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Cartographic visualization of fire hydrants accessibility for the purpose of decision making

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Abstract: The aim of this study is to present an exemplary cartographic visualization of fire hydrants data consisting of a set of thematic maps containing various information related to the location of hydrants, buildings and driveways in geographic space, and relationships existing between them. Identification of these relationships requires spatial analysis, and illustrating them requires the use of appropriate cartographic presentation methods. The study was conducted on a part of the city of Poznan using data on hydrants' location and type collected and provided by the Fire Department. Geometric data, obtained using geoprocessing algorithms, were assigned appropriate symbols, which lets differentiate them qualitatively and quantitatively. An emphasis is placed on the use of adequate visual variables and on the cartographic communication efficiency. The result of the study is a cartographic visualization in the form of series of thematic maps arranged in a logical sequence, and providing information about the secured area. The thematic layers presenting the same area were arranged in different arrangements with maintenance of the reference layers, ensuring the ease of correlation. Such a cartographic visualization provides knowledge about the spatial distribution and diversity of objects and the relationships between them. It may be an important source of knowledge both at the identification stage and at the operational stage when conducting a firefighting action.

Keywords: cartographic visualization, decision support, hydrants, thematic maps

1. Introduction

Maps, as the spatial information carriers, are very important tools supporting work of the emergency services, without which it would be difficult to imagine their smooth functioning. In today's rescue, along with commonly used topographic and cadastral digital maps, we can expect the growing role of thematic maps allowing for detailed analysis of selected phenomena. The demand for spatial information in the emergency services continues to increase because, as experts in Fire Prevention and Communications note, „development of the civilization leads to an increase in a number of questions put to people directing the salvage operations" (Maciak and

Kreński, 2005). What decision-makers expect from maps is not only basic information, which is the location of objects and unambiguous semantic information (Robinson et al., 1988; Medyńska-Gulij, 2011; Ławniczak and Kubiak, 2013), but they also expect a visualisation of unknown, hidden, sometimes unapparent relations, connotations, which occur in space between topographic objects. Revelation of such information is carried out in the cartographic visualization process, which „involves creating a graphical presentation, usually in the form of maps, in order to understand and to clarify the ongoing spatial phenomena" (DiBase, 1990; Medyńska-Gulij, 2011). Spatial analysis is often essential in this process (Żyszkowska, 2008). Calculations and transformations, made within the scope of spatial analysis, are the way to prepare the information for decision making (Bielecka, 2008). "Cartographic visualization concept is particularly important for thematic mapping, since a large part of the thematic maps are developed to recognize spatial layouts and bring to light relations existing between the data" (Żyszkowska et al., 2012).

The purpose of these considerations was the use of traditional cartographic methods in visualizing information regarding fire hydrants. The main emphasis was placed on the presentation efficiency in the context of specific usability of a specific audience (Kraak and Ormeling, 2009). In this case, it means transferring information about various aspects of hydrants accessibility and their types to decision-makers in the Fire Brigade. In the cartographic visualization process, a number of thematic maps showing various information on hydrants were developed. As noted in the book *Thematic Cartography and Geovisualization* „Thematic maps can be used in three basic ways: to provide specific information about particular locations, to provide general information about spatial patterns, and to compare patterns on two or more maps" (Slocum et al., 2009). The three purposes can be met by a choice of correct visualization.

The aim of the developed visualizations was to transport information about:

- Hydrants' locations and types with information about the way of starting them (point signatures method);
- Euclidean distances to neighboring hydrants (Triangulated Irregular Network) using Delaunay triangulation method;
- Distances from hydrants to buildings in 15-meters intervals, which indirectly enables to estimate the number of fire hose sections required (equidistances method);
- Direction to the nearest neighboring hydrant, its type, and the number of neighboring hydrants within a radius of 150 m;
- Topographic azimuths to neighboring hydrants;
- Types of use of buildings being secured (based on Database of Topographic Objects) and the number of hydrants within a 75 meters radius around buildings;
- Hydrant affected zones (optimal zones of influence for hydrants) – determined on the basis of distances between neighboring hydrants (Thiessen polygons / Voronoi diagrams).

2. Methodology

The basis for spatial analysis was data containing locations and types of exterior hydrants in Poznan developed by the fire brigade based on data from water supply company and the City Hall. The study did not include hydrants located in the areas of industrial plants nor internal hydrants placed in buildings. What was important in conducting this study is Polish standards concerning the location of hydrants in relation to each other and in relation to protected buildings or driveways (the ordinance of the Minister of Interior and Administration of the 24th of July, 2009 on the fire water supply and fire roads). They were the basis for defining the analysis parameters, and also for qualitative differentiation of analysis results expressed graphically on map. In accordance with the ordinance, fire hydrants should be located up to 15 m from the edge of the roadway. The distance between two adjacent hydrants should not exceed 150 m, while the distance from a hydrant to the walls of a protected building should be greater than 5 m and less than 75 m (Fig. 1).

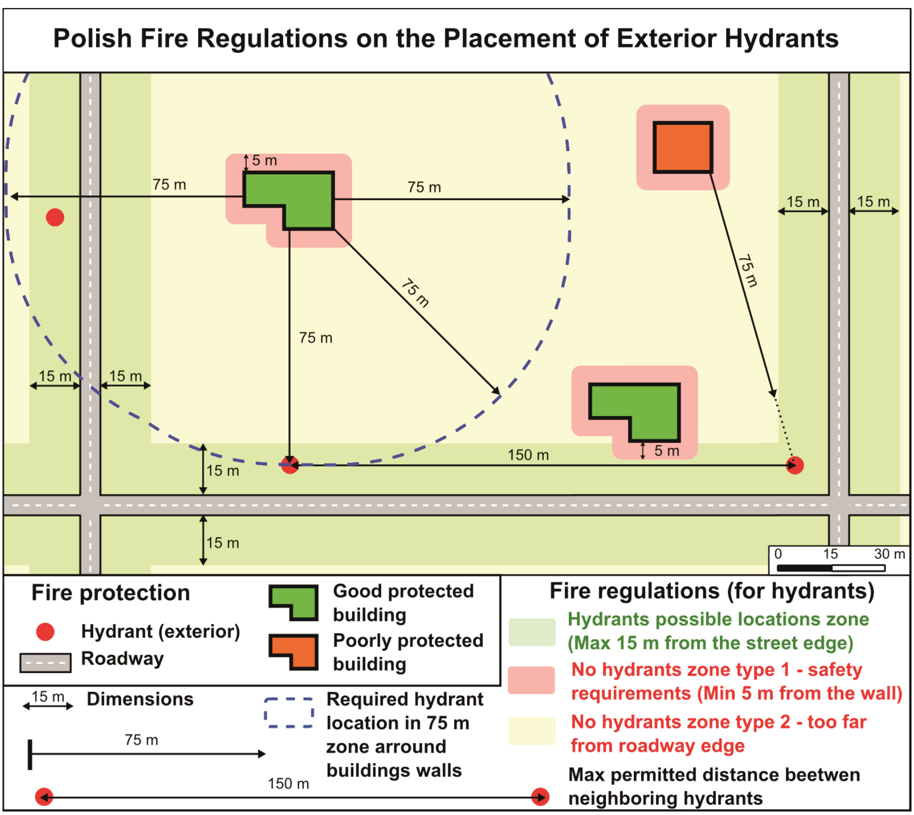

Fig. 1. Graphical interpretation of polish standards concerning the location of hydrants (based on the ordinance of the Minister of Interior and Administration of the 24th of July, 2009 on the fire water supply and fire roads)

Research procedure concerning creation of the visualization included the following tasks:

- Selection of theme and contents (thematic layers) for each map and planning sequence of particular thematic maps (visualization composing);
- Selection of a proper data projection according to the habits of map readers (not disrupting the perception of space) and adoption of a coordinate system appropriate for the scale of the mapping – 1: 3 500 (building a platform for proper transmission of all information in the study);
- Selection of effective cartographic presentation methods in order to pass certain, specific information graphically – it concerns objects geometry (building a platform for transmission of particular pieces of information);
- Conducting spatial analysis (done mainly on a point layer containing hydrants) using parameters established on the basis of binding Polish fire protection standards (acquisitioning of new vector data for new thematic layers);
- Selection of visual variables in accordance with the intended effect of influence on perceptual impression of a recipient – it concerns individual graphic coding of elements. Assignment of symbols to geometric elements in accordance with qualitative and quantitative characteristics with reference to the standards. Selection of symbols of hydrants according to their type using associative colors (building a visual message for decision-maker).

The result of the research is the cartographic visualization in the form of six thematic maps, presented on figures 3 and 4. Additionally on figure 5 was an alternative image presented. It is a result of more complicated, but also providing more accurate information, analysis method, that can be used to solve hydrants accessibility problem.

2.1. Descriptions of mapping methods and procedures used in the study

Spatial analysis conducted in this study start from the location of hydrants, not from the location of building, where a fire has been found. Both approaches have their justification. The first one appears to be more useful for exploration of secured area, it is also more favourable in terms of visualization. The second one can be probably better from point of view of rescue action conducting, but is harder to show on a map.

2.1.1. Point signatures – information about hydrants' types and distribution

Location of fire hydrants and their types are the basic information. For the purpose of marking hydrants, simple circle shaped point signatures were used. They represent well objects' silhouette seen from above. In order to distinguish different types of hydrants, distinguishable colors were used, which refers to symbols using by firefighters in the database of hydrants on Google Maps (Fig. 2). The raw data with hydrants location were downloaded from online database of hydrants of Municipal Headquarters of the State Fire Service in Poznan in Keyhole Markup Language format and then converted to ESRI Shapefile to enable them to be processed in GIS applications (most geoprocessing operations in this study were conducted in Quantum GIS freeware software).

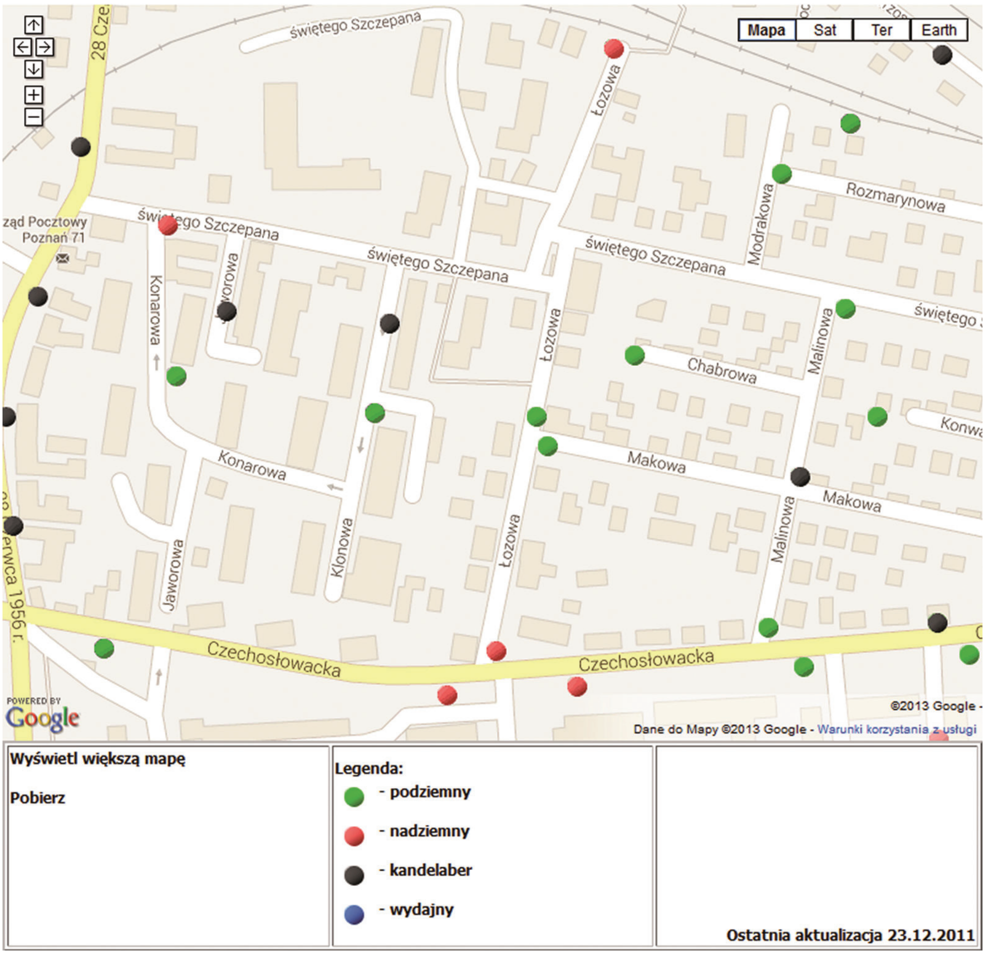

Fig. 2. Online database of hydrants of Municipal Headquarters of the State Fire Service in Poznan developed in Google Maps by Poznan firefighters (www.hydranty.kmpsp.poznan.pl) with source data used in the study

In the source database, fire hydrants were classified into 6 types, which are divided into subgroups. The basic division includes above-ground hydrants and, more difficult to find in the field, underground hydrants. Above-ground hydrants as a group are characterized by large internal variation. Due to the water flow volume per time unit, hydrants can be divided into standard and efficient hydrants. Among above-ground hydrants one can distinguish old „kandelaber" hydrants, characterized by a different way of starting, and other hydrants, with a special value (as old elements of infrastructure). Some of kandelaber hydrants have been modified. Therefore, it was also necessary to include this information.

Initially, the creation of symbols, which represent the technical design of a hydrant type was considered (Table 1). Finally, a simplified version was adopted, because signatures with more complex graphical structure were found to be less effective. Things that influenced the decision about that were a relatively small number of hydrants classes (6 classes) and quantitative differences in the share of the most significant hydrants' feature which is the location towards the ground. There is a large variety of above-ground hydrants (5 classes) whereas there is absence of differentiation in case of underground hydrants (one class).

Table 1. Division of hydrants into 6 types (associated with their properties) and proposals of point signatures with varying complexity level

	Signature				Hydrant feature							
	Simpler	More complex			Location typ		Efficiency		Starting direction		Age / historical significance	
Nr	Fulfill based			Contour based	Under-ground	Above ground	Standard (10 dm³/s)	High (15 dm³/s)	Right (clockwise)	Left (counter-clockwise)	Modern	Antique
1					☑		☑		☑		☑	
2						☑	☑		☑		☑	
3						☑	☑		☑			☑
4						☑	☑		☑			☑
5						☑	☑			☑		☑
6						☑		☑	☑		☑	
Lettering features					U	A	S	H	R	L	M	Q

1 - underground hydrant (USRM)
2 - typical above ground hydrant (ASRM)
3 - "antique" hydrant (ASRQ)
4 - modificated "Kandelaber" hydrant (ASRQ)
5 - "Kandelaber" hydrant (ASLQ)
6 - efficient hydrant (AHRM)

Above-ground hydrants are marked red, which refers to the color, in which this type of fire hydrants are generally painted. Underground hydrants are marked green, which is associatively the opposition of the red color. Furthermore, efficient hydrants belonging to the above-ground hydrants group are marked blue, which in cartography is assigned to water. In addition to distinguishing types using colors, hydrant signatures have yellow borders, which has two functions. On the one hand, it visually separates the signature from its background. On the other hand, it emphasizes the connection with the thematic layer that illustrates distances between hydrants, on which hydrants form a network and constitute its nodal elements.

In case of kandelaber hydrants, an arrow was added to the signature visualizing the counter-clockwise way of starting it. In the context of information about hydrant types and distances between them, point signature was enriched with another additional arrow indicating the nearest neighboring hydrant and its type. The total number of neighboring hydrants accessible within a 150 meters radius is stored in the form of a text signature.

2.1.2. Delaunay Triangulation – information about Euclidean distances between adjacent hydrants and about topographic azimuths

The point layer containing hydrant data, together with the aid of spatial analysis, enabled to mark out segments connecting the nearest neighboring hydrants, which were described using text signatures informing about distance between hydrants with the accuracy of up to 0.1 m. Geometric data for this thematic layer was obtained as a result of triangulation. The Delanuay triangulation algorithm, applied here, gives the result in which „none of the vertices of a triangle get into the circle circumscribed on the vertex of any other triangle formed during triangulation" (Bielecka, 2006). In reference to the requirements of the ordinance, lines for distances greater than 150 m were removed, which enables to exclude hydrants located too far for conducting effective firefighting operations.

The same lines, which connect hydrants, were used for depicting the information about topographic azimuth values pointing at the adjacent fire hydrant. They are given with the accuracy of 1 degree. For better understanding, arrows showing that direction were added. They coincide with each other halfway between hydrants.

2.1.3. Thiessen Polygons – information about optimal (from the point of view of distances to hydrants) hydrant zones

The fire hydrants layer was also used to determine an optimum service zone for each device. It became possible by using Thiessen polygons, which formed variously dense, irregular network (Ratajski, 1973). Borders of Thiessen polygons, which are convex polygons, are located exactly in the middle of the distance between neighboring hydrants. This means that the distance from any hypothetical location within a designated area to the hydrant is shorter than to any neighboring hydrant. Polygons' borders were marked red, and the filling was left transparent.

2.1.4. Equidistant lines – information about distance to a hydrant at constant intervals and about the required number of fire hose sections

Equidistant line, belonging to distance isolines group (Ratajski, 1973), is the line of equal distance from an object, in this case point one (a fire hydrant). They were drawn at constant distance interval of 15 meters. The mentioned distance is equal to the standard fire hose section length. Thanks to such a choice of the interval, it is not only possible to assess an approximate distance from a particular object (e.g. a building) to the hydrant, but also to predict the minimal number of fire hose sections necessary for leading water from the hydrant. Naturally such interpretation in many cases will be an oversimplification – with increasing distances it becomes more and more unlikely that the water hoses can be rolled out in a straight line from a hydrant to a target building, so we can expect, that the number of fire hoses sections will be probably higher, but not less.

Equidistant lines, drawn within the range of 0 to 150 meters, were obtained as a result of buffering operation performed on points representing hydrants. Concentric circles, obtained in the above way, which are of the same distance value were merged with each other in places where they overlap. A polycentric map (Witt, 1967) of equidistant lines was created. Its coverage refers to the maximal allowed distance between two adjacent hydrants. In accordance with the ordinance, distance from a fire hydrant to the wall of protected building cannot exceed 75 meters. This is why equidistant zones (Ratajski, 1973) were divided into two groups using a bipolar color scale.

2.1.5. Method of „overlapping circles" – information about the number of fire hydrants available within the range of 75 meters

The thematic layer showing the number of hydrants available from a particular location was created as a product of overlapping of 75-meter-width buffers around hydrants. The more of the circles overlap, the darker the zone coloring gets. Areas of a higher number of neighboring hydrants are „better" in terms of accessibility to different hydrants. In this case, the information about the number of hydrants within the range of 75 meters from a given place was more crucial than marking the influence zones of hydrants. Due to the fact that we are interested in the quantitative approach, we assume that each hydrant is equally important. If we mark an area within the optimal range from a hydrant using a selected hue and incorporating transparency, the overlapping circles' parts will create a color of lower brightness indicating higher number of available hydrants. Due to the fact that the increase in the intensity of the color coming from the sum of overlapping translucent objects wasn't large enough for the clear discrimination of classes, it was necessary to divide the study area into pieces homogeneous in terms of the number of available hydrants and to assign them a color palette like on a choropleth map.

3. Result

Visualizations presented in the article concern an area located in a district of the city of Poznan, which is characterized by a great diversity of exterior hydrants types. Presenting all the information on one map would certainly reduce significantly its readability. Therefore, the thematic layers were put on a set of maps showing the same area and containing the reference layers, which facilitates a comprehensive reading. On all the maps, the linear scale basis was selected so that it corresponds to the interval of equidistant lines. Figure 3 presents the maps, whereas an emphasis was set on information about the spatial relationships between hydrants were put. In the first instance, visualization based on the orthophotomap was used (Fig. 3A). In this case, the amount of information which reaches the receiver is very large, and using this form of presentation results in a very close link between graphics and perceived visual reality. It is very beneficial from the point of view of orientating the map in the field, which determined the way of presentation of this visualization as the first one. Intersections visible on the orthophotomap, which carrying labels of street names with halo mask, are the easy-to-find reference points.

Figure 3B is a polycentric map showing equidistant lines of hydrants and distances between them. On this map, on the lines connecting the hydrants exact distances are given and hydrants having particularly favorable relative positions are marked. Hydrants being up to 75 m away from each other were connected with thick lines in order to emphasize their particular importance. An arrow indicating the closest hydrant and its type was attached to every hydrant. Textual information about the number of neighboring hydrants within a radius of 150 meters was placed inside signatures indicating hydrants. Hydrants are marked with a large signature, exceeding significantly the actual size of the objects. It was done in order to obtain sufficiently large colored surface, which affects the receiver and lets him retrieve the information efficiently.

Thanks to three reference layers, it is possible to capture the spatial correlation between maps 3A and 3B. In the first place, it is the shape of Thiessen polygons, then it is hydrants locations. Equidistant lines form the third layer. On the orthophotomap (Fig. 3A), equidistant lines are dotted in order to reduce a screening of the content visibility, and on map B they were differentiated qualitatively using a bipolar color scale. In case of the map A one may conclude on the distance to the hydrant from basing on the radius of the circle, whereas in case of the map B, from the color of the equidistant zone.

Map 3C shows the information about topographic azimuths of the neighboring hydrants by the means of appropriately directed arrows and their descriptions. The map presents also the number of hydrants within a distance not exceeding 75 meters. One can also identify places where the distance to hydrants exceeds 75 meters reducing the effectiveness of water supply, which may indicate significant importance of Firetrucks' on-board water reservoirs. Moreover, this map provides hydrants' address markings.

The aim of the visualization presented in figure 4 is to pass the information about hydrants in relation to buildings and their types. Map in figure 4A presents directions, in which buildings are located in relation to the hydrants. 22.5-degree sectors, which axes of symmetry are the eight geographic directions of the second degree, are marked using colors that can be associated with times of the day (north – black, south – white,

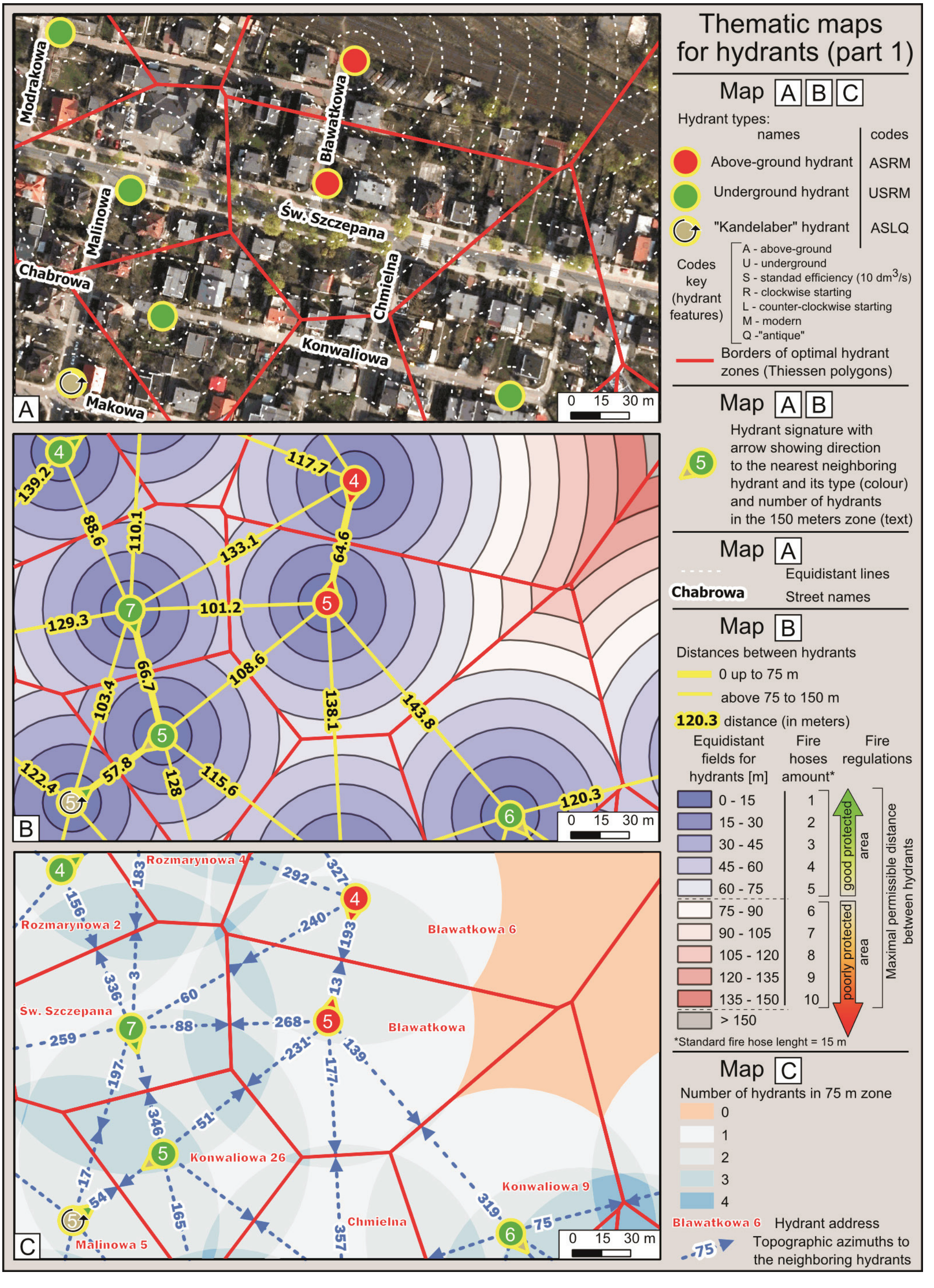

Fig. 3. Visualization of information about hydrants in the context of spatial relations

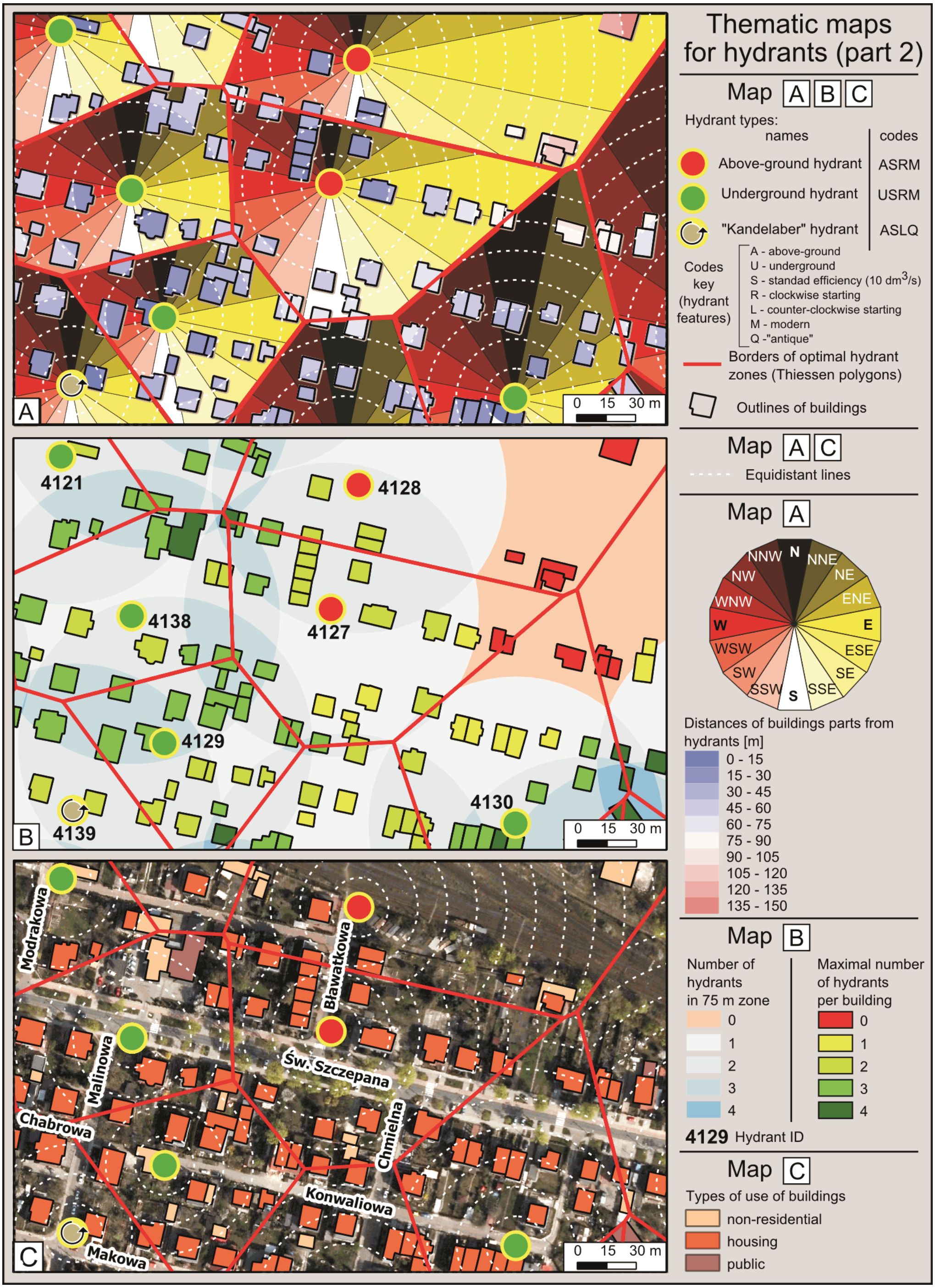

Fig. 4. Visualization of information about hydrants in relation to buildings and their types

east – yellow, west – red). Elongation and colored surface of these sectors emphasize visually directions, in which the distance from the hydrant to the zone border is significant. It can be especially helpful when analyzing hydrants' spatial distribution. Euclidean distances to the building parts were designated based on equidistant fields that intersect the buildings layer. On map 4B, buildings are marked in different colors according to the maximal number of hydrants within the radius of 75 meters. It gives visual pictorial information about the degree of protection of specific buildings.

Map C in figure 4 presents buildings' types of use on top of the orthophotomap. The employed classification and coloring come from the Database of Topographic Objects (BDOT). The visualization divided into two parts ends with the image containing the same cartographic background, with which has formed the start.

Presented here visualizations based only on the geometric properties, which do not account for barriers in access paths, as the only one source of information could be insufficient for a practical use. The credibility of the information read from so prepared visualization decreases as one moves away from fire hydrant, which is associated with a higher probability of occurrence of new obstacles and thereby lengthening the true distance. However, this doesn't rule out the value of analyzes carried out in this way – they give information about general patterns in the spatial distribution of fire hydrants and allow decision-makers to pre-outline possible scenarios for action. Helpful in decision-making process could be additional information from other sources, such as Google Maps Street View, that provide information on objects in the surrounding space seen from the viewpoint on the mapped street through 360-degree street-level imagery. Naturally the final verification must always be followed in the field.

Taking into account in analysis all the obstacles faced by the firefighters during fire-fighting action would be impossible (for example badly parked cars). On the other hand, not all fixed obstacles such as fences will be a big barrier. It will depend on their height, amount and materials from which they are made (wire mesh, metal rods, brick, concrete) and compactness (large or small cracks). Trees as point objects generally will also not constitute a greater impediment. The biggest obstacle in accessing hydrants from the place where fire has been reported are buildings.

Inclusion of buildings as barriers for more accurate analysis results would require the use of raster analysis. It would extend the time needed for visualization preparation. An example of the result of so conducted analysis and comparison with earlier described simple vector-based analysis was shown on figure 5. The main differences between map on figure 5A and 5B are visible in the center of maps, where long buildings are restricting access to the hydrants.

The map on figure 5B was created in few steps. First, cost surface had to be prepared (raster layer with 0,1 meter pixel resolution excluding buildings was created). In application ArcInfo with Spatial Analyst extension Cost Distance analysis was conducted. Then continuous raster map was reclassified and finally converted to vector layer in order to increase the visualization capabilities. Hydrants affected zones were calculated witch Cost Allocation tool and finally also converted to vector layer.

The result of alternative analysis on map B (Figure 5) is more reliable, because it shows the cumulative distance of the walls of buildings from fire hydrant in contrast to the map A showing Euclidean distance between hydrants and buildings. It may have particular significance in case of compact settlement and in case of buildings, which have considerable length.

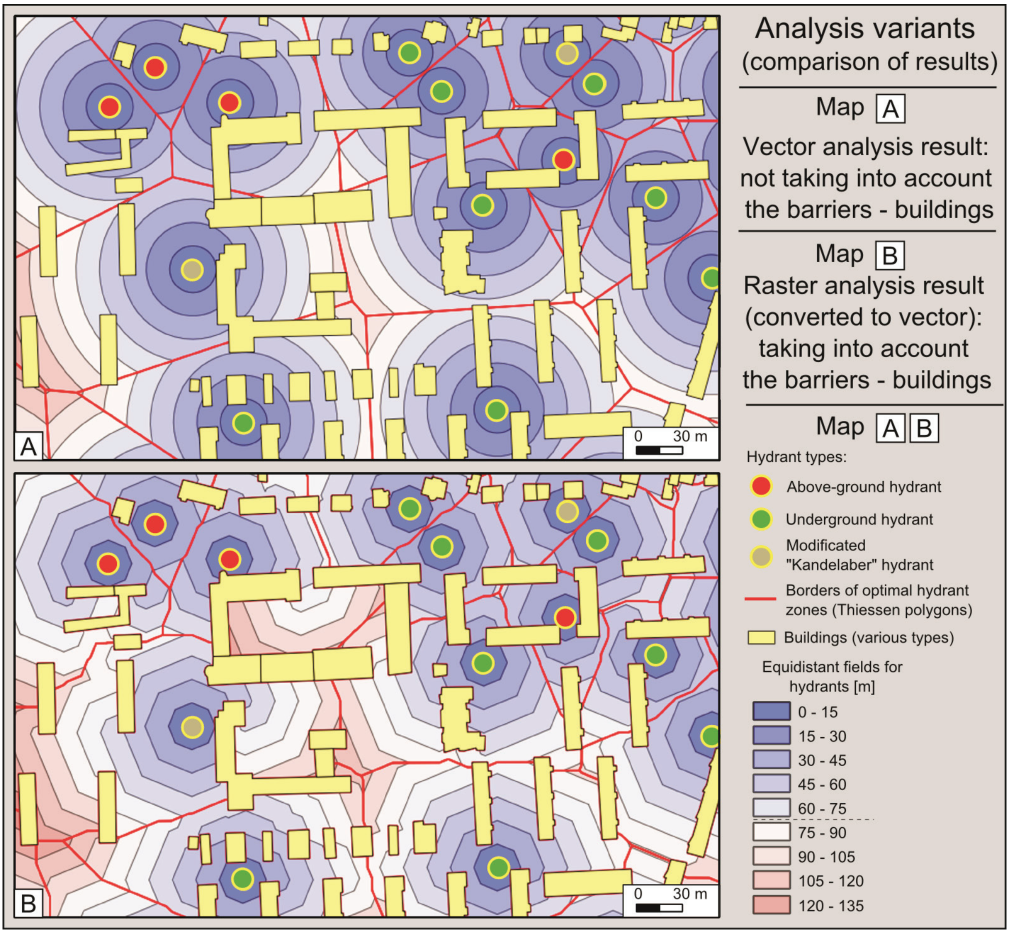

Fig. 5. Comparison of visualizations created as a result of two way of analysis: A) vector-based analysis excluding buildings as barriers, B) raster-based analysis including buildings as barriers

4. Conclusion

Cartographic visualization can be understood as the process of map creation. However, visualization means also the result of this process, namely, set of maps meeting this objective. In case of this study, a possibility of the visualization of spatial data regarding fire hydrants for the purpose of decision making support for people directing a firefighting action was shown.

The developed thematic layers can be displayed in various arrangements, and the created visualizations will often be temporary maps. Maps serving as decision making aids can't be overburdened with content. Thus it is better to use a couple of pictures of the same area, on which thematic content is spread. This allows one to focus on the analysis of the selected issue.

Thiessen polygons and the equidistance method were applied as the basic methods of cartographic presentation. Thiessen polygons play an important role in the organization of graphical message and in passing information, because it divides area into hydrant zones, to which we can relate other thematic layers. Various shape of the polygons enables one to associate maps spatially with each other efficiently. Furthermore, they are basic reference units, on the basis of which one may do statistical comparisons regarding, for instance, buildings' area together with their types of use and the distances to the hydrants for particular zones. Whereas equidistant lines adapt appropriately the observer's way of reading distances on a map. It is done using the lines indicating radius of equidistant zones.

The design principles for point signatures consisting of quantitative information about 6 types of hydrants turned out to be perfect. Nevertheless, combination of a few different mapping methods turned out to play the key role in cartographic images creation process. It was a combination of buffering, Delanuay triangulation and Thiessen polygons creation. The visualizations in figure 4A, 4B and 3C seem to be the most striking ones, while the visualizations in figures 3A, 3B and 4C are useful in terms of operational suitability for fire-fighting actions. The comparison of the two maps on figure 5 show that in some cases conducting more complicated analysis taking into account the buildings as the main obstacles on path to a hydrant can give better, more reliable results. It can be significant in context of practical use of proposed visualizations. The presented research is of theoretical nature. It uses capabilities of GIS and graphics software while preserving the rules of the cartographic design and mapping techniques variants. Further studies might include evaluation of the prepared visualization in the context of efficiency for decision support conducted by experts, people who direct firefighting actions.

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Wizualizacja kartograficzna dostępności hydrantów ulicznych na potrzeby podejmowania decyzji

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Streszczenie

Celem niniejszego artykułu stało się zaprezentowanie przykładowej wizualizacji kartograficznej dla danych dotyczących hydrantów ulicznych, złożonej z szeregu map tematycznych przybliżających różne informacje związane z lokalizacją w przestrzeni geograficznej hydrantów, budynków i dróg dojazdowych oraz tworzonymi przez nie relacjami. Zidentyfikowanie tych zależności wymaga przeprowadzenia analiz przestrzennych, a ich zobrazowanie zastosowania odpowiednich metod prezentacji kartograficznej. Badania przeprowadzono na przykładzie fragmentu miasta Poznania wykorzystując dane o lokalizacji i typie hydrantów zebrane i udostępnione przez straż pożarną. Danym geometrycznym uzyskanym dzięki zastosowaniu algorytmów przetwarzania nadano odpowiednią symbolikę, pozwalającą na zróżnicowanie ich w sposób jakościowy i ilościowy. Szczególny nacisk położono na zastosowanie adekwatnych zmiennych wizualnych i efektywność przekazu kartograficznego.

Wynik badań stanowi wizualizacja kartograficzna w postaci szeregu map tematycznych ułożonych w pewien logiczny ciąg, dostarczająca informacji o obszarze chronionym. Warstwy tematyczne prezentujące ten sam obszar ułożono w różnych konfiguracjach z zachowaniem warstw referencyjnych zapewniających łatwość korelacji. Tak przygotowana wizualizacja kartograficzna dostarcza wiedzę o przestrzennym rozmieszczeniu i zróżnicowaniu obiektów oraz zachodzących między nimi zależnościach. Może ona stanowić ważne źródło wiedzy zarówno na etapie rozpoznawczym jak i operacyjnym dotyczącym prowadzenia akcji gaśniczych.