu}}{\delta_{Pu3}}$$

- I_{SCH}: Index of relative service choice, similar to the previous one but considering both public and private schools instead of just public ones.

$$I_{SCH} = \frac{\delta_{S}}{\delta_{S3}}$$

- I_{CHb}: Index of service choice public-private balance. This index compares the previous average distances. The values range between 0 and 1. The closest the value is to 1, the more balanced is the the possibility of choice between people that can or cannot afford private education. The index is estimated as:

$$I_{CHb} = \frac{\delta_{S3}}{\delta_{Pu3}}$$

Considering:

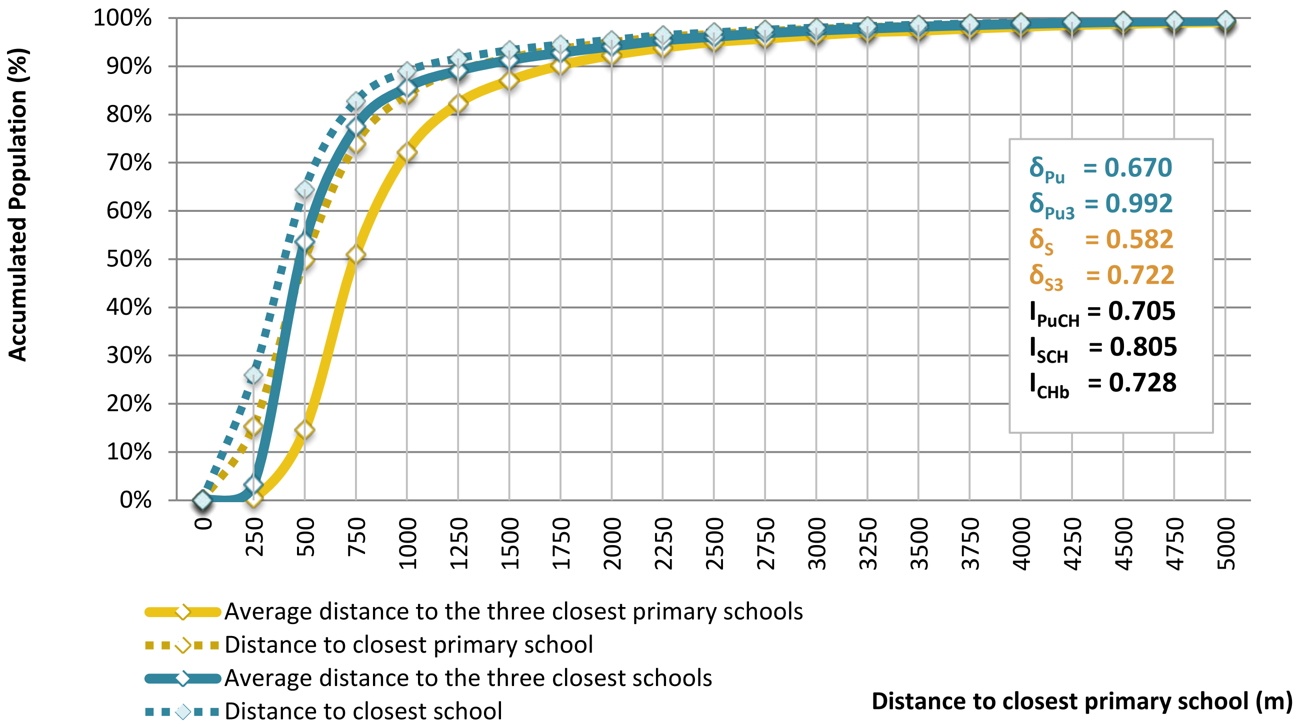
δ_{Pu}: Average distance to a public primary school, as estimated in Section 4.2.

P_{Pi}: Total population in the MUA (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j).

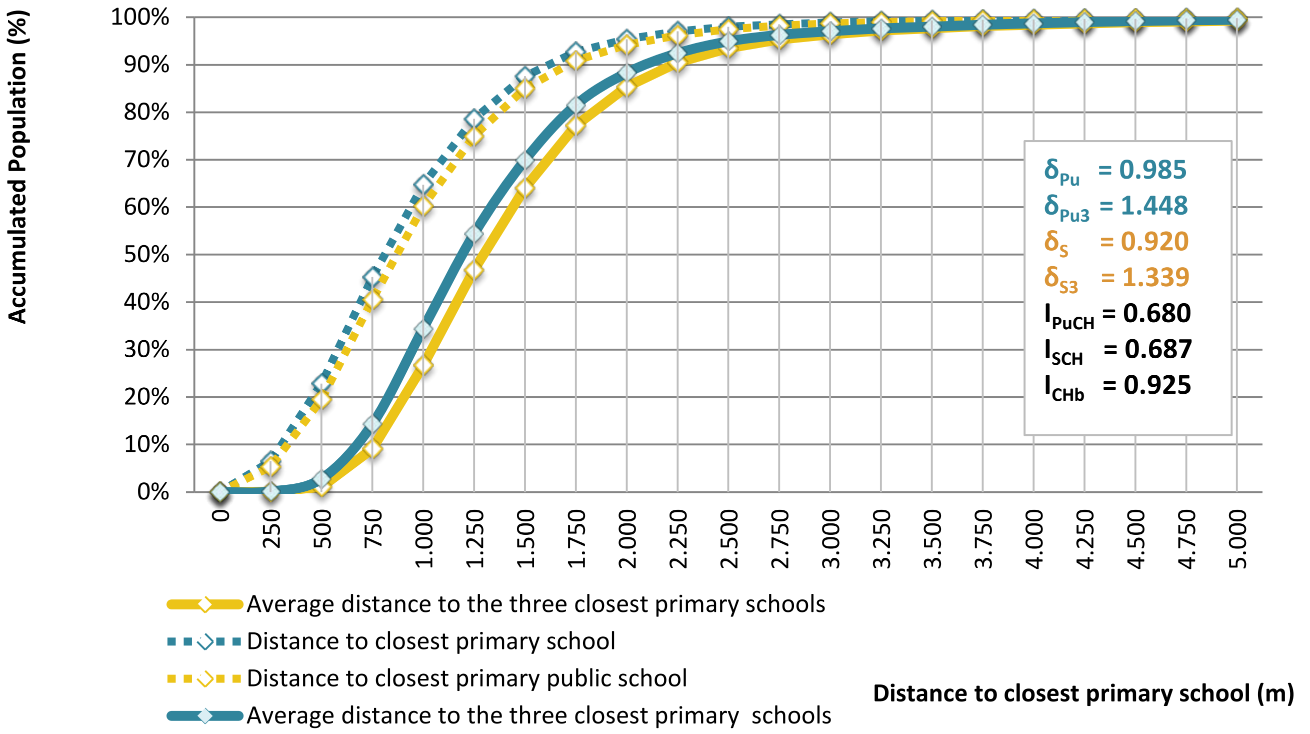
C_{ij}: Cost between the demand points (i) and their corresponding closest public school (j). For the analysis of this research, the considered cost is always the network pedestrian distance, classified in ranges from 0.25 to 10 km.

Graphs and indexes for each of the four case studies are provided next.

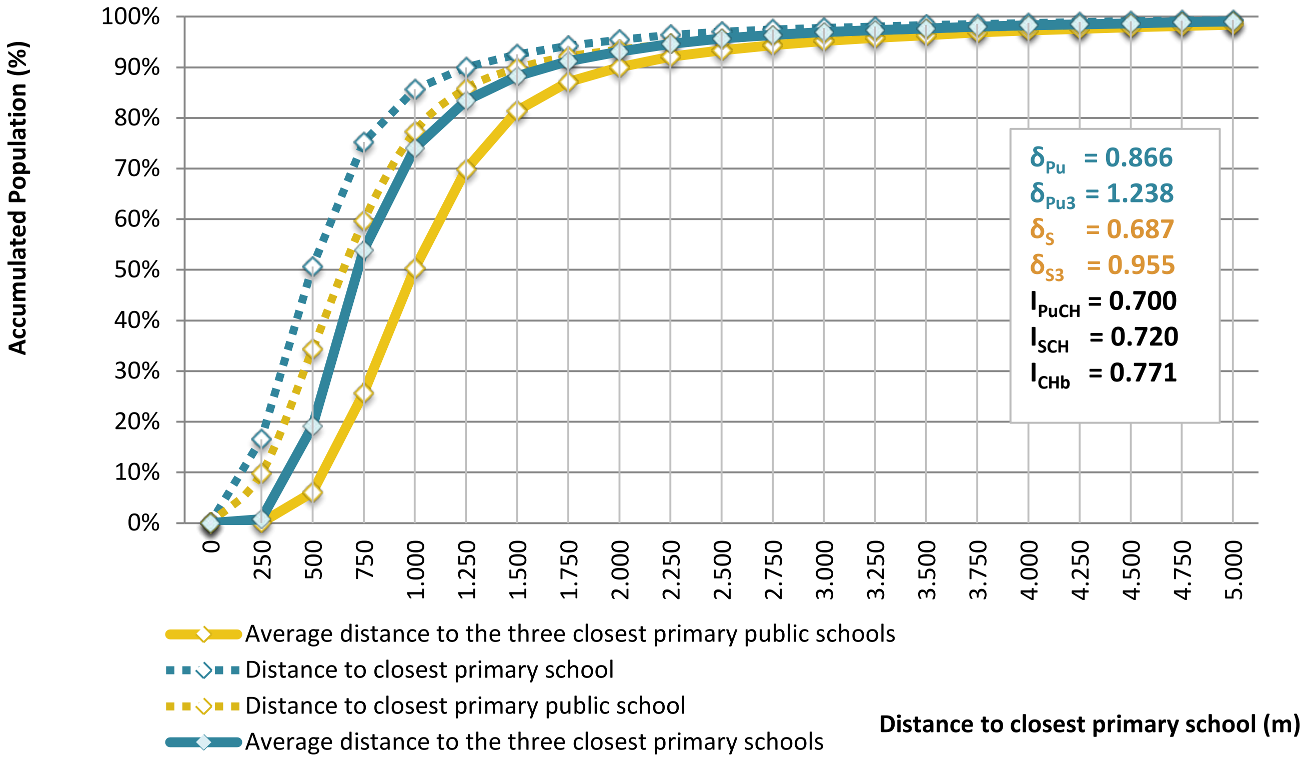
Graph 4.17: Population by distance to closest primary schools in Barcelona



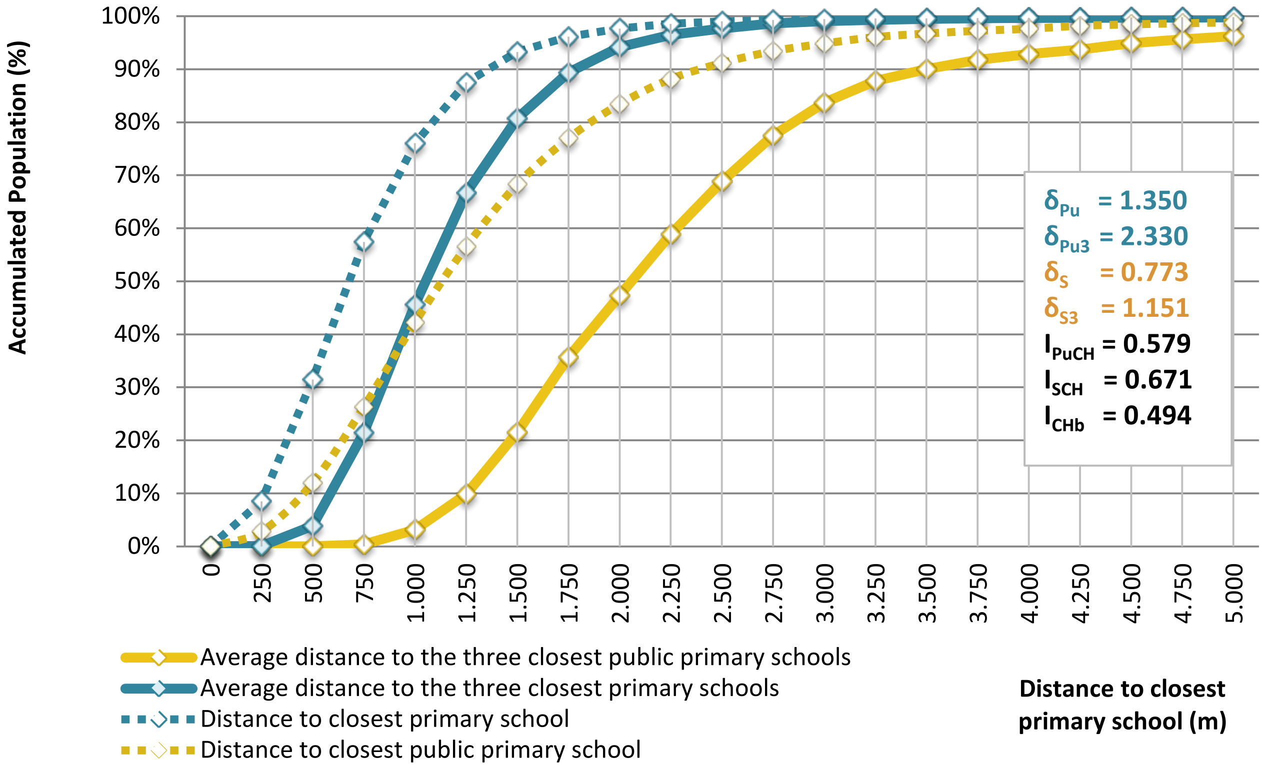
Graph 4.18: Population by distance to closest primary schools in London



Graph 4.19: Population by distance to closest primary school in Madrid



Graph 4.20: Population by distance to closest primary school in Rotterdam



The previous analyses provide an overall evaluation of choice in the MUA of the four case studies. However, a more disaggregated analysis is necessary to unveil potential deficiencies in specific urban areas. It could be expected that choice is poorer in certain urbanizations of peripheral areas that are served by just one public school. In these cases, distance to closest schools may be acceptable whereas choice may be poor since other schools may be found at long distances in other urbanizations.

In accordance with the analyses performed in Section 4.3.2, the results obtained from the location model have been aggregated according to the same hexagonal grid (2000 m diameter). Figures 4.8 and 4.9 represent the average distance to the three closest public primary schools and the average distance to closest public primary school respectively, so they can be easily compared.

Figures 4.8 shows the expected distribution of service coverage, greater in the central areas and poorer in the periphery. The comparison between the two figures shows that there are not major differences, although a more detailed insight reveals certain slight positive variations in central areas and negative ones the periphery, especially in the south areas, where the number of “blue” hexagons is greater revealing longer average distance to schools and therefore a poorer choice.

Figure 4.8: Average distance to the three closest public primary schools in London MUA

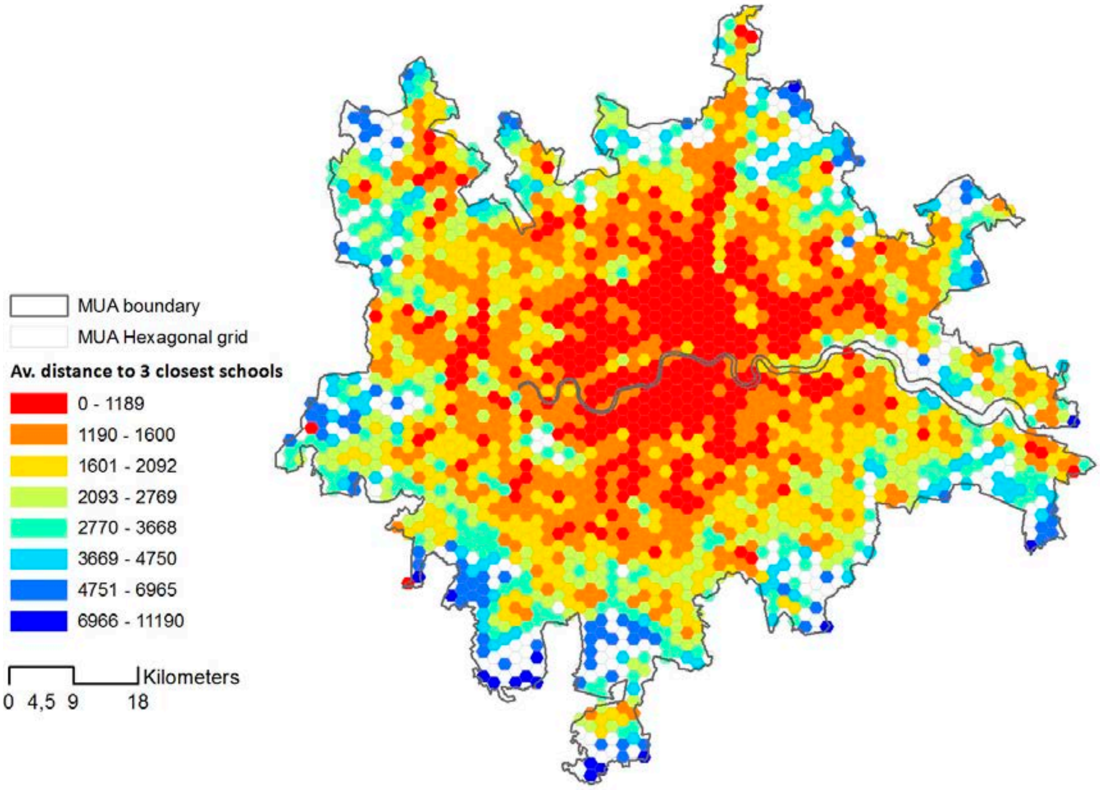
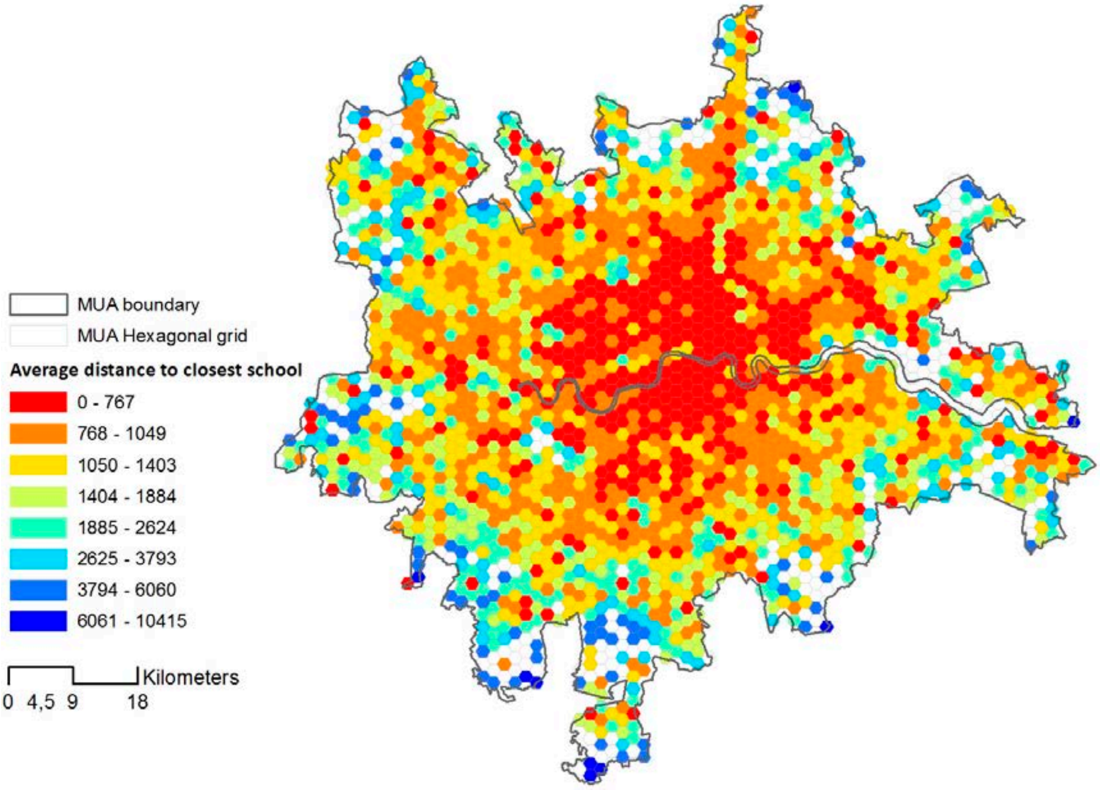


Figure 4.9: Average distance to closest public primary school in London MUA



5. Evaluation of Public Services location: comparing the existing spatial coverage to an optimal one

The previous section analyses the existing coverage of primary schools in the four case studies in order to find possible deficiencies or imbalances and compares the obtained results in the four cities. The service coverage is determined by the location of a specific number of facilities and it is influenced by other factors such as population density, the urban fabric or the quality of the transport system, factors that impact in different ways in the four case studies.

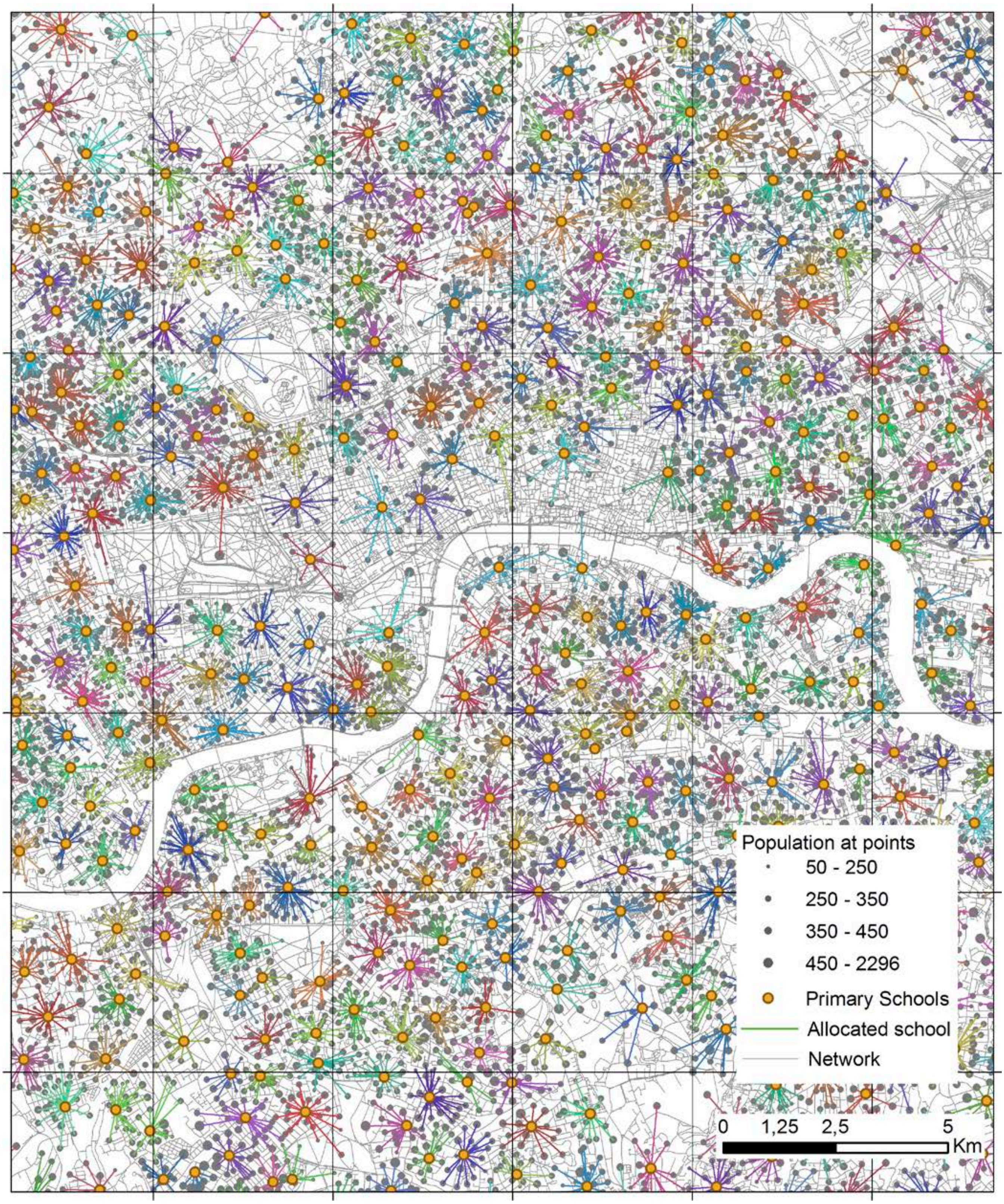
Because of this, when evaluating public facilities location, we cannot simply compare the different service coverages that result from the distribution of the same amount of facilities per capita in two different cities. For instance, cities with low population density rates will need more facilities in order to get the level of coverage of more dense cities. Section 4 reveals that, in comparison to Barcelona or Madrid, London gets a worse service coverage from the distribution of a greater number of primary schools per capita. However, the analysis discloses that the distribution of London's schools is slightly better that the one of Barcelona and Madrid. This means that what makes London less efficient is not the location of its facilities but the other previously mentioned factors.

The objective of this section is to evaluate, in each of the four case studies, the location of the existing public primary schools by comparing the resulting coverage in relation to the one that would result from the optimal distribution of these facilities. The results will give us important information to take into account when considering potential policies and planning measures regarding education policies.

5.1 Estimation of the public primary schools optimal location

We have estimated the optimal location of public and private primary schools in the four case studies by using a location model oriented to solve the *Minimize Impedance Problem* (also known as the *P-median* problem defined by Hakimi (1965)), since the solution to this problem is commonly used as a basis to locate public sector facilities (Hamacher & Drezner, 2002). The model locates a defined number of facilities such that the sum of all weighted costs between demand points and the facilities (the demand allocated to a facility multiplied by the impedance to the facility) is minimized. The model has been run in a GIS environment, by applying the *Location-Allocation* tool within the *Network Analyst* extension of the software ArcMap 10.3 (ESRI). This tool calculates network distances and uses the renowned Dijkstra's algorithm for finding shortest paths (Dijkstra, 1959), as well as the *Find Closest Facility* tool used in Section 4 when estimating the existing coverage, so both coverages can be compared. In order to guarantee this comparability, the network has been defined in the same way: considering just pedestrian mobility, excluding non-pedestrian roads such as highways, and introducing the street length as impedance.

Figure 5.1. Optimal location of primary schools and allocated demand. Example in Central London.



5.2 Comparing the existing spatial coverage to the estimated optimal one

This section analyses and compares the primary public school coverage that correspond to the existing facility distribution and to an optimal one, according to what it has been previously defined. In order to evaluate the coverage we have calculated the next distances and index:

- δ_{Pu}: Current average distance to a public primary school in the MUA, estimated as:

$$\delta_{Pu} = \frac{\sum_i \mathrm{P}_{Pi}\,\mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- δ_{Op}: Average distance to a public primary school in the MUA, according to an optimal distribution of facilities, estimated as:

$$\delta_{Op} = \frac{\sum_i \mathrm{P}_{Pi}\,\mathrm{C}_{ij*}}{\sum_i \mathrm{P}_{Pi}}$$

- I_{OA}: Index of current public primary schools coverage in relation to the optimal public primary school coverage estimated as it is defined in Section 5.1. The greater the value the better is the distribution of existing facilities. The maximum value (the corresponding to an optimal distribution) would be 1. The index is estimated as:

$$I_{OA} = \frac{\delta_{Op}}{\delta_{Pu}}$$

Considering:

P_{Pi}: *Total population* in the MUA (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j).

C_{ij}: Cost between the demand points (i) and their corresponding closest existing public school (j) or their corresponding closest school optimally located (j*). For the analysis of this research, the considered cost is always the network pedestrian distance, classified in ranges from 0.25 to 10 km.

Graphs and indexes for each of the four case studies are provided at the end of this section.

When analysing the obtained results, the most surprising finding is that the four cities present very similar level of optimization in the distribution of their public primary schools: the I_{OA} value is 0.740, 0.765, 0.723 and 0.738 for Barcelona, London, Madrid and Rotterdam respectively. The direct consequence is that the different existing coverages obtained for each city are more related to other factors such as the number of existing facilities per capita or other inherent factors of the city (like population density or the urban fabric) than to better location strategies.

For instance, a comparative analysis of Barcelona and Madrid reveals that, having similar levels of optimization in the distribution of facilities, while population per public school is 7,301 and 4,494 in Barcelona and London respectively (London has a 62% more of public primary schools per capita), the optimal average distance to these schools is 0.518 and 0.753 km in Barcelona and London respectively (45% longer distance). The comparison also uncovers that the optimal service coverage London could offer (δ_{Op}= 0.753) is worse than the existing one in Barcelona (δ_{Op}= 0.700), with much more resources deployed.

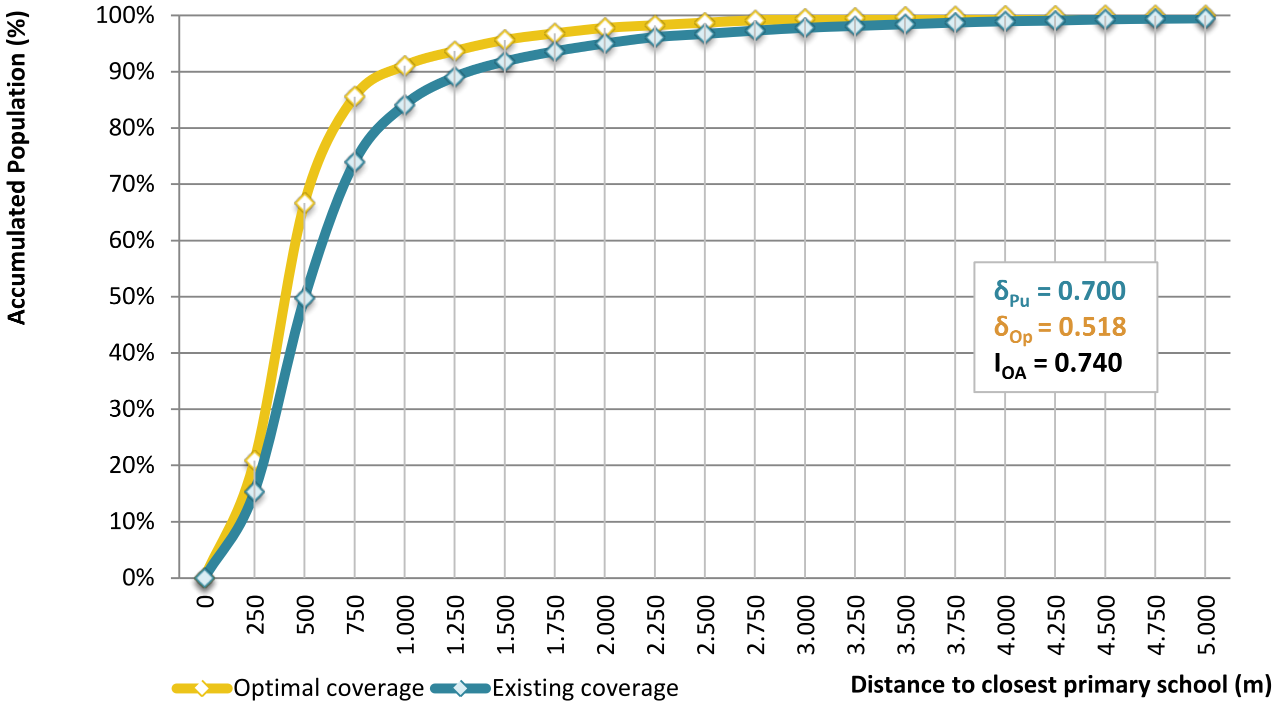
The comparison between Madrid and Rotterdam uncovers the importance of the population density factor. Again, both cities present similar levels of optimization in the distribution of facilities (I_{OA} = 0.723 and 0.738 respectively) but in this case both also have similar number of schools per capita (population per public school is 9,030 and 9,218 respectively). However, the optimal service coverage is significantly better in Madrid (δ_{Op}= 0.630) than in Rotterdam (δ_{Op}= 0.996). Factors like the urban fabric or more probably the poorer network connectivity of Rotterdam because of the interruptions created by the river are not probably having a deep impact on the coverage of this service, since distances to school are not high enough, so the main reason behind this coverage variance is the different population density in both cities: 1,638 people per km^2 in Madrid MUA and 908 people per km^2 in Rotterdam MUA.

The next table reflects the main figures regarding the existing and optimal school coverage in relation to other data such as population density and number of schools per capita, in the four case studies.

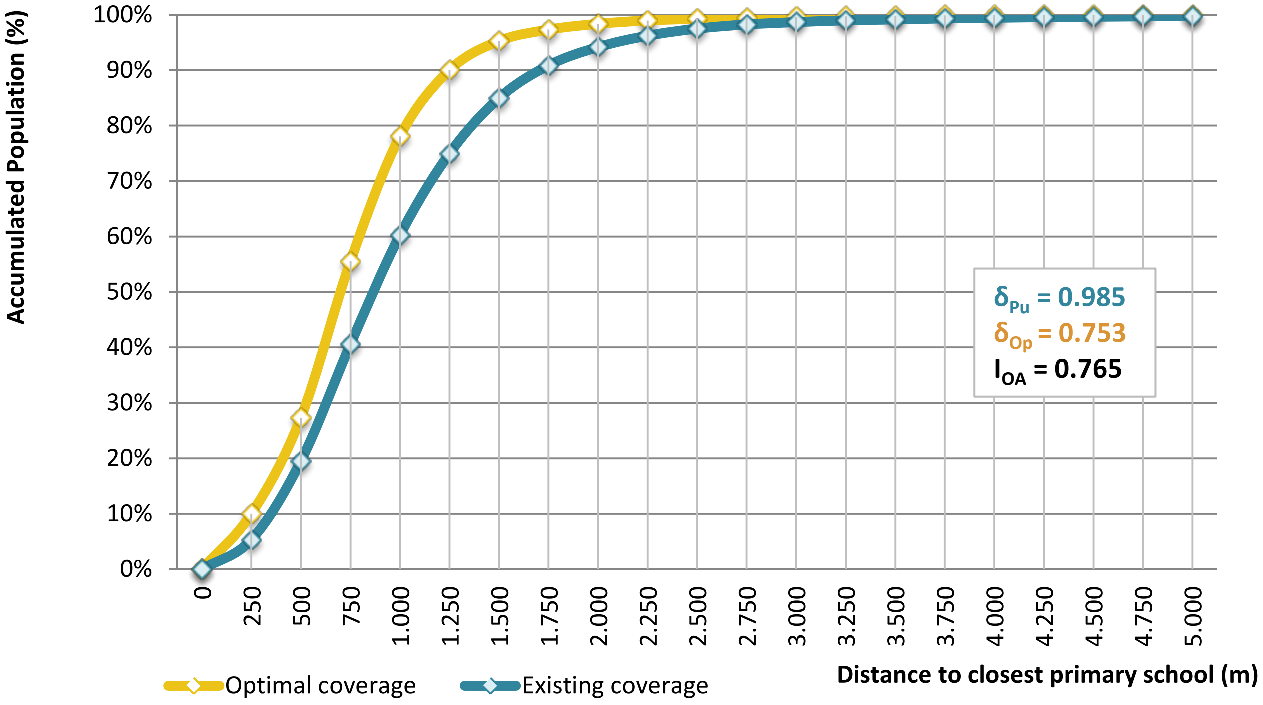
Table 5.1. Existing and optimal primary schools services in the four case studies

Data description	Barcelona	London	Madrid	Rotterdam
Population MUA	3,686,816	9,410,522	5,734,288	1,050,890
Public schools	505	2.094	635	114
Population by public school	7,301	4,494	9,030	9,218
Population density MUA (People per km^2)	3,004	1,568	1,638	908
δ_{Pu}	0.700	0.985	0.866	1.350
δ_{Op}	0.518	0.753	0.630	0.996
I_{OA}	0.740	0.765	0.723	0.738

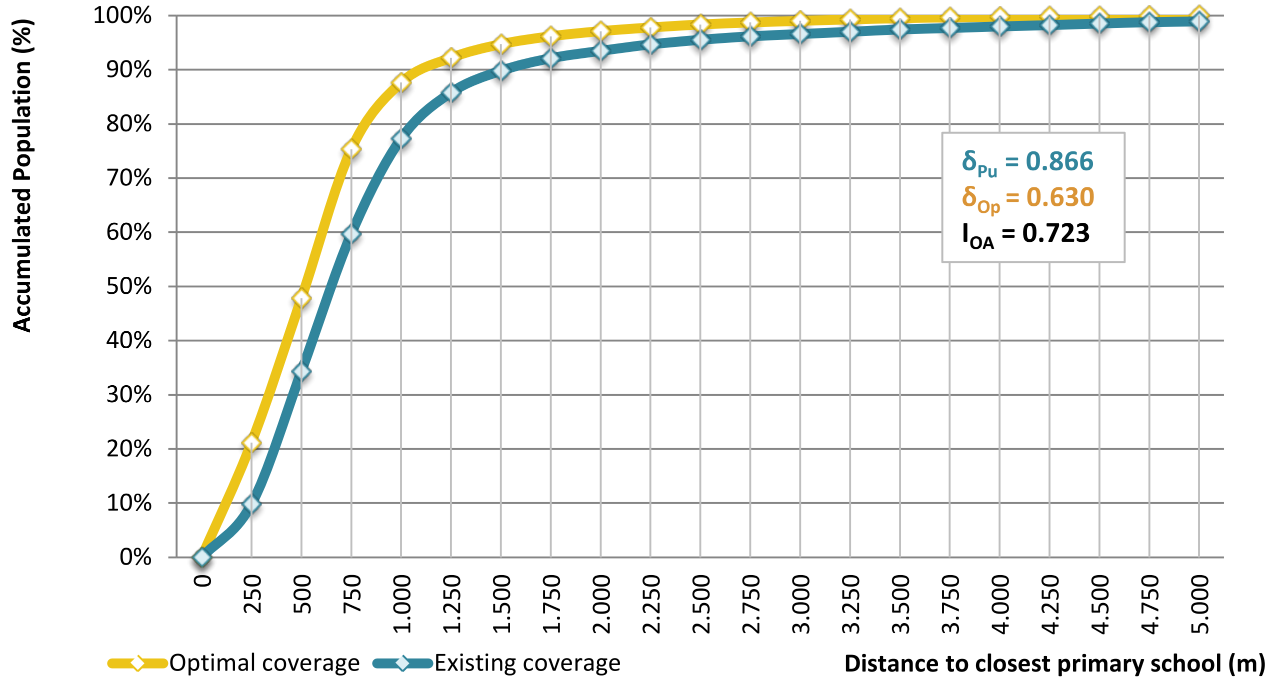
Graph 5.1: Population by distance to closest public primary school in Barcelona



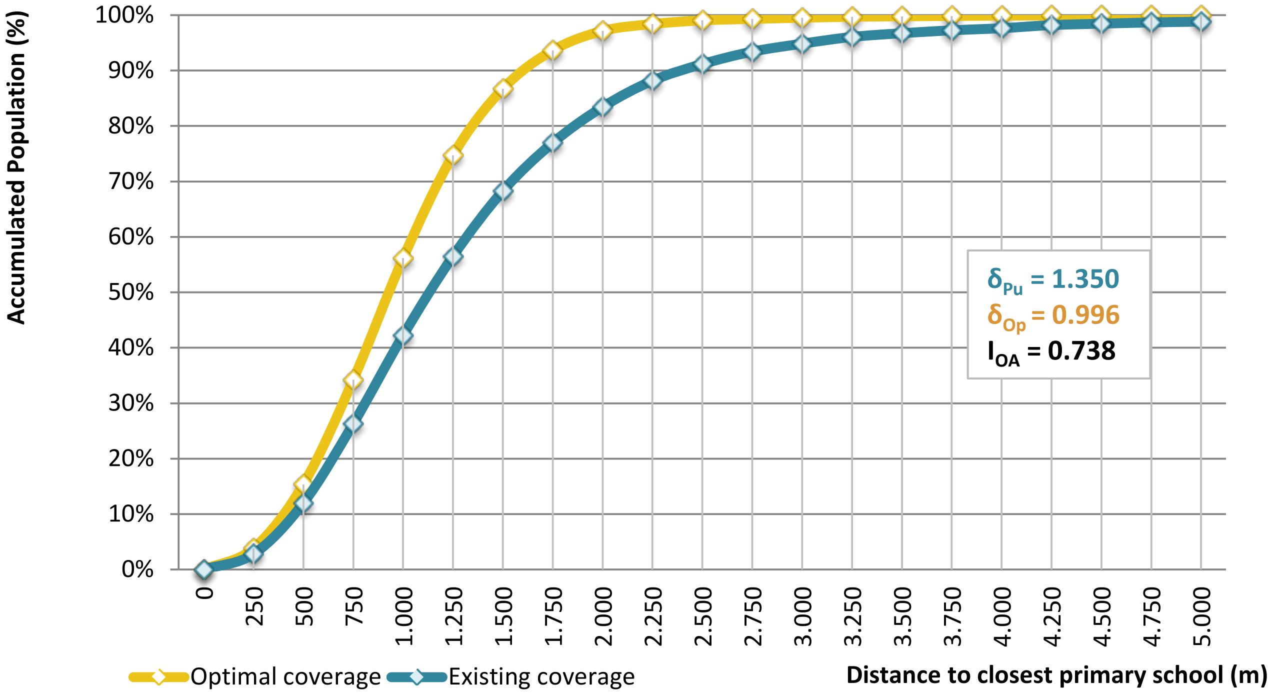
Graph 5.2: Population by distance to closest public primary school in London



Graph 5.3: Population by distance to closest public primary school in Madrid



Graph 5.4: Population by distance to closest *Openbare* school in Rotterdam



6. Modeling potential scenarios

6.1 Definition of potential future scenarios

The general goal of this study is to develop a methodology that may assist policy makers and urban planners when dealing with the location of public services. From the diverse stages distinguished in the Policy Cycle defined in the INSIGHT document *D2.2 Urban Planning and governance: current practices and new challenges*, this methodology aims at being especially useful at three of them: the analysis of current scenario, the definition of policies and measures and the evaluation of future scenarios.

Sections 4 and 5 are focussed on the first stage, since they basically analyse the existing primary school coverage in the four cities and evaluate their degree of optimization. In this section we analyse potential future scenarios related to the application of different measures.

First, a number of measures that are being or may be applied in the current European context have to be defined. As stated in Section 2, in many European countries but especially in the southern ones, austerity policies have led to budget cuts, reducing some basic public services such as education (Theodoropoulou & Watt, 2011) or health (Brand & Rosenkötter, 2013; Karanikolos et al., 2013). It seems then important to work in this scenario of shrinking public resources and analyse the consequences of the application of these cuts so that their impact can be minimized, especially in the most fragile urban areas and for the most vulnerable groups of demand.

Table 6.1 shows a number of possible measures proposed as a result of the different analysis performed and according to the obtained results. The table simplifies the variety of results that could be obtained from the different analyses in order to reduce the number of measures to be finally tested. Location models have been commonly applied to optimally locate new facilities in a growing system, especially recently, due to the existence of fast expanding urban areas in Latin America or Asia (Menezes & Pizzolato, 2014). However, due to the current European context, this section will focus on developing location models that respond to four different measures related to a shrinking public sector policy:

M1.Reducing facilities. Location models will be applied in order to reduce the global number of public schools in an optimal way, so that the service coverage is minimally affected.

M2.Dealing with Public-Private partnerships. This measure could lead to more efficient global service coverage, taking advance of the location of both private and public systems.

M3.Reducing facilities considering choice. A gravity-location model allocates demand not completely to the closest facility but in proportion to the distance to all facilities, considering the presence of competitors.

M4.Relocating facilities. A scenario that combines closing and opening new facilities will be modelled for those cases in which an existing facility distribution is far from being optimal

Table 6.1. Diagnosis and measures related to the obtained public service analysis

Analysis type	Index and distance value	Analysis / Diagnosis	Measures
1. Public and private coverage and service balance	$\delta_{Pu} \leq 0.800$	Good public coverage	Reduce facilities with minimum service coverage reduction (M1)
	$\delta_{Pu} > 0.800$ $I_{SP} << 1$	Poor public school coverage and imbalanced public/private educational service	Promote public-private partnerships (M2)
	$\delta_{Pu} > 0.800$ $I_{SP} \sim 1$	Poor schools coverage	Evaluate school location (5) and promote relocation if necessary (M4)
2. Public service coverage in different urban areas	$\delta_{Pe} > 0.800$	Poor public schools coverage in peripheral areas	Analyse I_{PM}
	$\delta_{M} > 0.800$	Poor public schools coverage in central areas	Analyse I_{PM}
	$I_{PM} \sim 1$	Balanced public service	Reduce facilities with minimum service coverage reduction (M1)
	$I_{PM} >> 1$	Imbalanced public service, with disadvantaged peripheral areas	Avoid reduction of schools in peripheral areas + Promote public-private partnerships (M2)
	$I_{PM} << 1$	Imbalanced public service, with disadvantaged central areas	Avoid reduction of schools in central areas + Promote public-private partnerships (M2)
3. Public service coverage of different groups of demand	$\delta_{T} > 0.800$	Poor public school coverage for the Target group of demand	Analyse I_{PM}
	$\delta_{V} > 0.800$	Poor public school coverage for the Vulnerable groups of demand	Analyse $\mathrm{I_{PM}}$
	$I_{TP} >> 1$	Imbalanced public service, with disadvantaged Target demand	Relocate schools or promote public-private partnerships considering Target demand (M1)
	$I_{VP} >> 1$	Imbalanced public service, with disadvantaged Vulnerable demand	Relocate schools or promote public-private partnerships considering Vulnerable demand (M1)
4. Public service choice	$\delta_{Pu3} > 1.600$	Poor service choice	Reduction of facilities considering choice (M3)
	$I_{PuCH} << 1$	Poor relative public service choice	Relocate schools by choosing centres with a Maximize Market Share model
	$I_{PuCH} \geq 0.660$	Good relative public service choice	Reduce facilities with minimum service coverage reduction (M1)
5. Evaluation of Public service location	$I_{OA} \sim 1$	Good public facility distribution. (The closest the value is to 1 the more optimized is the distribution)	Evaluate school coverage (1) and reduce facilities with minimum service coverage reduction (M1)
	$I_{OA} << 1$	Bad public facility distribution	Evaluate school coverage (1) and promote relocation of facilities if necessary (M4)

6.2 M1: Reducing facilities

This section analyses the changes of the public service coverage in the hypothetical scenario of having to reduce the number of public facilities by 10% in the four case studies.

Two location models have been applied in order to reduce the global number of public schools in an optimal way, so that the service coverage is minimally affected. The first one takes into account the capacity of facilities so that population is allocated considering this limitation. The second one simplifies the estimation and allocates the demand to the closest facility regardless its capacity. Both models have been applied to the city of Barcelona in order to compare the results. Since we have no data about the real capacity of centres and both results do not differ significantly, only the second location model has been applied to the four case studies.

In order to evaluate the new service coverage, we have calculated the next distances and index:

- δ_{Pu}: Current average distance to a public primary school in the MUA, as estimated in Section 4.
- δ_{r90}: Average distance to a public primary school in the MUA, considering the reduction of facilities, estimated as:

$$\delta_{r90} = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij*}}{\sum_i \mathrm{P}_{Pi}}$$

- I_{r90}: Index of service coverage reduction. The index shows the increase of the average distance to schools when reducing the number of facilities according to the model applied. The index is estimated as:

$$I_{r90} = \frac{\delta_{r90}}{\delta_{Pu}}$$

Considering:

P_{Pi}: *Target group of demand* (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j).

C_{ij}: Cost between the demand points (i) and their corresponding closest existing public school (j) or their corresponding closest remaining school taking into account the reduction of facilities (j*). For the analysis of this research, the considered cost is always the network pedestrian distance.

The application of both location models is described next and the corresponding graphs and indexes are provided in the next section 6.3, together with the results of the application of measure M2.

6.2.1 Reducing facilities considering capacity

Considering that closing centres implies distributing their corresponding demand among the remaining centres, we should take into account the limited capacity of schools in order to get more realistic results. Data about the current demand and the maximum capacity of primary schools were not available, so they have been supposed as described next.

First, a provisional allocation of demand has been estimated by assigning the *Target group of demand* (as defined in Section 3.3.3) to the closest existing facility, with no capacity limitations. We applied the same location model used in Section 5, based on solving a *Minimize Impedance Problem*, in this case with a defined number of facilities (all the existing ones) such that the sum of all weighted costs between demand points and the facilities is minimized. Then we have established a maximum capacity according to the obtained results. We decided to exclude the top 10% of most demanded schools (in very dense areas, some of the schools reached 4,000 students) and the capacity of schools was limited to 900 students.

Then, another location model has been applied considering the finite capacity we established before, by using the *Location-Allocation* tool within the *Network Analyst* extension of the software ArcMap 10.3 oriented to solve the *Maximize Capacitated Coverage* problem type. The model reallocated the *Target group of demand* and adjusted it to what we considered a better approximation to the real demand distribution.

Finally, a maximum school capacity has been estimated, considering that schools could host a number of extra students (by densifying the existing facilities). We limited the maximum capacity to an extra 20% of students at the most, supposing that this densification could be viable. The model was run again considering these new capacities. All the existing schools were defined as “candidates” in the model but the “facilities to choose” were limited to a 90% of them, leaving out the 10% less efficient in relation to the *Minimize Impedance Problem*, already defined in Section 5.

6.2.2 Reducing facilities regardless of capacity

In this case we have applied the same location model used at the first stage of the previous section, based on solving a *Minimize Impedance Problem*. We used the *Location-Allocation* tool within the *Network Analyst* extension of the software ArcMap 10.3 oriented to solve the mentioned problem without limiting the capacity of schools. Again, all the existing schools were defined as “candidates” in the model and the “facilities to choose” were limited to a 90% of them, leaving out the top 10% inefficient public primary schools.

Both models were applied in Barcelona with no significant difference in the obtained results. When reducing facilities considering capacity, we obtained I_{r90*}= 1.113 and when applying the model regardless of capacity we obtained I_{r90}= 1.093 (see Graph 6.1). Greater differences would be expected when considering real school capacities instead of the estimated ones, but since this information is not available, the comparative analysis of the four case studies has been done according to the results obtained from the application of the second model.

6.3 M2: Dealing with public-private partnerships

Public-Private Partnerships (PPPs) are experimenting a global resurgence, becoming more and more popular (Hodge & Greve, 2007) and increasingly present in sectors like health (Buse & Walt, 2000) or education (Patrinos, Osorio, & Guáqueta, 2009). Leaving aside the debate around PPPs advantages and disadvantages present in the literature (Hodge & Greve, 2007), in the context of this study it is interesting to explore the possible benefits that these partnerships would bring.

Reducing public facilities is a dramatic measure that leads to poorer public service coverage and the previous location models can just minimize its impact. Dealing with PPPs may be a complementary measure that, with a minimum economic impact, would lead to more efficient global service coverage, taking advantage of the location of both private and public systems. Furthermore, PPPs can be considered also a good measure to reduce social segregation (one of the main objectives according what is considered in Section 1) since they would allow a number of people with limited resources to attend private schools.

PPPs could be especially interesting in those cases in which the analysis of the existing public and private coverage (Section 4.1) reveals a poor public coverage ($\delta_{Pu} > 0.800$) and a public-private imbalanced educational service ($I_{SP} << 1$). The measure would be proposed in the urban areas where public facilities are deficient, poorly covering a small demand that could be benefited from the presence of close private centres partially funded by the state.

With the aim of analysing the possible benefits of promoting PPPs, we have modelled its application as a complementary measure in the previously defined hypothetical scenario of having to reduce the existing number of public facilities by 10%. In this case, the students of the closing schools could be distributed among the closest schools, considering not only the remaining public schools but also the private ones. In order to limit the offer of possible partnerships, the number of private schools will be restricted to the same number of closed public schools (10% of them).

In a first step, we have applied the same location model previously used to optimally reduce the number of public facilities by selecting the 90% by using the *Location-Allocation* tool within the *Network Analyst* extension of the software ArcMap 10.3 oriented to solve the *Minimize Impedance Problem* without limiting the capacity of schools. Again, all the existing schools were defined as “candidates” in the model and the “facilities to choose” were limited to a 90% of them, leaving out the top 10% inefficient public primary schools.

In a second step, the model was run again introducing the same demand (the Target group of demand as defined in Section 3.3.3) but considering as potential facilities not only the remaining public schools, introduced as “required” facility type, but also the private schools, introduced as “candidates”. Finally the number of facilities to choose has been set to 100% of the originally existing public schools.

The obtained results define the demand allocated to the chosen private schools, whose capacity of hosting extra-students could be limited according to their real capacity. Since we do not have this information, a maximum capacity has not been defined.

In order to evaluate the new service coverage obtained from the application of modelled PPPs measures and compare it with the coverage obtained by just reducing the number of facilities, the next distances and indexes have been calculated:

- δ_{Pu}: Current average distance to a public primary school in the MUA, as estimated in Section 4.
- δ_{r90}: Average distance to a public primary school in the MUA, considering the reduction of facilities, estimated as in Section 6.2.1.
- δ_{PPPs90}: Average distance to a public primary school in the MUA, considering the reduction of facilities according to the gravity location model applied, estimated as:

$$\delta_{PPPs90} = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij*}}{\sum_i \mathrm{P}_{Pi}}$$

- I_{PPPs90}: Index of service coverage improvement considering PPPs. The index shows the reduction of the average distance to schools when reducing the number of facilities considering possible PPPs.

$$I_{PPPs} = \frac{\delta_{PPPs90}}{\delta_{r90}}$$

Considering:

P_{Pi}: *Target group of demand* (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j).

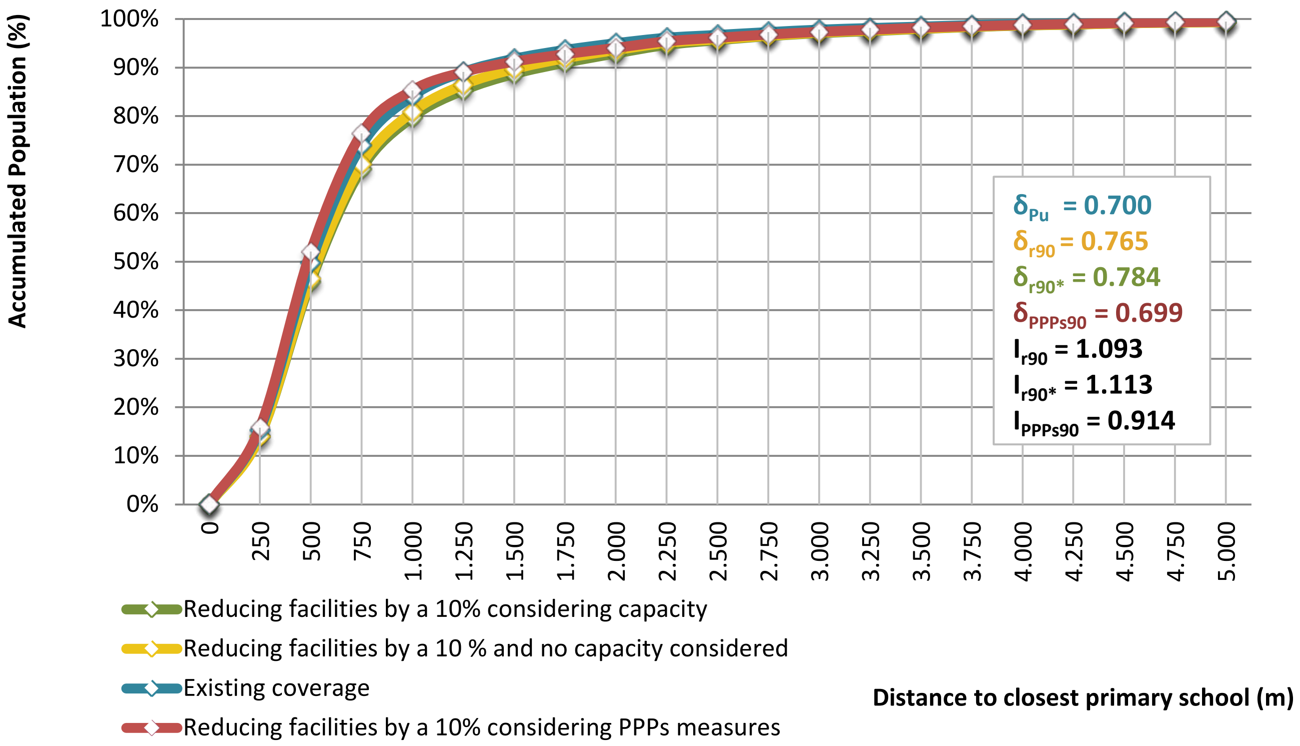
C_{ij}: Cost between the demand points (i) and their corresponding closest existing public school (j) or their corresponding closest remaining public school or private school (j*).

The corresponding graphs and indexes (provided next) show that the reduction of the existing facilities by 10% would not lead to a substantial increase of average distance to school (with the exception of Barcelona where it is increased by 10%) if the schools to drop out are selected following the methodology described in the previous sections. However, it is important to highlight that the redistribution of students has been done assuming that schools could afford an extra 20% of the current number of students, something that may not be possible in some cases. For more accurate results, the analysis should be done considering the existing capacities and the real maximum ones.

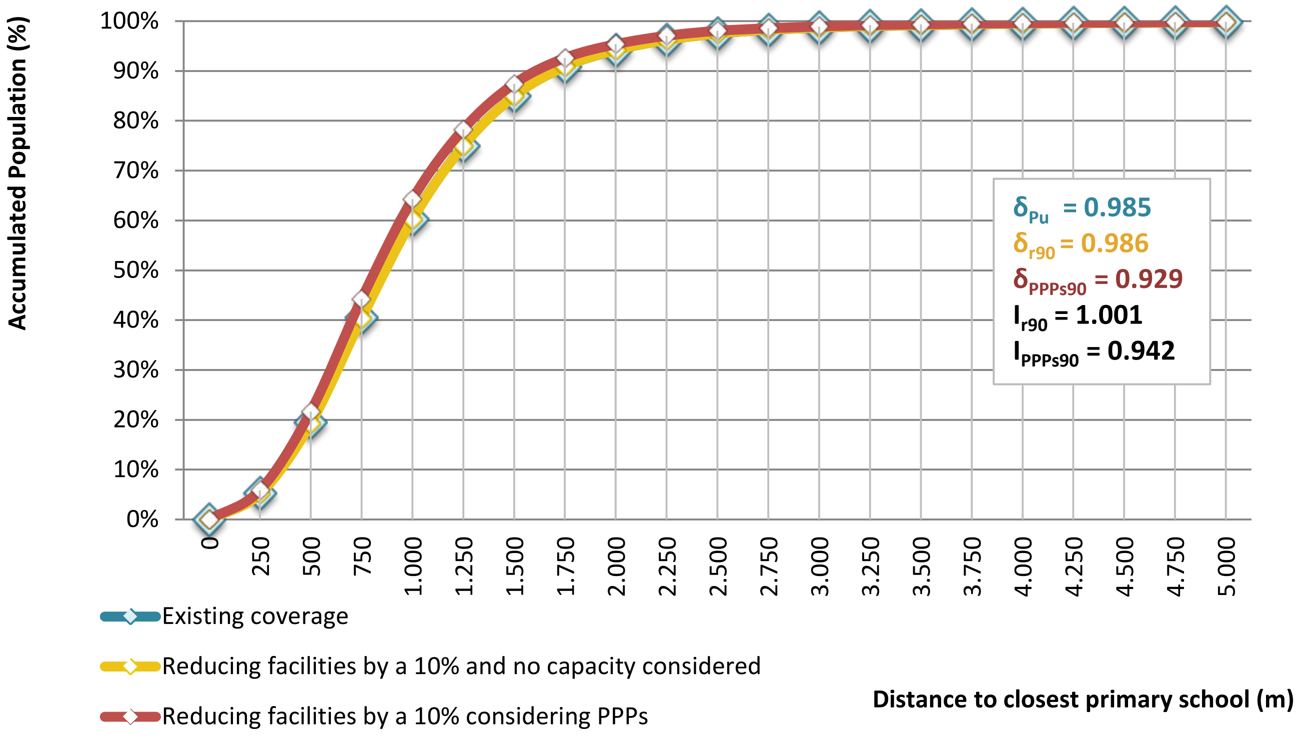
In contrast, considering Public-Private Partnerships as proposed in this section would have significant positive impact. In the four case studies this measure would reduce the average distance to school not only compared to the first scenario (facilities reduced by 10%) but also to the original scenario. This fact indicates that the locations of the 10% closed public schools were inefficient compared to the selected private ones.

In the particular case of Rotterdam, we have to consider that the schools are not really classified in Public / Private but in *Openbare* / *Denominatie* schools, so the proposed partnership would be between these two different kinds of schools.

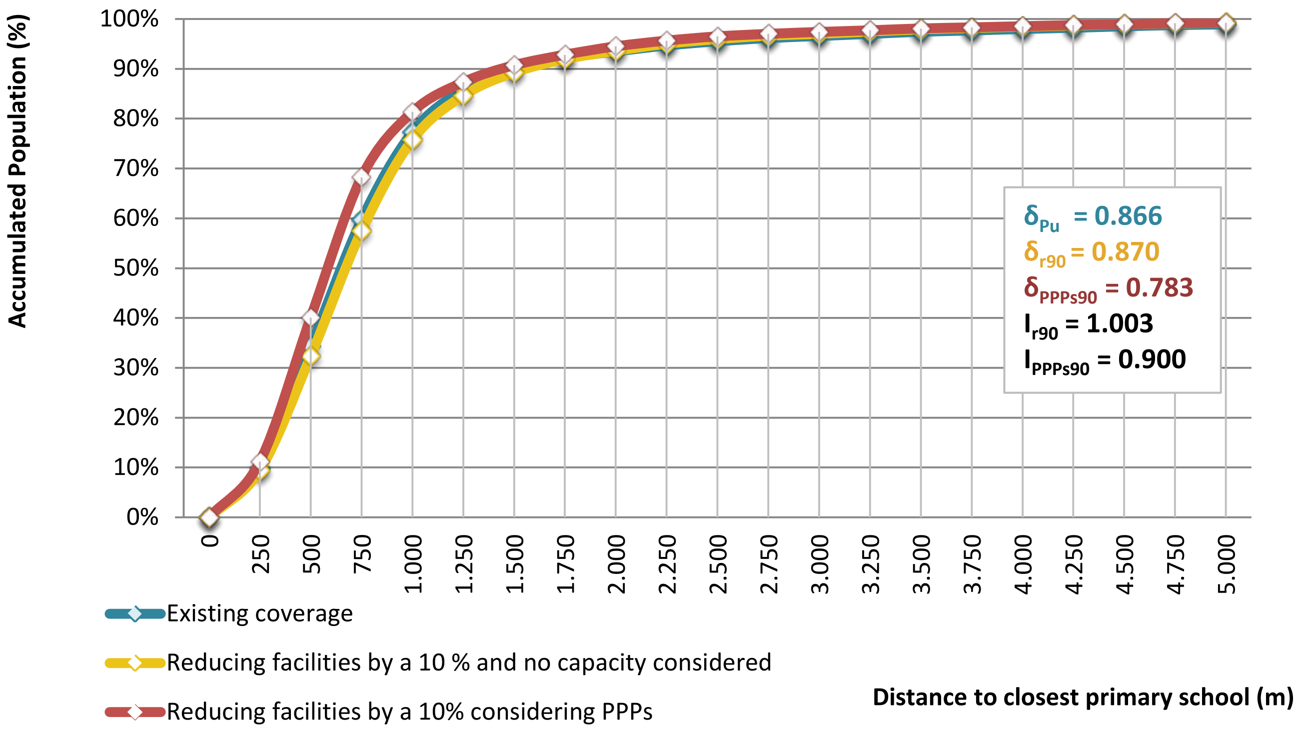
Graphic 6.1: Population by distance to closest primary school in Barcelona



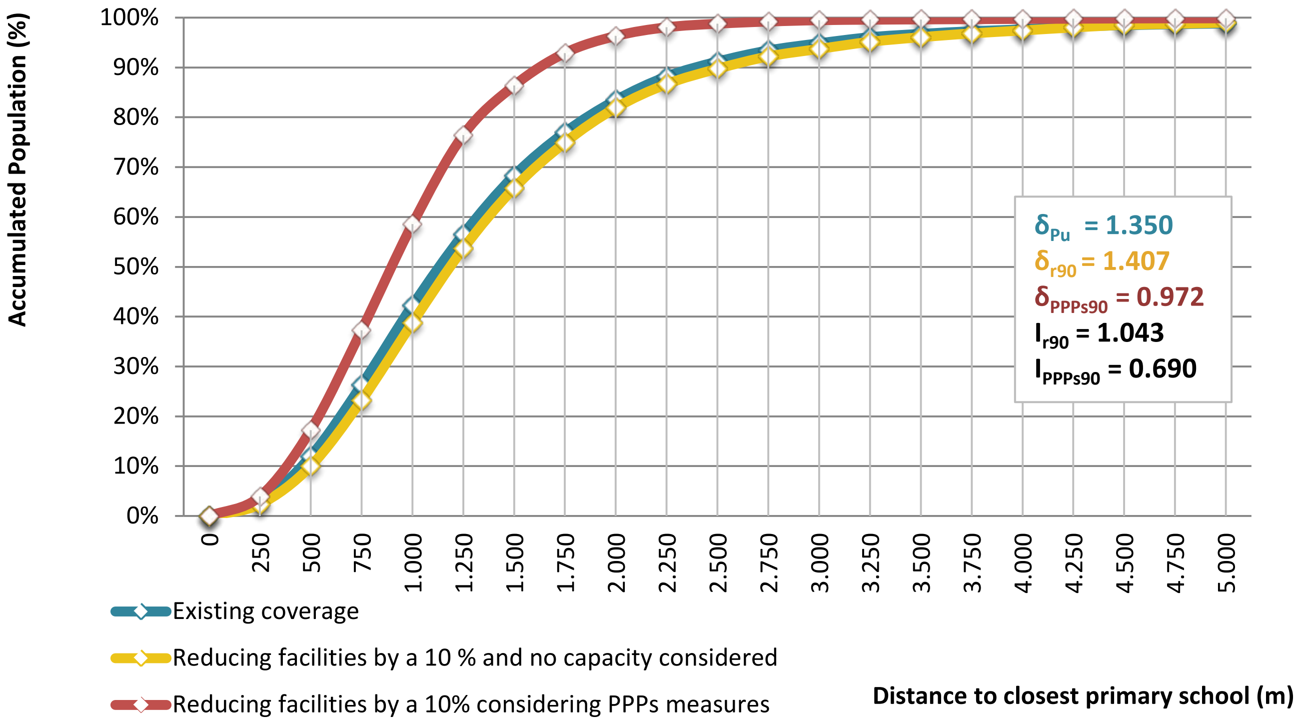
Graphic 6.2: Population by distance to closest primary school in London



Graphic 6.3: Population by distance to closest primary school in Madrid



Graphic 6.4: Population by distance to closest primary school in Rotterdam



6.4 M3: Reducing facilities considering choice

As mentioned in Section 4.5, increasing public service choice is becoming one of the main objectives in Europe since people are increasingly demanding diversity in the public offer, especially in services like transport or education. Regarding primary education, parents choose a school considering different criteria. According to Ibrahim et al (2014), the most important considered factor is academic performance, the second one is location and then there are other important factors like school facilities. Therefore, although distance to school is one of the main factors, it is not determinative. Children do not necessarily attend the closest school.

In consequence, public service policies should undertake not only the presence of at least one school as close as possible but also the existence of several more at a reasonable distance so that the possibility of choice can be guaranteed. Accordingly, location models should consider this choice when estimating the optimal distribution of a limited number of resources.

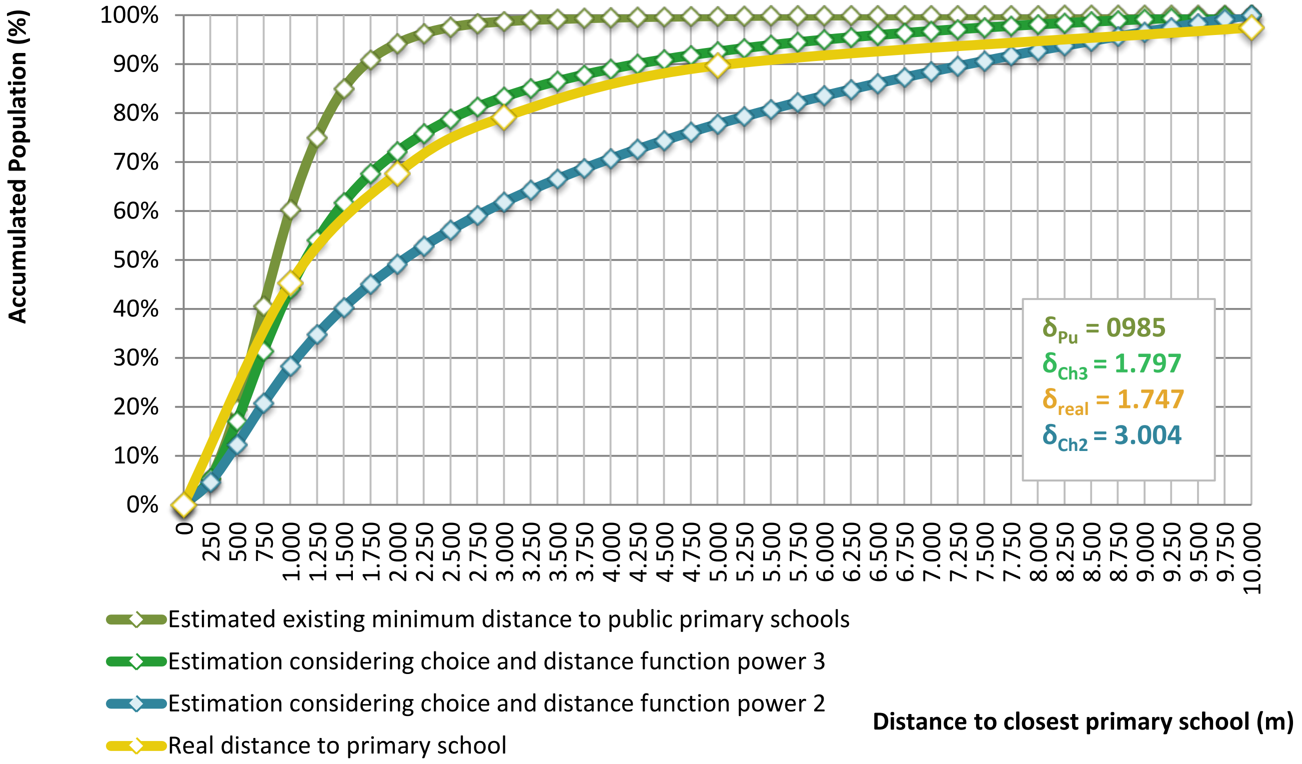
In the context of this study, assuming the previous hypothetical scenario of having to reduce the existing number of facilities by 10%, a gravity location model has been applied in order to estimate the most efficient schools (the remaining 90%) considering choice. The gravity location model does not assign the demand to the closest facility but to all facilities according to a distance function, considering the presence of "competitors". This distance function may vary substantially across different cities, depending basically on how much extra distance people are willing to travel to a school that they consider better than the closest one. In order to get realistic results, the model should be calibrated by considering the distance function that better adjusts the estimated average distance to the existing schools to the real distance that could be obtained from local transport surveys.

This information was available in the case of London (*Census at school*, 2011), so different distance functions were introduced in the model, a linear function and two power functions (with values 2 and 3) obtaining the different results that are illustrated in the Graph 6.5. This graph also shows that accumulated population by distance estimated by applying the power 3 distance function in the model was the one that better fitted the real average distance to school, so this is finally the one considered in London when applying the model again in order to estimate the effects of reducing the number of facilities by 10%. In absence of this real distance to school information for the other three case studies, we have considered the same distance function, so the four case studies could be compared. The application of this model is supposed to estimate more truthful average distances to school. In order to evaluate the impact of a reduction of the existing facilities by 10%, the model has been also applied to the current scenario (100% of facilities), so that both results can be compared.

The model has been run in a GIS environment by applying the *Location-Allocation* tool within the *Network Analyst* extension of the software ArcMap 10.3. It has been oriented to solve what the software names the *Maximize Target Share problem*. By considering the presence of competitors and the mentioned allocation of demand to all facilities according to a defined distance function, the model chooses the set of facilities that maximize the total allocated demand.

This tool calculates network distances and uses the Dijkstra's algorithm for finding shortest paths (Dijkstra, 1959), as the other models used in this study does. With the aim of reducing calculations, a cut-off distance has been considered and established in 10 Km, since the demand assigned to schools located at greater distances is not relevant. Finally, in order to guarantee the comparability with the other analyses of this study, the network has been defined in the same way: considering just pedestrian mobility, excluding non-pedestrian roads such as highways, and introducing impedance as the street length (metres).

Graphic 6.5: Population by distance to primary school in London



In order to evaluate the new service coverage, the next distances and indexes have been calculated:

- δ_{r90}: Average distance to a public primary school in the MUA, considering the reduction of facilities, estimated ass in Section 6.2.1.
- δ_{rCH90}: Average distance to a public primary school in the MUA, considering the reduction of facilities according to the gravity location model, estimated as:

$$\delta_{rCH90} = \frac{\sum_i \mathrm{P}_{Pi}\, \mathrm{C}_{ij*}}{\sum_i \mathrm{P}_{Pi}}$$

- I_{rCH90}: Index of service coverage reduction considering choice. The index shows the “extra” distance people would be willing to travel with respect to the distance to the closest facility, according to the function distance introduced (power 3 in the four study cases) in the gravity location model applied. The index is estimated as:

$$I_{rCH90} = \frac{\delta_{rCH90}}{\delta_{r90}}$$

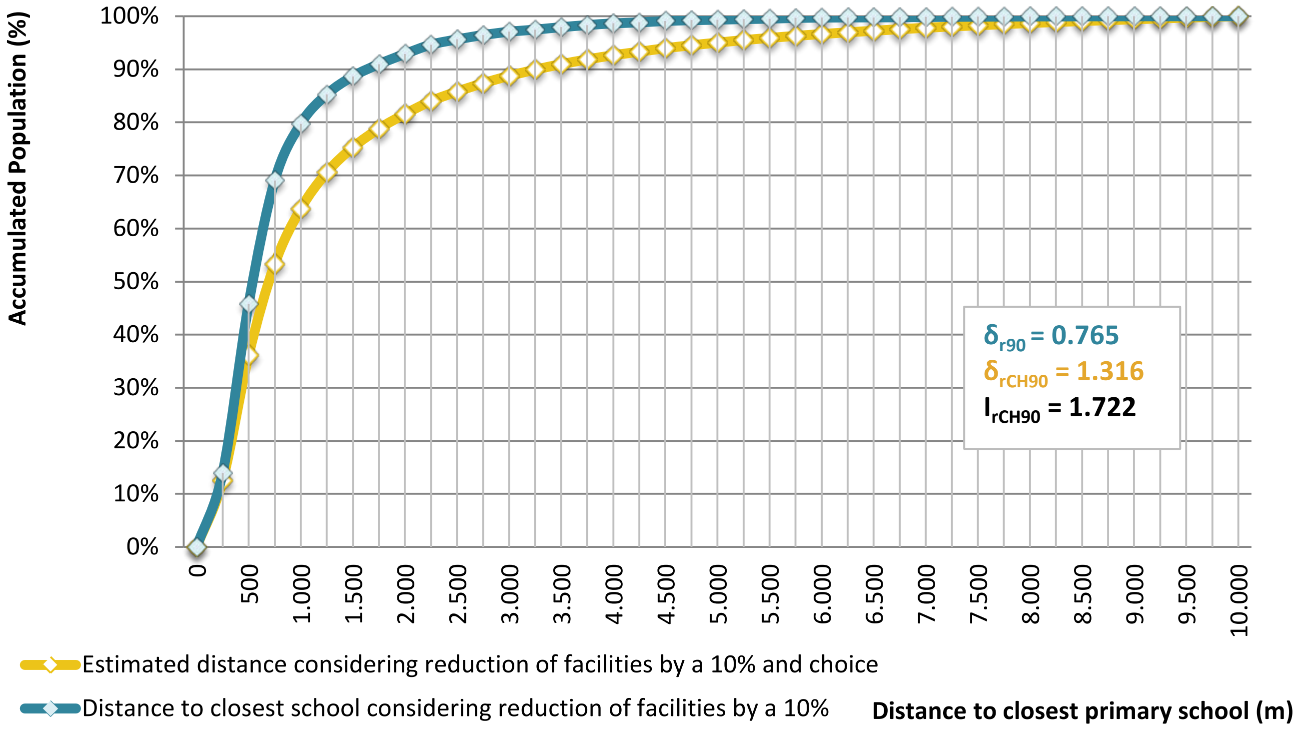
Considering:

P_{Pi}: *Target group of demand* (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j).

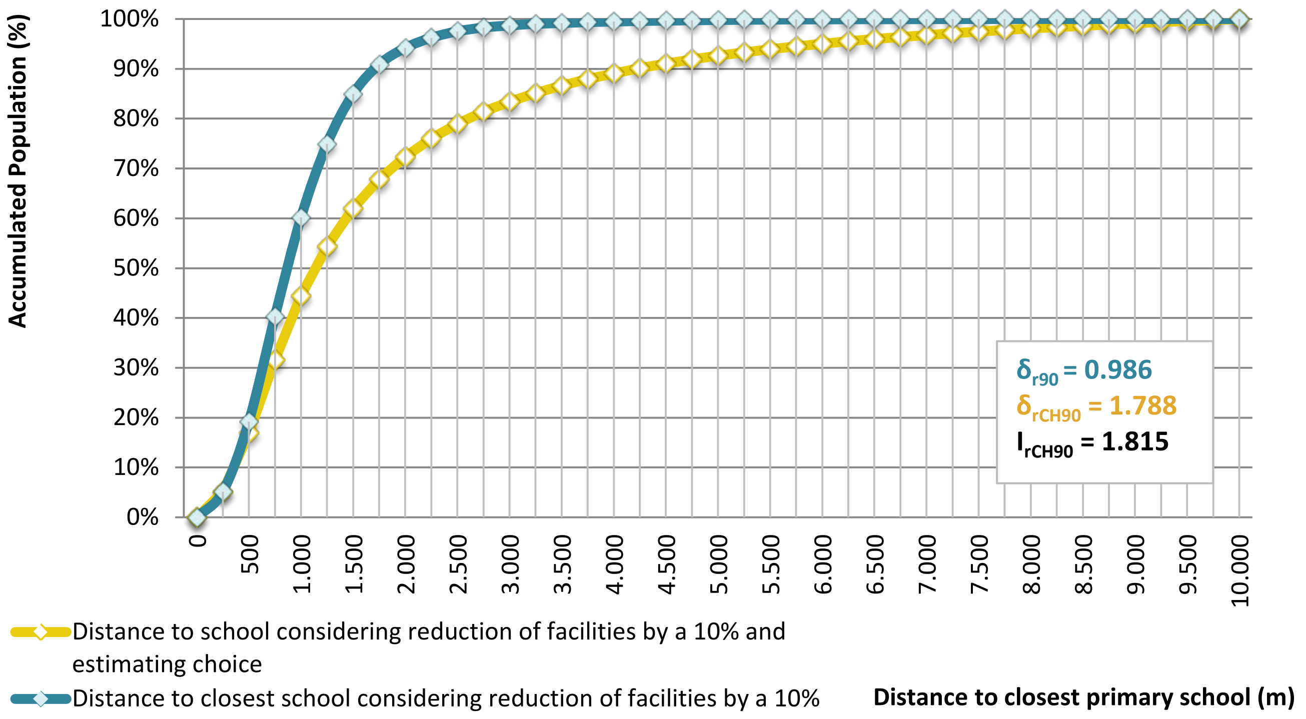
C_{ij}: Cost between the demand points (i) and their corresponding closest existing public school (j) or their corresponding closest remaining school taking into account the reduction of facilities defined by the application of a gravity location model (j*).

The corresponding graphs and indexes (provided next) show the big difference between the average distance to the closest facility and the "real" one that people travel. They also evidence the importance of considering choice when analysing the location of facilities and the way they may affect, for instance, to the real walk mode share analysed in Section 4, which should be estimated according to these distances.

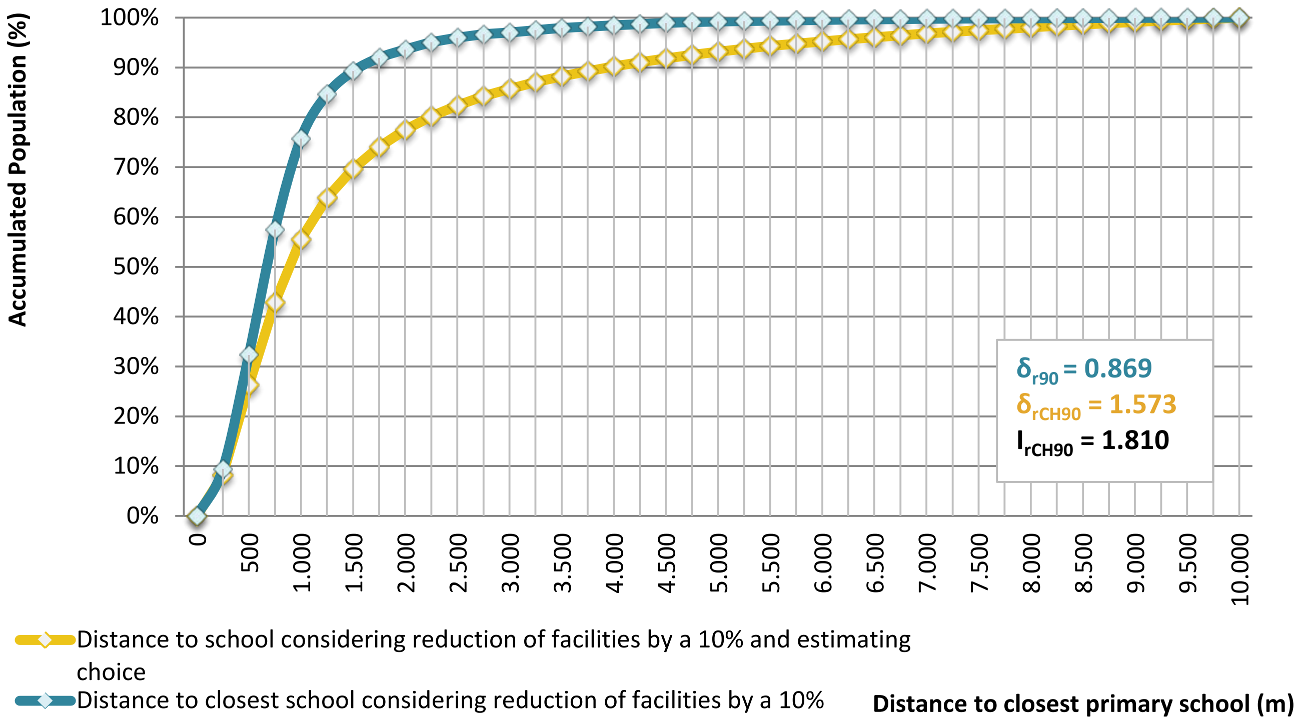
Graphic 6.6: Population by distance to closest primary school in Barcelona



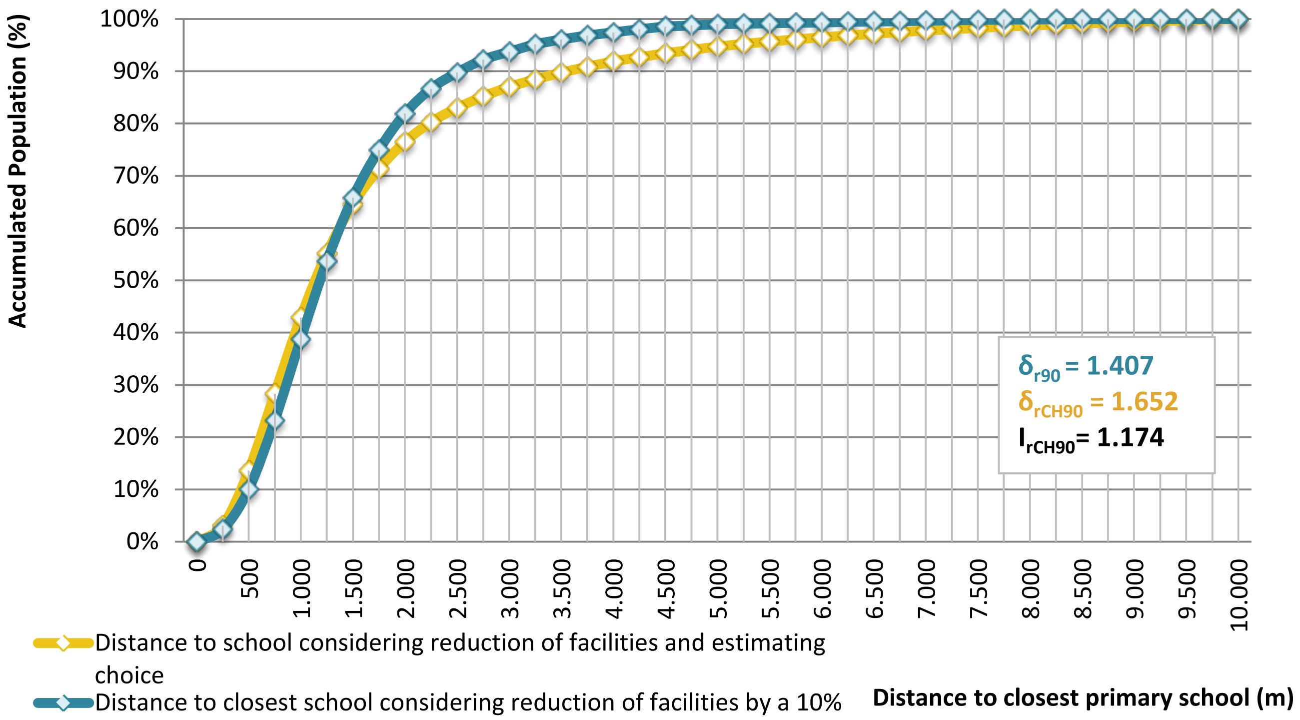
Graphic 6.7: Population by distance to closest primary school in London



Graphic 6.8: Population by distance to closest primary school in Madrid



Graphic 6.9: Population by distance to closest primary school in Rotterdam



6.5 M4: Relocating facilities

The public service distribution analysed in Section 5 may reveal that the location of facilities is far from being optimal. Relocating facilities is an expensive measure, but its adoption may be necessary in critical cases, when other measures to increase service coverage, like Public-Private Partnerships (PPPs), cannot be adopted.

The methodology is similar to the one followed in Section 6.3 when considering PPPs measures. In a first step a Location model oriented to solve the *Minimize Impedance Problem* has been applied in order to select the most efficient 90% of facilities and drop out the 10% most inefficient ones. In a second step, the model was run considering the same Target group of demand and setting as potential facilities the remaining 90% of public schools, introduced as "required" facility type, and a large number of "candidates" distributed all across the MUA (we have used the population point dataset of the four case studies, that range from 15,000 to 37,000 points). Finally the number of facilities to choose has been set to the number of originally existing public schools.

Since the analysis of the level of optimization of the service facility distribution in the four case studies (Section 5) does not reveal significant differences, we do not expect relevant variations between them. The model has been just applied in the city of London.

In order to evaluate the new service coverage, the next distances and indexes have been calculated:

- δ_{Pu}: Current average distance to a public primary school in the MUA, as estimated in Section 4.
- δ_{rloc10}: Average distance to a public primary school in the MUA, considering the relocation of 10% of the existing facilities according to the location model, estimated as:

$$\delta_{rloc10} = \frac{\sum_i \mathrm{P}_{Pi}\,\mathrm{C}_{ij}}{\sum_i \mathrm{P}_{Pi}}$$

- I_{rCH90}: Index of service coverage improvement due to the relocation of facilities, estimated as:

$$I_{rCH90} = \frac{\delta_{rloc10}}{\delta_{Pu}}$$

Considering:

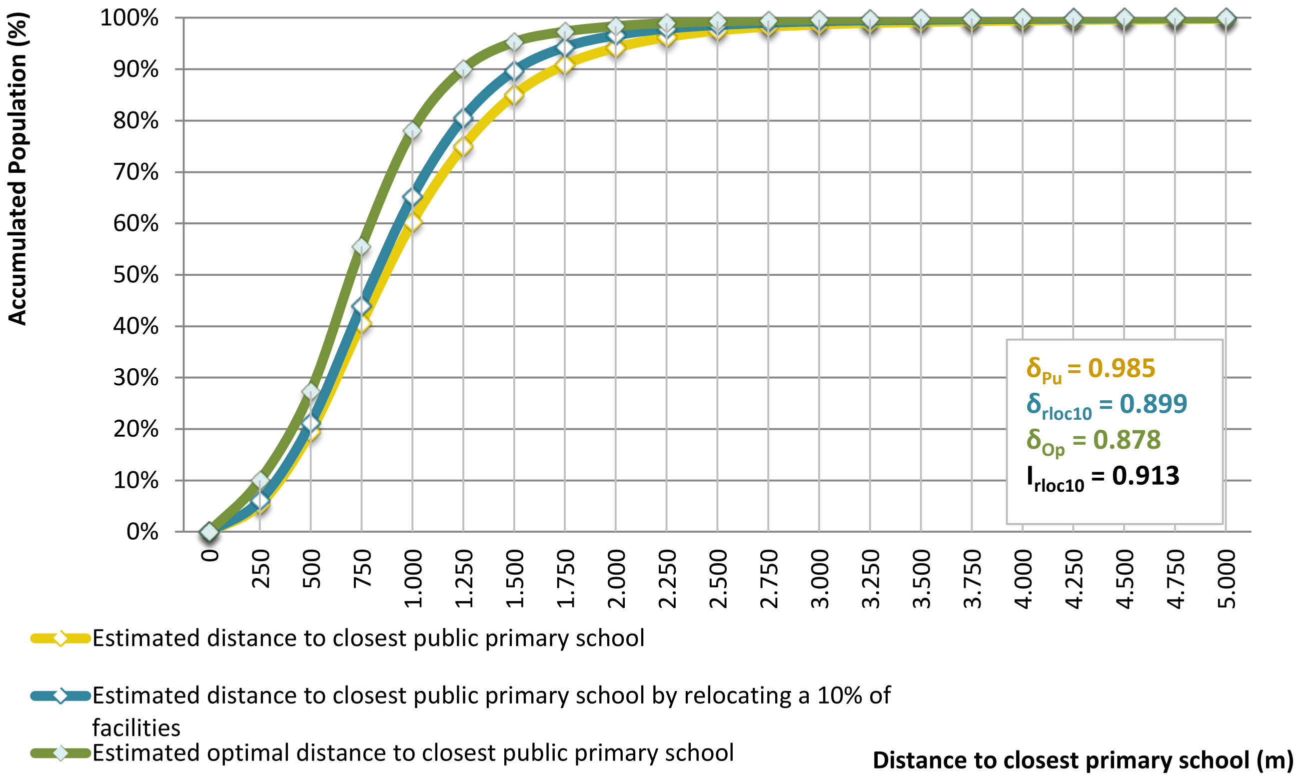
P_{Pi}: *Target group of demand* (as defined in section 3.3.3) accumulated in the points (i) at a specific range of cost from their closest facility (j).

C_{ij}: Cost between the demand points (i) and their corresponding closest public school (j). For the analysis of this research, the considered cost is always the network pedestrian distance, classified in ranges from 0.25 to 10 km.

The results (represented in the graph, distances and index provided next) are surprising. They reveal an important improvement of the service coverage (I_{rCH90}= 0.913), specially taking into account that the average distance to the closest school went down from δ_{Pu}=0.985 to δ_{rloc10}= 0.899 and considering that the distance to the closest school in the scenario of an optimal distribution of facilities was δ_{Op}= 0.878, only 13 m lower.

Relocating all public schools is an unrealistic measure, whose consequences were estimated in this research in order to get an optimization index of the existing location of facilities. However, relocating a limited number of facilities may be feasible in some extreme cases (in which the location of certain schools is clearly inefficient) and really beneficial as the London case studies evidences.

Graphic 6.10: Population by distance to closest primary school in London



7. Conclusions

The goal of this research was to explore the application of different location models to different case studies in order to create new approaches and methodologies that may be useful to policy makers and urban planners at some of the *Policy Cycle* stages (such as the analysis of the current scenario, the definition of policies and measures and the evaluation of future scenarios) when dealing with public services. The main objective has been achieved by proposing different useful applications and methodologies, based on the use of location models that revealed important information at different levels, from the evaluation of the service facility distribution to the estimation of possible inequalities or imbalances derived from it.

Regarding the application of diverse location models in the analysis of the current public services, some considerations and findings may be highlighted:

- The analysis of public service should be performed considering the existence of the private one. It is not possible to understand each of them separately, since they are complementary. Analysing just the public system may lead us to consider that a service is poorly covered while it can be simply mostly covered by the private sector, revealing possible inequalities. Furthermore, detecting these public-private imbalances is also important in the current context of the European Union, as one of the main goals is reducing the growing social polarization that threats many of its cities.

  The analysis of the four case studies reveals significant differences in the public service coverage as well as in the overall coverage including the private sector. These differences become more significant when considering the amount of resources displayed per capita, evidencing the importance of different urban variables, especially the population density.

- At the same time, considering different urban areas is important in order to identify possible spatial imbalances that can contribute to the manifestation of spatial segregation. The analysis of the central urban areas and the peripheral one, or the spatial analysis of the whole metropolitan area in a more disaggregated way, may reveal the existence of significantly different service coverages. This kind of analysis should be taken into account when considering possible measures oriented to reduce public services, so that the impact in the areas that are currently poorly covered is minimized.

- Taking into account different groups of demand is also essential when analysing public services, since most of them are mainly oriented to a specific segment of the population and also because it is relevant to analyse specifically those groups that are more dependant of public services, as they are the ones that could suffer more the consequences of public service cuts. The analysis of the three considered groups of demand (*Total population, Target population and Vulnerable population*) reveals that, fortunately, there are not significant imbalances in the four case studies. Furthermore, the estimated public coverage of the *Vulnerable population* group was greater than the obtained for the *Total population* one in the four cities.

- The comparison of the existing public service coverage to the ideal one, derived from the optimal location of the existing facilities (Section 5), is an important analysis in order to evaluate the level of optimization in the distribution of facilities. The analysis also evidences the limits established by the "nature" of the city (defined by basic characteristics such as its population density or its urban morphology) and to what extent location models may play an important or a limited role in the improvement of the service coverage. Since similar levels of optimization are found in the four case studies, the substantial differences found in the analysis of existing coverage (Section 4) brings out the importance of the mentioned characteristics.

With respect to modelling the potential scenarios that may result from the application of specific measures, we would like to underline that:

- The application of different location models is really useful in order to evaluate measures and propose alternative or complementary ones. Furthermore, this is crucial in the current European context, since these measures can minimize the effect of the application of austerity policies. Dealing with Public-Private Partnerships (PPPs) or relocating facilities may not only minimize this effect but can even improve the global service.

- The different approaches based on the application of location models allowed us to estimate the future scenarios that may result from the application of a specific measure and evidenced the different consequences that this measure could have in different locations. This fact reinforces the idea that policies can be globally launched but they must be applied through specific measures that are sensitive to the local characteristics and particularities of each city or urban area.

- Gravity -location models may be used to simulate the impact of choice by calibrating distance function (Section 6.4). The use of these gravity models is fundamental when estimating the real average distance to school instead of average distances to closest school. This real distance is also crucial when estimating the transportation mode share, particularly the walk mode share. And we must highlight that increasing the walk mode share in trips to school is one of the common objectives in many countries.

Finally, we would like to point to future research and applications. Although this study is focussed on the analysis of public primary education, the different approaches and methodologies developed here can be applied to other public services, helping policy makers and urban planners to think about, define, analyse, simulate and evaluate more sustainable and effective policies and measures.

Annex 1. Abbreviations and Acronyms

EEA: European Environment Agency

ESPON: European Observation Network, Territorial Development and Cohesion

FUA: Functional Urban Areas

GIS: Geographic Information Systems

GISCO: Geographic Information System at the European Commission

LUZ: Large Urban Zones, as defined by Urban Audit

MAUP: Modifiable Areal Unit Problem, firstly defined by Kendall (1939)

PPPs: Public-Private Partnerships

UMZ: Urban Morphological Zones, as defined by EEA

References

Alçada-Almeida, L., Coutinho-Rodrigues, J., & Current, J. (2009). A multiobjective modeling approach to locating incinerators. *Socio-Economic Planning Sciences*, *43*(2), 111–120.

Ashley, L., Duberley, J., Sommerlad, H., & Scholarios, D. (2015). *A qualitative evaluation of non-educational barriers to the elite professions*. Retrieved from http://dera.ioe.ac.uk/23163/1/A_qualitative_evaluation_of_non-educational_barriers_to_the_elite_professions.pdf

Bedi, A. S., & Garg, A. (2000). *The effectiveness of private versus public schools: The case of Indonesia*. *Journal of Development Economics* (Vol. 61). doi:10.1016/S0304-3878(00)00065-1

Berman, O., Drezner, Z., & Wesolowsky, G. O. (2001). Location of facilities on a network with groups of demand points. *IIE Transactions (Institute of Industrial Engineers)*, *33*(8), 637–648. doi:10.1023/A:1010927114887

Bivand, R. S. (1998). A review of spatial statistical techniques for location studies.

Brand, H., & Rosenkötter, N. (2013). Austerity policies in Europe—bad for health. *BMJ: British Medical …*, *3716*(June), 13–14. doi:10.1136/bmj.f3716

Brewer, D. J., Eide, E. R., & Ehrenberg, R. G. (1999). Does it pay to attend an elite private college? Cross-cohort evidence on the effects of college type on earnings. *Journal of Human Resources*, 104–123.

Brunsdon, C., Fotheringham, S., & Charlton, M. (1998). Geographically weighted regression. *Journal of the Royal Statistical Society: Series D (The Statistician)*, *47*(3), 431–443.

Buse, K., & Walt, G. (2000). Global public-private partnerships: part I-a new development in health? *Bulletin of the World Health Organization*, *78*(4), 549–561.

Census at school. (2011). Retrieved from http://www.censusatschool.org.uk/

Church, R. L. (1999). Location modelling and GIS. *Geographical Information Systems 2nd Edition*, 293–303.

Church, R. L. (2002). Geographical information systems and location science. *Computers and Operations Research*, *29*(6), 541–562. doi:10.1016/S0305-0548(99)00104-5

Church, R. L., & Velle, C. R. (1974). The maximal covering location problem. *Papers in Regional Science*, *32*(1), 101–118.

Colini, L., Czischke, D., Güntner, S., Tosics, I., & Ramsden, P. (2013). *Against divided cities in Europe*.

Cooper, L. (1963). Location-allocation problems. *Operations Research*, *11*(3), 331–343.

Deacon, R. T. (1978). A demand model for the local public sector. *The Review of Economics and Statistics*, 184–192.

Dee, T. S. (1998). Competition and the quality of public schools. *Economics of Education Review*, *17*(4), 419–427. doi:10.1016/S0272-7757(97)00040-X

Dijkstra, E. W. (1959). A note on two problems in connexion with graphs. *Numerische Mathematik*, *1*(1), 269-271.

Epple, D., Figlio, D., & Romano, R. (2004). Competition between private and public schools: Testing stratification and pricing predictions. *Journal of Public Economics*, *88*(7-8), 1215–1245. doi:10.1016/S0047-2727(02)00187-1

European Commission. (2010). Lisbon Strategy evaluation document.

European Environment Agency. (2006). *Urban sprawl in Europe - The ignored challenge*. *EEA report* (Vol. 10). doi:10.1080/02697451003740312

Ewing, R., Schroeer, W., & Greene, W. (2004). School Location and Student Travel Analysis of Factors Affecting Mode Choice. *Transportation Research Record*, *1895*(1), 55–63. doi:10.3141/1895-08

García-Palomares, J. C., Gutiérrez, J., & Latorre, M. (2012). Optimizing the location of stations in bike-sharing programs: A GIS approach. *Applied Geography*, *35*(1-2), 235–246. doi:10.1016/j.apgeog.2012.07.002

Gerrard, R. A., Church, R. L., Stoms, D. M., & Davis, F. W. (1997). Selecting conservation reserves using species-covering models: Adapting the ARC/INFO GIS. *Transactions in GIS*, *2*(1), 45–60.

Goodchild, M. F. (2009). What problem? Spatial autocorrelation and geographic information science. *Geographical Analysis*, *41*(4), 411–417.

Griffith, D. A. (1992). What is spatial autocorrelation? Reflections on the past 25 years of spatial statistics. *Espace Géographique*, *21*(3), 265–280.

Grubesic, T. H., & Murray, A. T. (2002). Constructing the divide: Spatial disparities in broadband access. *Papers in Regional Science*, *81*(2), 197–221.

Hakimi, S. L. (1964). Optimum locations of switching centers and the absolute centers and medians of a graph. *Operations Research*, *12*(3), 450–459.

Hakimi, S. L. (1965). Optimum distribution of switching centers in a communication network and some related graph theoretic problems. *Operations Research*, *13*(3), 462–475.

Hamacher, H. W., & Drezner, Z. (2002). *Facility location: applications and theory*. Springer Science & Business Media.

Hamnett, C. (2003). Gentrification and the middle-class remaking of Inner London, 1961-2001. *Urban Studies*, *40*(12), 2401–2426. doi:10.1080/0042098032000136138

Hillier, F. S. (2010). Applications of Location Analysis, *157*. doi:10.1007/978-1-4614-1900-6

Hodge, G. a., & Greve, C. (2007). Public Private Partnerships: An International Performance Review. *Public Administration Review*, *67*(3), 545–558. doi:10.1111/j.1540-6210.2007.00736.x

Ibrahim, N. M., Osman, M. M., & Bachok, S. (2014). Public School Development and Planning: Parents' Criteria of Selecting Public School in Gombak District. *Procedia - Social and Behavioral Sciences*, *153*(2014), 274–285. doi:10.1016/j.sbspro.2014.10.061

Karanikolos, M., Mladovsky, P., Cylus, J., Thomson, S., Basu, S., Stuckler, D., … McKee, M. (2013). Financial crisis, austerity, and health in Europe. *The Lancet*, *381*(9874), 1323–1331. doi:10.1016/S0140-6736(13)60102-6

Kendall, M. G. (1939). The geographical distribution of crop productivity in England. *Journal of the Royal Statistical Society*, 21–62.

Klose, A., & Drexl, A. (2005). Facility location models for distribution system design. *European Journal of Operational Research*, *162*(1), 4–29. doi:10.1016/j.ejor.2003.10.031

List, G., & Mirchandani, P. (1991). An integrated network/planar multiobjective model for routing and siting for hazardous materials and wastes. *Transportation Science*, *25*(2), 146–156.

Liu, N., Huang, B., & Chandramouli, M. (2006). Optimal siting of fire stations using GIS and ANT algorithm. *Journal of Computing in Civil Engineering*, *20*(5), 361–369.

McDonald, N. C. (2008). Children’s mode choice for the school trip: the role of distance and school location in walking to school. *Transportation*, *35*(1), 23–35.

McKee, M., Karanikolos, M., Belcher, P., & Stuckler, D. (2012). Austerity: A failed experiment on the people of Europe. *Clinical Medicine, Journal of the Royal College of Physicians of London*, *12*(4), 346–350. doi:10.7861/clinmedicine.12-6-603a

Menezes, R. C., & Pizzolato, N. D. (2014). LOCATING PUBLIC SCHOOLS IN FAST EXPANDING AREAS: APPLICATION OF THE CAPACITATED p-MEDIAN AND MAXIMAL COVERING LOCATION MODELS. *Pesquisa Operacional*, *34*(2), 301–317. doi:10.1590/0101-7438.2014.034.02.0301

Min, H., & Melachrinoudis, E. (2001). The Three-Hierarchical Location-Allocation of Banking Facilities with Risk and Uncertainty. *International Transactions in Operational Research*, *8*(4), 381–401.

Murawski, L., & Church, R. L. (2009). Improving accessibility to rural health services: The maximal covering network improvement problem. *Socio-Economic Planning Sciences*, *43*(2), 102–110.

Murray, A. T. (2010). Advances in location modeling: GIS linkages and contributions. *Journal of Geographical Systems*, *12*(3), 335–354.

Murray, A. T., & Tong, D. (2009). GIS and spatial analysis in the media. *Applied Geography*, *29*(2), 250–259.

Open Public Services. (2014). Retrieved from https://www.gov.uk/government/publications/open-public-services-2014-progress-report

Orr, D. (2014, December 10). Choice in public services is a myth exploited by big corporations. *The Guardian*. Retrieved from http://www.theguardian.com/commentisfree/2014/dec/10/choice-public-services-myth-big-corporations

Patrinos, H. A., Osorio, F. B., & Guáqueta, J. (2009). *The role and impact of public-private partnerships in education*. World Bank Publications.

Pozueta, J., Lamíquiz, F., & Porto, M. (2009). La ciudad paseable. *Recomendaciones Para Un Planeamiento, Un Diseño Urbano Y Una Arquitectura Considerada Con Los Peatones CEDEX, Ministerio de Fomento, Madrid*.

ReVelle, C. (1991). Siting ambulances and fire companies: new tools for planners. *Journal of the American Planning Association*, *57*(4), 471–484.

Revelle, C., Marks, D., & Liebman, J. C. (1970). An Analysis of Private and Public Sector Location Models. *Management Science*, *16*(11), 692–707. doi:10.1287/mnsc.16.11.692

Rushton, G. (1979). *Optimal location of facilities*. COMPress Wentworth, New Hampshire.

Teixeira, J. C., & Antunes, A. P. (2008). A hierarchical location model for public facility planning. *European Journal of Operational Research*, *185*(1), 92–104.

Teixeira, J. C., Antunes, & Peeters, D. (2007). An optimization-based study on the redeployment of a secondary school network. *Environment and Planning B: Planning and Design*, *34*(2), 296.

Theodoropoulou, S., & Watt, a. (2011). Withdrawal symptoms: an assessment of the austerity packages in Europe. *Working Papers*, *Working Pa*, 40 pages. Retrieved from http://www.etui.org/Publications2/Working-Papers/Withdrawal-symptoms-an-assessment-of-the-austerity-packages-in-Europe

Toregas, C., Swain, R., ReVelle, C., & Bergman, L. (1971). The location of emergency service facilities. *Operations Research*, *19*(6), 1363–1373.

Valeo, C., Baetz, B. W., & Tsanis, I. K. (1998). Location of recycling depots with GIS. *Journal of Urban Planning and Development*, *124*(2), 93–99.

Verter, V., & Lapierre, S. D. (2002). Location of preventive health care facilities. *Annals of Operations Research*, *110*(1-4), 123–132.

Yeh, A. G.-O., & Chow, M. H. (1996). An integrated GIS and location-allocation approach to public facilities planning—An example of open space planning. *Computers, Environment and Urban Systems*, *20*(4-5), 339–350. doi:10.1016/S0198-9715(97)00010-0