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KATARZYNA SITEK, WOJCIECH POKOJSKI, IZABELA GOŁĘBIOWSKA
University of Warsaw
Faculty of Geography and Regional Studies
sitek.kat@gmail.com
orcid.org/0000-0003-3473-3512; wpokojski@uw.edu.pl
orcid.org/0000-0002-4307-7054; i.golebiowska@uw.edu.pl

Evaluation of time availability of the selected rescue service of a large city. A case study of Warsaw

Abstract. This article presents the GIS analysis of time availability of the Voivodship Emergency Ambulance and Sanitary Transport Station operates an Independent Public Health Care Facility "Meditrans" in Warsaw. The research focuses on determining the level of service for residents in each district with the emergency service station. In addition, an attempt was made to improve accessibility on the example of three selected districts. The authors attempt to select methodology of planning the location of the emergency service station in order to optimize the level of service for residents.

Keywords: time availability, emergency service, time isolines, Warsaw

1. Introduction

For all emergency response teams caring for safety and providing assistance in emergencies, travel time to the place of the accident is of key importance. The rapid response time of the service significantly increases the chances of successful intervention. This is primarily due to the knowledge of the spatial location of emergency services, which must reach the event in the shortest possible time. The relationship described above presents the issue of time availability and it is one of the important examples of the use of GIS systems in emergency services. Nowadays, the possibilities of geographical information systems allow to analyze the effectiveness of a given rescue service, among others in terms of the level of service to potential patients, as well as the diversity of time availability depending on the place of stationing and the potential change of the location of the emergency service station. These factors affecting the effectiveness of the service are a significant challenge, especially for large urban areas, where the issue of passing through a crowded city is a big challenge, even for emergency vehicles. Therefore, it is particularly important to develop and improve the already known methods of analyzing the availability of the emergency service in a large city and also considering possible scenarios: the consequences of changing the location of this service's stationing using currently available GIS tools and data. This study is an attempt at a multi-stage analysis of the availability of emergency services in the area of a large metropolitan city on the example of Warsaw.

2. Research on the time availability

F. Galton is considered as the author of the first study of time accessibility, who created the map "Isochronic Passage Chart for Travelers" in 1881. The London's accessibility in days, from anywhere in the world, was presented with isolines, called by the author as isochrones. The map of F. Galton was particularly helpful to traders, who, due to London function at that time, traveled to the city.

Over the next decades, the subject of time accessibility was developed by geographers and cartographers, followed by planners. In

Poland the research was highly affected by politics and undergoing changes taking place in the country. Origins of these studies can be found in the interwar period (W. Pietrusiewicz 1996). Accessibility studies focused then mainly on socio-economic issues, tourism and communication of the population (W. Kubijowicz 1923, W. Rewieńska 1929, M. Rowicki 1934, E. Boczar 1933, J. Wąsowicz 1934).

After World War II, research on time accessibility was forced mainly by intensive industrialization and urbanization of the country (Z. Baja 1948, A. Gawryszewski and S. Pietkiewicz 1966, C. Ziembowa 1969, W. Maciejewski 1973, W. Sobczyk 1985). The latest studies include GIS methods (E. Bielecka and A. Filipczak 2010, P. Śleszyński 2014, J. Burdziej 2016, 2019) similarly to the investigations conducted in other countries (N. Street 2006, C. Schurmann 2010).

The multiplicity and complexity of factors that play role in the issue of time availability analysis, requires the selection of appropriate methods. The review of research on time accessibility indicates three main methodological approaches (tab. 1), which take into account various source materials and address various aspects of time accessibility in emergency services.

Table 1. Most frequently applied methods in studies on time availability (own study)

Method	Description	Sample publications
Interpolation	− based on connecting points with the same time values; − a method adequate for use with a sufficiently dense grid of measuring points; − various interpolation methods (e.g. IDW, Spline, Kriging, TIN)	F. Kara, I. Egresi 2013; H. Miller, Y. Wu 2000; E. Bielecka, A. Mościcka, J. Tomala 2014; J. Burdziej 2016; K. Podkonieczny, J. Tomala, A. Mościcka 2017
Network analysis	− ready-use modules for network analysis; − based on choosing the shortest route by distance or time from a given place, taking into account the given conditions	P. Cichociński, E. Dębińska 2012; Ł. Wielebski 2012
2SFCA	− testing the demand (the potential number of people who want to use the services of a given facility) and supply (the number of services that the medical facility has to offer); − easy comparability of results within the studied area; − inaccurate results on peripheral parts of the study area	M. McGrail 2012; M. Liam, J. Struthers, M. Schootman 2012; M. Stępniak 2013; S. Kanuganti, A. Sarkar, A. Singh 2014; S. Wiśniewski 2015; N. Maloo et al. 2014
Modifications to the 2SFCA method		
E2SFCA	− takes into account the unequal relationship between demand and supply	J. Ni et al. 2015
3SFCA	− takes into account the surroundings of other medical facilities providing medical services at the same / different level	N. Wan, B. Zou 2012; S. Wiśniewski 2016; P. Panda, V. Ranga 2014
MC2SFCA	− demand is determined by a complex indicator, not one factor	B. Lin et al. 2016

The most popular classic methods of time availability presentation include the isochron method, which is based on interpolation of points of equal values. According to the classification (W. Schjering 1903, J. Riedel 1911), isochrones take into account the direction of determining – outside or inside the analyzed area as well as the number of starting points – monocentric or polycentric isochrones.

Nowadays, maps are usually published in digital format and it is constantly developed in terms of technology, which translates into the creation of an interactive cartographic visualization system. An example of the Traffigram method presents an innovative combination of algorithms for calculating the shortest distances when interactive isochronous maps are displayed (C. Aragon. R. Hong 2014). A similar study was created as part of the Mapumental project, which provides a map of Great Britain showing the real time of travel to the selected address, identified by the postal code.

Previous studies focused on the subject of time availability of rescue services usually refer only to determining the time of arrival of the service to the incident place. However, it is reasonable to measure the effectiveness of a rescue services not only on the basis of arrival time, but also by including the number of people who rescue services can help. The lack of combination of these two most important aspects of the time availability analysis in the available studies prompts an attempt to determine the methodology for the example of a large city with varying degrees of urbanization.

3. Analysis of the time availability of a large city

3.1. Study area

Warsaw is considered as a global metropolis[1] and its official population currently exceeds 1.7 million people. The cluster of the most important universities in the country and wide range of job opportunities affect large migration. Due to the lack of obligation to register at the place of residence, it is difficult to estimate the real number of people residing in Warsaw, in which the Voivodship Emergency Ambulance and Sanitary Transport Station operates an Independent Public Health Care Facility (WSPRiTS "Meditrans" SPZOZ). It is considerably larger number than indicated by the official statistics.

As suggested by the calculations on the basis of the mobile phones log-in database in May 2018, the number of people in Warsaw on working days during the daytime can be in average 2,275,000 during the day, and 2,070,000 at night. (P. Śleszyński, M. Niedzielski 2018). These values exceed the official statistics provided by the Statistics Poland (central statistical office in Poland).

These results are similar to those obtained in reported here study (stage 2). According to the assessment of the calculations carried out on the basis of the usable area and area resources per capita in individual districts, the number of people in Warsaw is 2,162,000 people, which is a difference of only 92 thousand of people comparing to the number concerning the night-time population given above.

The statute, goals and tasks, organization as well as economy are determined in the resolution No. 3/2007 of January 8, 2007. Emergency medical teams are divided into (1) specialized and (2) basic teams. The specialist teams consist of at least three authorized persons, including a physician and a nurse or a paramedic. The basic teams consist of at least two authorized persons, including a nurse or a paramedic (WSPRiTS "Meditrans" SPZOZ 2019).

"Meditrans" service stations are currently located in 14 districts of Warsaw and are subject to regionalization, which means that they operate only within the district in which they are located. Administrative units (districts) in which the station "Meditrans" does not work is mainly the outskirts of Warsaw (districts of Rembertów, Wesoła, Wilanów and Włochy).

3.2. The study methodology

Development of accessibility maps requires testing various methods and verification of obtained results at every stage of work. Selection of the study area and choice among mono- or polycentric map are made in the first part of the study. In the following steps, the type of

[1] The concept of Globalization and the City of Work Research Network developed by the Faculty of Geography of the University of Loughborough in Leicestershire in Great Britain; a city with an international scope of influence in the economic, cultural and political fields.

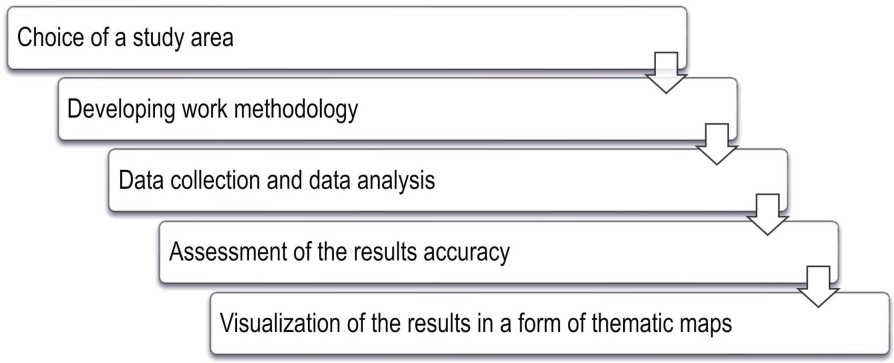

Fig. 1. Stages of the work (own elaboration)

transport and time calculation method should be selected. The method of counting time outside the measuring points is also selected (fig. 1). The most work-consuming stage is collecting data, which are often timetables of various carriers, and performing calculations. The final part of the study is the assessment of the accuracy of the obtained results and their publication in the form of a thematic map.

3.3. Data analysis

The following input data were included in the study of the time accessibility of the rescue service: statistical data about WSPRiTS "Meditrans", topographic data from source BDOT10k (two thematic layers: (1) buildings, constructions and equipment as well as (2) communication network) to be used to calculate the time of reaching an incident place. Moreover, there was applied information on the average usable floor space of an apartment per inhabitant for each district, data on the distribution of the population of Warsaw in a grid of 1 km squares obtained from the 2011 National Census, and population data provided by Statistics Poland. Initial data processing included the selection of information and its division by administrative units of the city of Warsaw. Next, assumptions was made about four ranges of emergency service travel time to the place of the incident (up to 10, 15, 20 and over 20 minutes). The times were obtained from Google Maps for the afternoon communication peak (4.00−5.00 pm) for the business day. The workflow is divided into three steps:

Step 1. The basis for determining the range of temporal availability in any time range was to create an irregular and sufficiently dense grid of points in a given district. The grid of points was constructed arbitrarily on the basis of data obtained from the BDOT10k geobase, concerning the distribution of roads to housing estates and building complexes in each district.

Then, from the given waiting station location, the shortest route was determined that the car can travel to the given point. Taking into account the current delays in the afternoon rush hour, accessibility limits were set following the road network, and in cases where it was impossible, the borders were carried out between buildings, according to the travel time indicated by Google Maps for the afternoon communication peak (4.00−5.00 pm) for the business day .

Step 2. Due to the lack of data on the number of people registered in specific buildings, the estimations of population were conducted using the following input data: the total usable floor area of the residential building, calculated on the basis of the number of storeys and the surface area (the numbers was reduced by 20%, which was assumed as corridors areas). Additionally the Warsaw population density grid was also included in the population estimation stage. The verification of the correctness of the estimation of the number of inhabitants was based on official statistical data.

Step 3. Determining the level of service for residents is based on the selection of buildings according to the adopted range of travel time. The level of service is therefore an estimated

number of residents that can be assisted by the rescue service over a given time period.

In the districts where the location of the "Meditrans" station is located at a distance 500 meters from the administrative border (districts of Ochota, Bemowo and Targówek), an analysis of accessibility differences was performed when considering the scenario of changing the location to the midpoint of a given district. In the event that such a point was designated in an open area, it was moved to the nearest building. Next, the steps described above were followed.

4. Results

4.1. Defining travel time ranges

The elaboration of travel time ranges for individual districts showed a large diversity in the research area (fig. 2). Districts that are characterized by the fastest time of arrival (up to a maximum of 15 minutes) constitute a definite minority among all the districts of Warsaw. Administrative units, in which the maximum travel time does not exceed 20 minutes (6 out of 14 districts) constitutes almost half of the city's districts.

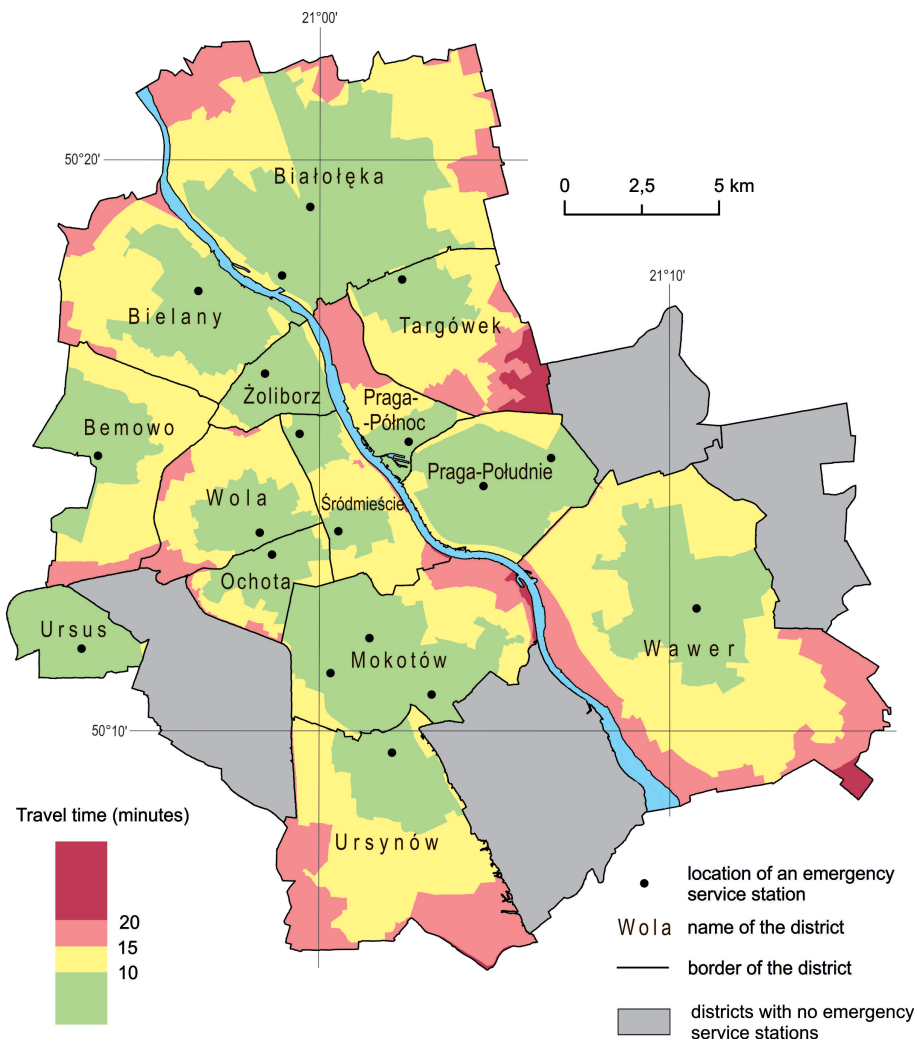

Fig. 2. Travel time (in minutes) in Warsaw districts (own elaboration)

Districts with two rescue service's stations (Śródmieście, Białołęka, Praga-Południe) do not feature optimal availability, despite the increased number of "Meditrans" stations. The ambulance travel time in the Praga-Południe district is the shortest and amounts to a maximum of 15 minutes, in the Białołęka district – up to 20 minutes, while in Śródmieście the journey time exceeds 20 minutes.

In the Mokotów district, in which there are three emergency service stations, the time of arrival exceeds 20 minutes. Despite the highest concentration of stations in the district, the time of arrival is still outside the previously accepted time ranges.

4.2. Determining the number of inhabitants available in the time ranges

The calculations conducted at stage II showed a considerable overestimation of the population in districts (fig. 3). The increased population values ranges from about 19% to almost 33% compared to official statistics provided by the Statistics Poland.

The largest share of the population is most often in the first time range (up to 10 minutes). This refers to eleven districts of the city of Warsaw. The remaining three districts (Bemowo, Wawer and Wola) are characterized by a higher value of the estimated population in the second range (up to 15 minutes) than in the first range. In addition, in five districts (Mokotów, Śródmieście, Targówek, Ursynów, Wawer), in which the range is "over 20 minutes", only in two administrative units are areas inhabited by the population (Targówek and Ursynów). This means that in the remaining three districts there are no residential buildings in this time range. The percentage distribution of estimated population in the time range is presented in figure 4.

4.3. Determining the level of service for residents in districts

Determining the level of service for residents is a key step in determining the time availability of a given district. The number of population per 1 paramedic in a given time range of the district informs about where the service of residents, i.e. providing quick medical assistance, is at a high / low level (fig. 5). For the time of reaching 10 minutes, the best accessibility is in the following districs: Śródmieście, Praga-Północ and Ochota, while the lowest are in Żoliborz, Mokotów and Targówek.

An attempt to improve time availability in the studied area is analysis of a scenario of changing the location of the "Meditrans" station to the midpoint of the district and then perform calculations from the above described steps. This analysis was conducted for three districts: Bemowo, Targówek and Ochota, where the distance from the current location of the station to the administrative border of the district is below 500 m.

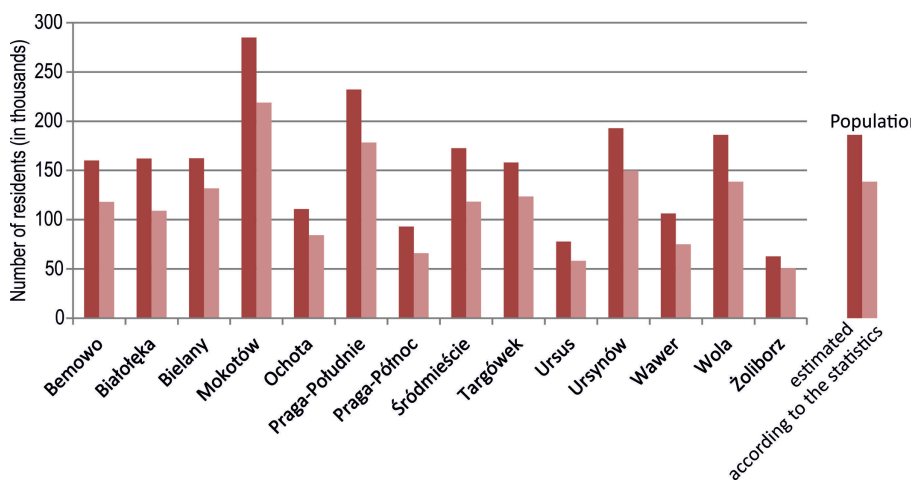

Fig. 3. Comparison of estimated population with official statistics (own study)

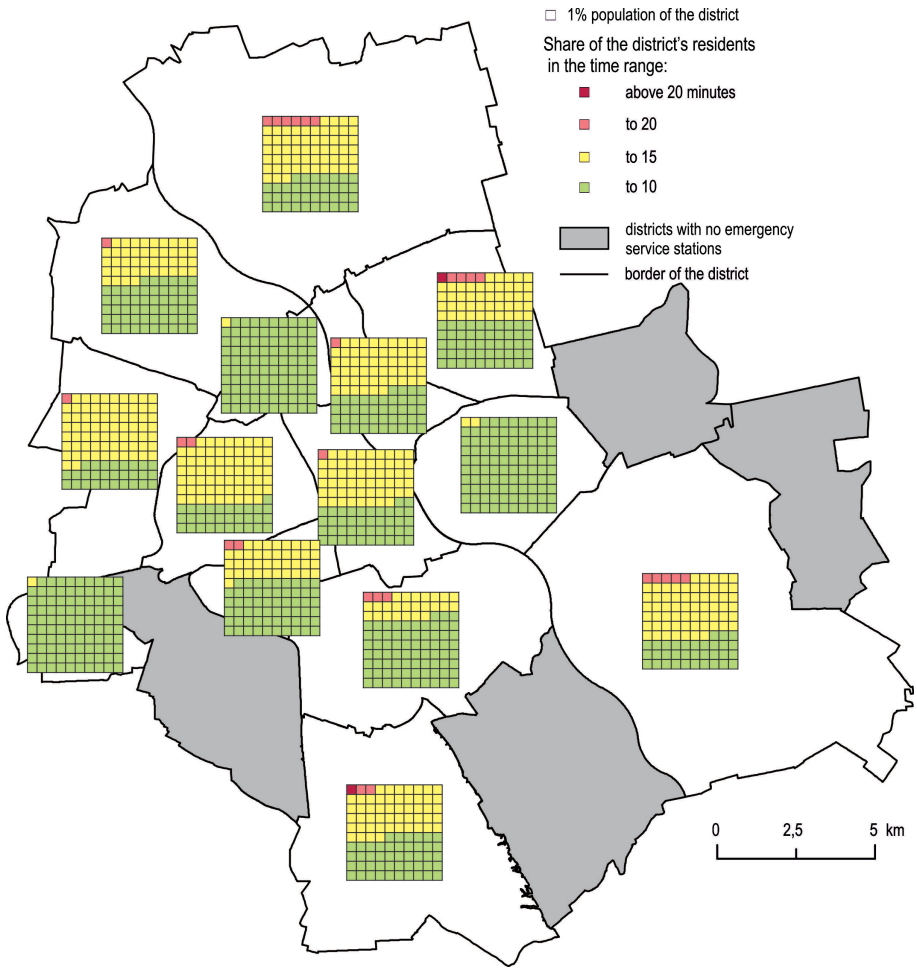

Fig. 4. Share of inhabitants in a given district's time range (own study)

In the case of the Bemowo district, time availability has not improved considerably and the maximum travel time in this area is still 20 minutes (fig. 6). Despite the change in the location of the station to the center of the district, especially the northern areas have significantly deteriorated in time availability. The time to reach the scene increased to 20 minutes. The opposite situation occurs in southern part of Bemowo, where accessibility has improved and amounts to a maximum of 15 minutes.

The change of location of the "Meditrans" station significantly influenced the improvement of time availability in the Ochota district. The maximum ambulance travel time to the scene does not exceed 15 minutes, and a considerable part of the Ochota district is within a reach of 10 minutes. A similar improvement can be observed in the Targówek district.

Re-estimation of the population showed that the largest concentration of population falls in the first range of travel time, up to 10 minutes. This situation applies to all three districts. The opposite situation can be observed in the second range − up to 15 minutes, where the decrease in the population living in this range in the Bemowo and Ochota districts is fivefold, and in Targówek − sixfold.

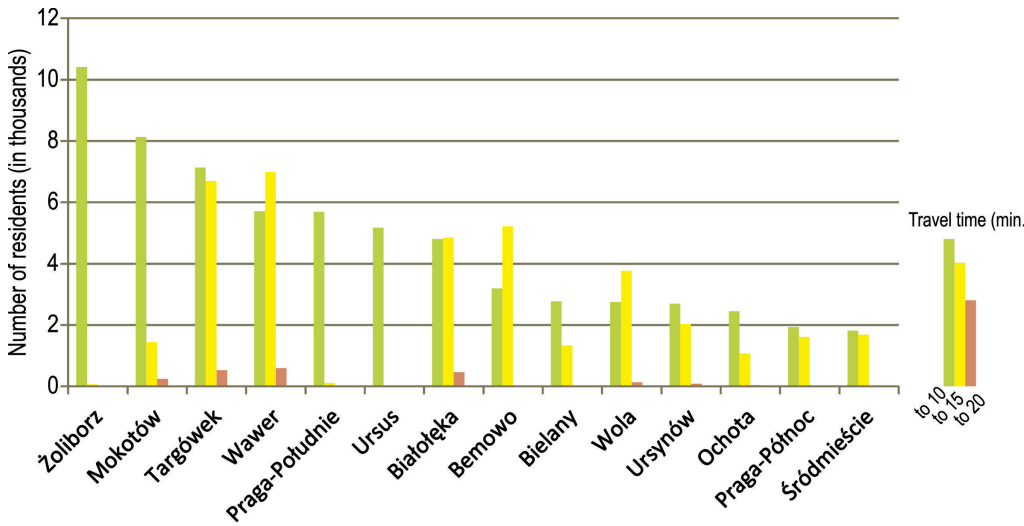

Fig. 5. Number of residents in the district per 1 paramedic at Meditrans station (own study)

With the assumed change of station location, the largest number of residents of the first range falls on the Targówek district − almost 10K people. The next places are occupied by the Bemowo district with a score of over 7K residents in terms of travel time to 10 minutes and the Ochota district, with a result more than 3 times lower than the Targówek district indicator.

A higher variation is noticeable in the second range, where the index values of all districts are very low compared to the values of the index of districts before the change of station location. Within the reach of service within 15 minutes, in the Bemowo and Targówek districts the drop in the number of inhabitants per 1 paramedic is about 4K, in the Ochota district about 800 people.

5. Discussion

The reported here adopted methodological assumptions differs to some extent from other studies, yet it is possible to compare them in several aspects. E. Bielecka, A. Mościcka, J. Tomala (2014) present a map of the temporal availability of Hospital Emergency Departments (SOR) in Warsaw, whose methodology was based on IDW interpolation. Despite this, some common features of both studies can be distinguished: the choice of means of transport, the method of obtaining data on travel time, the time of day for which time availability was developed and the use of polycentric and centrifugal isochron method. This study is based on raster analysis, which translates into time visualization as a continuous representation. Moreover, the time of arrival of potential patients, e.g. from the right bank of the city to the left bank (and vice versa) was set at the same level. It can therefore be concluded that the presentation of travel time on the basis of raster analysis is justified for some contexts and research area. Therefore, in the reported here study, the use of vector analysis seems to be reasonable, as it takes into account all barriers to temporary accessibility.

The determination of time availability in reported here work is related to the number of people who can be assisted, similarly to A. Murad (2018). The author presents the methodology for determining temporal availability in the city of Jeddah in Saudi Arabia, in the province of Mecca. The important step of analysis was classification of hospitals based on the number of patients using kernel density, determination of 30-minute isochron using the Network Analyst tool and classification the city of Jeddah according to the population living in given parts of the city. In the reported here work, important

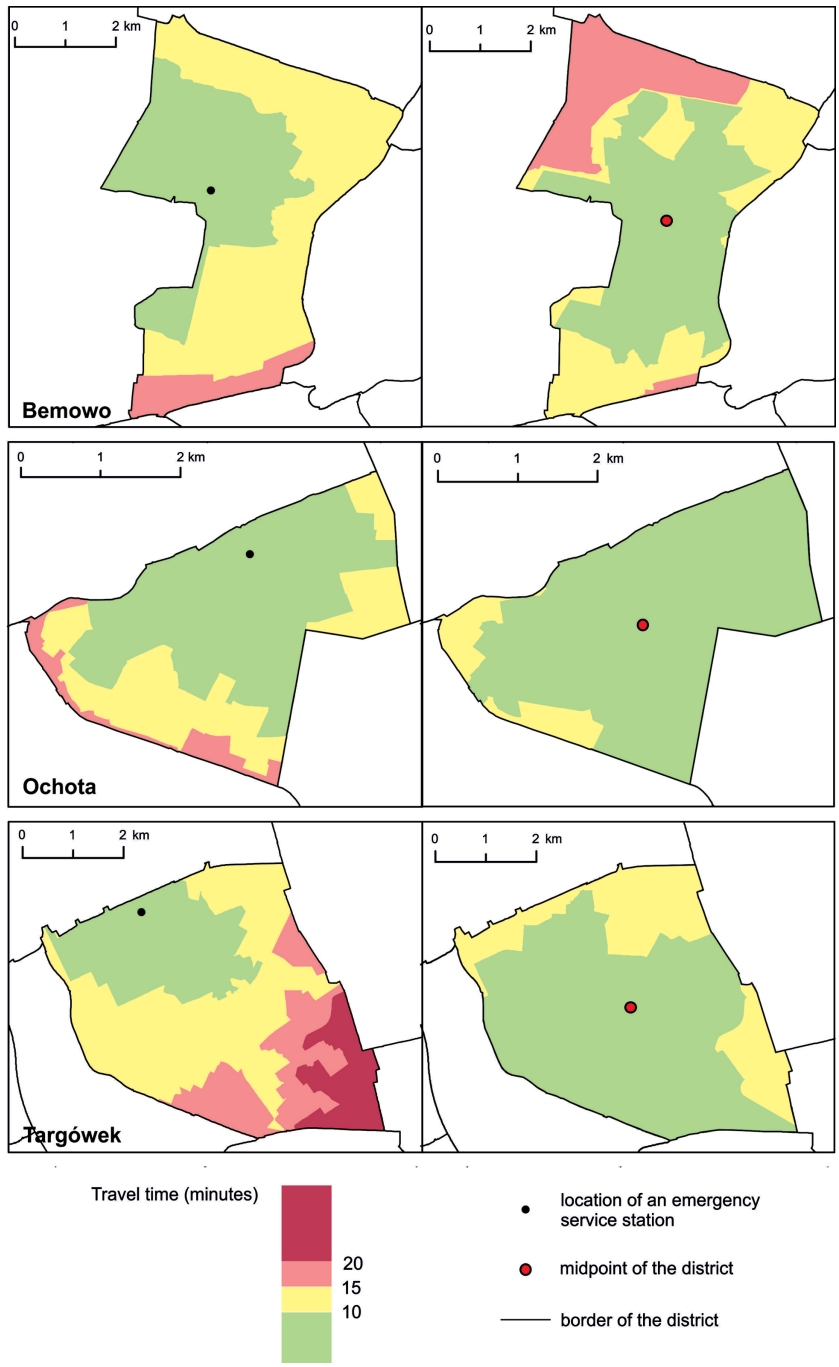

Fig. 6. Time availability in the Bemowo, Ochota and Targówek districts − before and after changing the location of the emergency service station (own study)

aspect is determining the level of service for residents, which consists of the number of inhabitants at a given time distance from the location of the station and the number of rescuers who can help. Similar assumptions were used in the work of A. Murad (2018). However, the author determined the level of service for residents only on the basis of the time distance from the location of the facility from which residents can get help. The author adopted only one isochrone for which it was designated classes of the population presented using a choropleth map.

This presented here study deals also with the subject of hypothetical accessibility by analyzing the change of station location. Rescue service research in this issue attempts to determine the methodology for planning the location station to maximize the availability of this station to residents.

6. Conclusions

The presented here work aimed at the analysis of the time availability of rescue services in large city on the example of Warsaw. The analysis applied a series of input data to estimate not only the time of reaching the place, but also incorporate the number of inhabitants that may be rescued in a given time range. Furthermore, the analysis included the scenario of changing the location of the station in order to compare how the reaching time may be improved.

Analysis showed that the level of service to residents in Warsaw is very diverse between districts. The study may contribute to further research on the effectiveness of emergency services and affect the rational planning of the station waiting for rapid response services.

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