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Michał M. Buczek[1], Sylwia A. Szlapińska[1], Nguyễn Quang Minh[2]

USING GIS FOR PUBLIC TRANSPORT ANALYSIS – THE CASE STUDY OF HANOI, VIETNAM

[1] AGH University Of Science And Technology In Cracow
[2] HUMG Hanoi University Of Mining And Geology

Keywords: bus network, rapid transit, population, GIS analyses, Hanoi metro

Abstract

Developing countries face the problem of overcrowded streets. It is caused by rapid urbanization processes, meanwhile, a development of public transport services is insufficient. Nowadays, south-east Asia cities invest in rapid transit systems. Construction of a metro line demands big financial expenses to create its infrastructure. On the other hand, bus service uses city roads, but travel is relatively slow and its operation depends on the traffic, especially during peak hours. Therefore, cities have to focus on complementary systems of buses and rapid transit.

The paper presents analyses of the existing bus network for the city of Hanoi. While the first two lines of a metro system are still under construction, the buses remain the only public transportation service in the city. The bus routes and bus stops are evaluated. The network coverage of residential areas is assessed and the blind spots are determined. The bus stops network is compared with newly constructed rapid transit stations. The strong and weak points of the transport system are discussed.

WYKORZYSTANIE GIS DO ANALIZ TRANSPORTU PUBLICZNEGO – PRZYKŁAD HANOI W WIETNAMIE

Słowa kluczowe: transport publiczny, kolej miejska, populacja, analizy GIS, metro w Hanoi

Abstrakt

Kraje rozwijające się stają przed problemem zatłoczonych ulic. Jest to spowodowane gwałtownymi procesami urbanizacyjnymi, którym nie towarzyszy równie szybki rozwój transportu publicznego. Miasta Azji Południowo-Wschodniej inwestują w budowę systemów szybkiej kolei miejskiej. Budowa systemu metra wymaga jednak dużych nakładów finansowych. Obecnie autobusy korzystają z istniejących ulic, ale podróżowanie nimi jest wolne i uzależnione od natężenia ruchu ulicznego, szczególnie w godzinach szczytu. Dlatego też należy skupić się na budowie wzajemnie uzupełniającego się systemu autobusów i kolei.

Artykuł prezentuje analizę istniejącej sieci autobusowej w mieście Hanoi (Wietnam). Podczas gdy dwie pierwsze linie metra są nadal w budowie, autobusy pozostają jedynym transportem publicznym w mieście. W publikacji przeanalizowano przebieg tras autobusów oraz rozmieszczenie przystanków. Wyznaczono pokrycie stref zamieszkania przez istniejącą sieć tras oraz określono „martwe punkty". Położenie istniejących przystanków autobusowych porównano z położeniem budowanych stacji metra. W oparciu o analizy omówiono mocne i słabe strony istniejącego i powstającego systemu transportu publicznego.

1. INTRODUCTION

The problem of the optimization of the public transportation network arises with the rapid urbanization of the cities area. The localization of the new bus, metro, tram or train stops is a complex problem. Raising a number of stops on the line increases the coverage of the residential areas, but decreases the speed of vehicles serving on the line, thus elongate the time needed to travel from point A to point B.

With the growth of the urban areas, the transportation networks have to be reorganized to reach equilibrium. Engineers and researchers developed approaches and algorithms to make networks as wide as possible with preserving its efficiency (Demetsky & Bin-Mau Lin, 1982; Gleason, 1975). Nowadays, the unconventional methods are applied to analyze and develop a transportation network, like mold colonies (Tero et al., 2010).

Developing countries, like Vietnam, face the problem of creating efficient transportation networks. This study focuses on the public transportation network of the capital city of Vietnam, Hanoi. Due to the rapid growth in the last decades and a positive birthrate, there is a need to analyze the structure of an existing bus network. While the first two lines of a metro system are still under construction, the buses remain the only public transportation service in the city.

Vietnam's economic growth has resulted in a massive increase in the number of private vehicles on its roads overwhelming the transport infrastructure in big cities (Geertman, 2010). Hanoi suffers from congested streets, not only in peak hours. The bus transportation system is inefficient and unattractive for passengers (Nakamura et al., 2012; Tran et al., 2012).

One of the solutions for lowering a number of vehicles is the construction of rapid transit system operating independently from street traffic. On the eve of opening first metro line in Hanoi, buses remain the main public transport service. The serious traffic congestion influences on service operation. Despite comfort and speed, people tend to choose private vehicles because they don't have access to public transport. Improving the bus stops coverage, buses operation and quality of service (more comfortable vehicles etc.) would result in an increasing number of passengers. More users of public transportation mean less private vehicles on the streets, what would increase the speed of public transportation. Anderson (2014) has observed this relation on the case study of transit workers' strike in Los Angeles. Le and Trinh (2016) described the tendency of drivers in Ho Chi Minh City (Vietnam) to use public transport if its quality is sufficient.

Access to the transportation network depends on many factors like the city topography, transport network density, but also users' habits. Researchers try to determine distances people tend to walk to access the public transport network for places all around the world. (Alshalalfah & Shalaby, 2007; Burke & Brown, 2007; Daniels & Mulley, 2013; El-Geneidy et al., 2014). The average walking distance varies for different countries, cities, or even districts of the specific city (Kittelson & Associates Inc., 2003). For the city centers, citizens are eager to walk about 400–500m meters. However, people tend to walk longer distances in the less urbanized areas and for faster services like trains (Kittelson & Associates Inc., 2003). The distances are also longer in developing countries, where public transportation infrastructure isn't well-developed (Johar et al., 2015).

The paper presents an application of the GIS analyzes for the bus network of Hanoi. The first aim was to evaluate the urban area coverage by existing bus network. The second aim was to assess the existing network combined with the lines under construction. The location of the existing bus stops as well as constructed metro lines' stations were analyzed and discussed. The multisource analyzes allowed to identify areas without the bus service access in two scenarios: 500m and 1km walking distance. The comparison of bus stop locations with bus routes and residential areas allowed to point the blind spots of the network. The strong and weak points of the analyzed network were discussed.

2. HANOI TRANSPORT NETWORK

Many cities have one, big terminus in the city center offering change the bus line, or transfer to trams or trains. The big advantage of Hanoi network is owning more than one main bus terminus. Bus terminals are located around the city center. Thanks to that, there is no one overcrowded hub. Some of them are placed outside the downtown, what allows to avoid the traffic jams, and reduce the chance of delay. Each bus terminus is the beginning point of bus lines going in similar directions. The downtown lines allow passengers to travel between those hubs. On the other hand, it may be confusing for passengers unfamiliar with the transport network.

Structure of public transport in Hanoi is well-considered and well-organized only in the city center. The oldest part of the city, where buildings and roads were made in previous centuries has good network connectivity. However, new residential areas which were made in last decades hadn't been considered enough in plans of public transport development. Due to that, travel from those districts to the city center of Hanoi could take two or three times more than a car or motorcycle ride.

Outside the downtown, bus routes are usually located along main roads. Those are the widest and the one with the highest capacity. This approach in public transportation network planning has many pros and cons. First, buses have higher velocity and time of travel is shorter. Second, passengers have the possibility to change easily the line, because many different buses stop in the same places. On the other hand, many highly developed places with big population are not placed in the near of any wide roads, thus the access to public transport is limited. Moreover, sometimes two bus lines have almost the same course, the only small part route is different. The number of bus lines itself is not enough to tell that coverage of the city is on the appropriate level. Owing to those facts, citizens choose their own vehicles and the traffic increases.

Currently, the first two metro lines are under construction. The line 2A goes from Cat Linh district to Ha Dong district, and line 3 from Nhon to Hoan Kiem (Hanoi Train Station). Figure 1 depicts the schema of the existing bus network and the first two metro lines. Both lines were designed in populous areas. The total number of people in all intersected districts is over 2 million people. The distance between metro stations is about 1km. According to the researches about walking distance to public transport, people tend to walk up to 1km to the rapid transit.

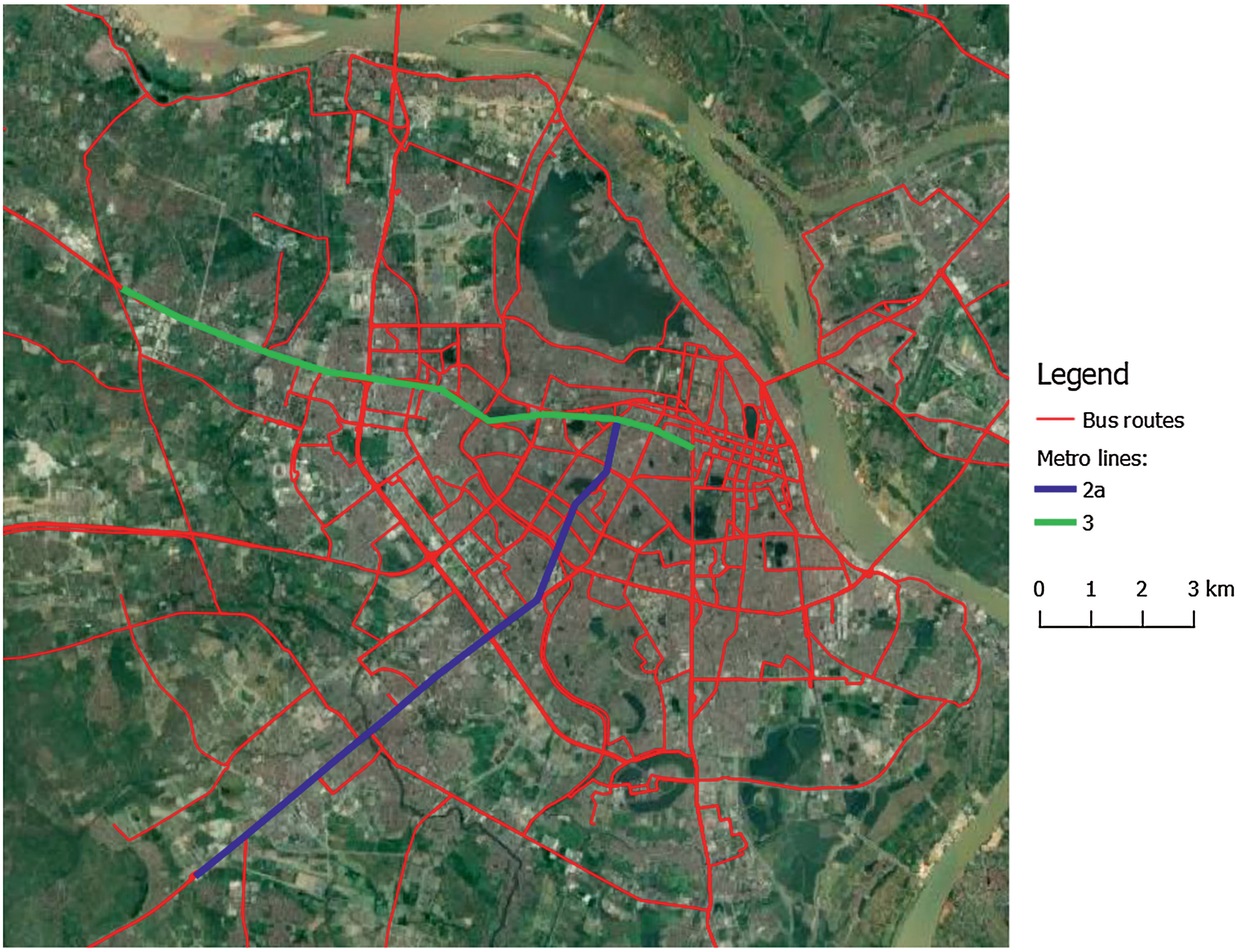

Fig. 1. Public transport network scheme (red – bus lines, blue – metro line 2A, green – metro line 3, background – airborne photo)
Rys. 1. Schemat sieci publicznego transport (czerwony – linie autobusowe, niebieski – metro linia 2A, zielony – metro linia 3, podkład mapowy – zdjęcie lotnicze)

3. DATA AND METHOD

The analyses were based on the multiple sources of data. The main layers are presented in Table 1. Before the main analyses, some data demanded to be pre-processed.

The residential areas data was collected from topographic maps in scale 1:25000. The urban areas were presented with three types of objects: area polygons (city center), single buildings polygons (public utility buildings) and buildings' symbols (small towns, villages). The buildings' symbols had to be converted into areas. The random distribution of symbols didn't allow to represent residential areas with convex hulls. Instead, the aggregated buffer of the 50-meter radius was applied. The new layer overlapped the water bod-

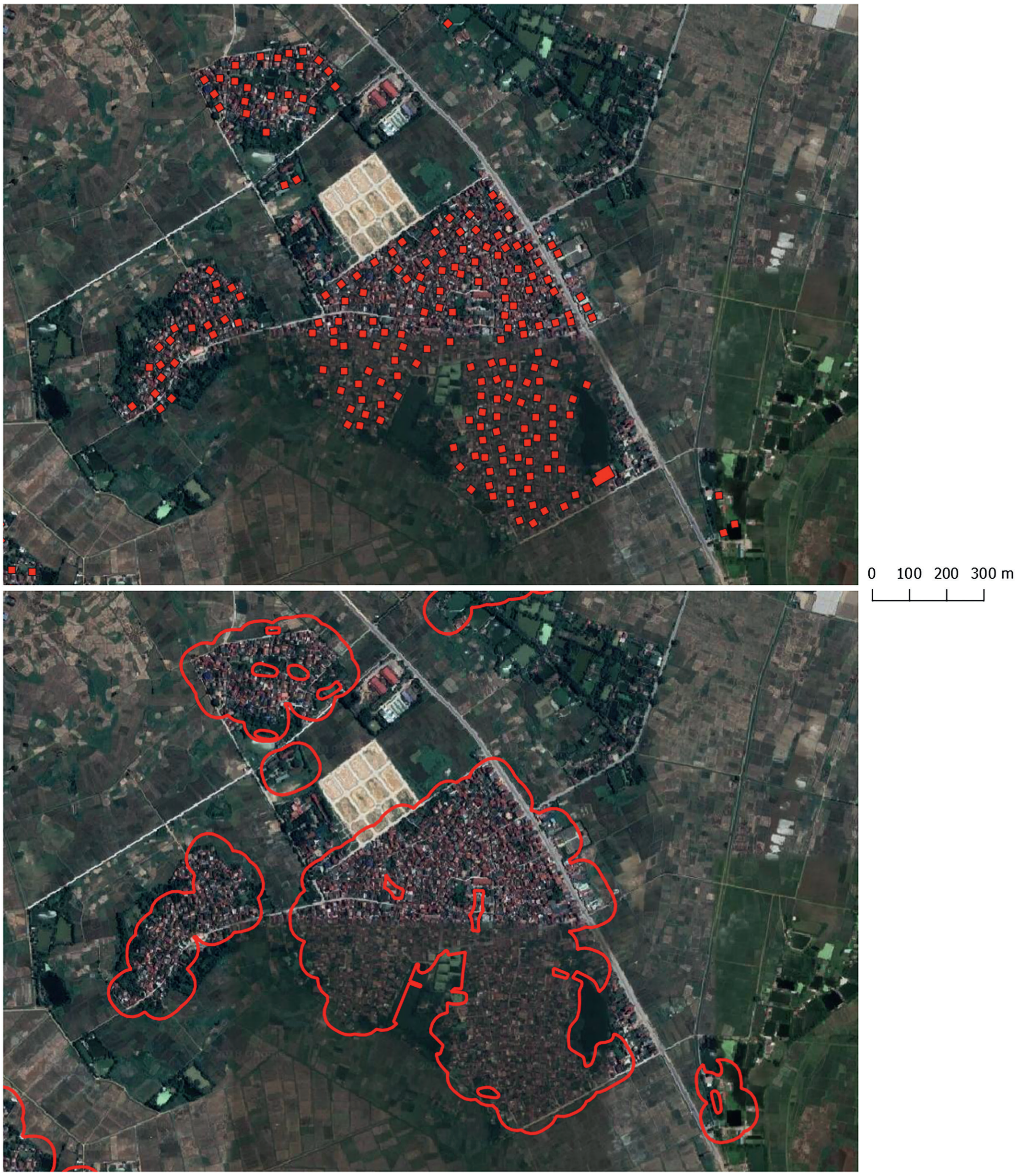

Fig. 2. Comparison of the residential area obtained from the topographic map and buffer layer after water bodies exclusion (airborne photograph from Google Maps)

Rys. 2. Porównanie obszarów mieszkalnych pozyskanych z map topograficznych z warstwą buforów opracowanych na podstawie rozmieszenia linii i przystanków autobusowych. Z analiz wykluczone zostały wody powierzchniowe (zdjęcie satelitarne Google Maps)

Tab. 1. Main data layers used in the analyses
Tab. 1. Główne warstwy danych użyte w analizach

Layer name	Type of data	Source
districts borders	area	Topographic map
residential areas	area	Topographic map
water bodies	area	Topographic map, OSM
bus routes	line	Timbus.vn, transerco.com.vn, Google Maps
bus stops	point	Timbus.vn, Google Maps
Metro stations	Point	Metro lines map (online), Google Maps

ies, which were not residential areas. Thus, the minus operation between the buffer layer and water bodies layer was applied. The results were compared with the airborne photographs to check the correctness of the process. Figure 2 presents an example of the results.

Bus routes and localization of the bus stops were obtained from the internet services dedicated to bus network of Hanoi. The vector data quality offered by those services is very low. The different bus lines going through the same roads have different tracks (Figure 3). This disabled the possibility of conducting any network analyses. Therefore, all routes were re-vectorized.

Most of the bus routes are two-way. To avoid the doubling of data, for each one of those lines only one-way was selected. Therefore, also the bus stops localizations were determined based on their localization. If it was a twin bus stop (for two different directions) on the opposite sites of the road, the middle point was taken. If it was a single bus stop, it was marked directly.

Table 2 presents the parameters of generated residential areas. The population data was mainly obtained from a census which took place in the year 2009 by General Statistics Office of Vietnam. Some of the districts' data were obtained in other years (for example Dong Anh in 2009, Chuong My in 2013). The oldest statistics, for Ba Vi district, are from 1999. But due to the positive birthrate, one has to assume an even higher number of citizens in all of the districts.

Due to the specific land use structure of Vietnam with the multiple water bodies (Figure 4), the popula-

Fig. 3. The example of different bus routes obtained from Google Maps (airborne photograph from Google Maps)
Rys. 3. Przykład różnic w przebiegu tras linii autobusowych pozyskanych z Google Maps (zdjęcie satelitarne Google Maps)

tion density was computed only for the residential areas. For example, in Tay Ho district only 30% of the terrain is a residential area, and over 40% is covered with water. Therefore the population density for the whole district is under 5000 pop. per km^2, but density only in the residential area is over 15000 pop. per km^2. The 3 groups of districts were distinguished: rural (R) (under 10000 pop. per km^2), small town/ suburbs (S) (10000–25000 pop. per km^2), and downtown (D) (over 25000 pop. per km^2).

Tab. 2. Residential areas in each district
Tab. 2. Powierzchnia obszarów mieszkalnych dla poszczególnych dystryktów

District Name	Population [p]	Residential area [km^2]	District area [%]	Population density [p/km^2]	District type
Ba Dinh	228352	8.07	85.5	28293.5	D
Ba Vi	242600	108.88	25.3	2228.2	R
Bac Tu Liem	320414	14.24	32.0	22501.1	S
Cau Giay	251000	8.13	65.4	30869.9	D
Chuong My	261000	64.97	27.3	4017.1	R
Dan Phuong	124900	17.18	21.9	7271.4	R
Dong Anh	376750	43.37	23.0	8687.6	R
Dong Da	408000	9.44	93.3	43228.2	D
Gia Lam	251275	26.13	22.1	9616.7	R
Ha Dong	250687	11.79	34.0	21268.9	S
Hai Ba Trung	378000	8.19	81.6	46131.1	D
Hoai Duc	188800	22.88	24.9	8252.3	R
Hoan Kiem	178078	4.15	80.3	42897.3	D
Hoang Mai	358277	16.65	40.9	21519.3	S
Long Bien	273706	19.59	32.5	13968.6	S
Me Linh	187536	26.82	18.8	6992.6	R
My Duc	167700	32.17	14.1	5212.7	R
Nam Tu Liem	232894	11.30	33.3	20616.0	S
Phu Xuyen	181500	32.97	18.9	5505.4	R
Phuc Tho	154800	25.58	21.3	6051.7	R
Quoc Oai	146700	38.26	25.1	3834.2	R
Soc Son	254000	74.85	24.3	3393.7	R
Son Tay	181831	38.17	32.1	4764.3	R
Tay Ho	115163	7.35	30.9	15678.8	S
Thach That	149000	42.00	22.2	3548.0	R
Thanh Oai	142600	29.28	21.8	4870.7	R
Thanh Tri	241000	19.44	30.6	12397.8	S
Thanh Xuan	259000	7.77	83.6	33351.6	D
Thuong Tin	208000	29.92	22.6	6952.3	R
Ung Hoa	193731	30.07	15.8	6441.7	R

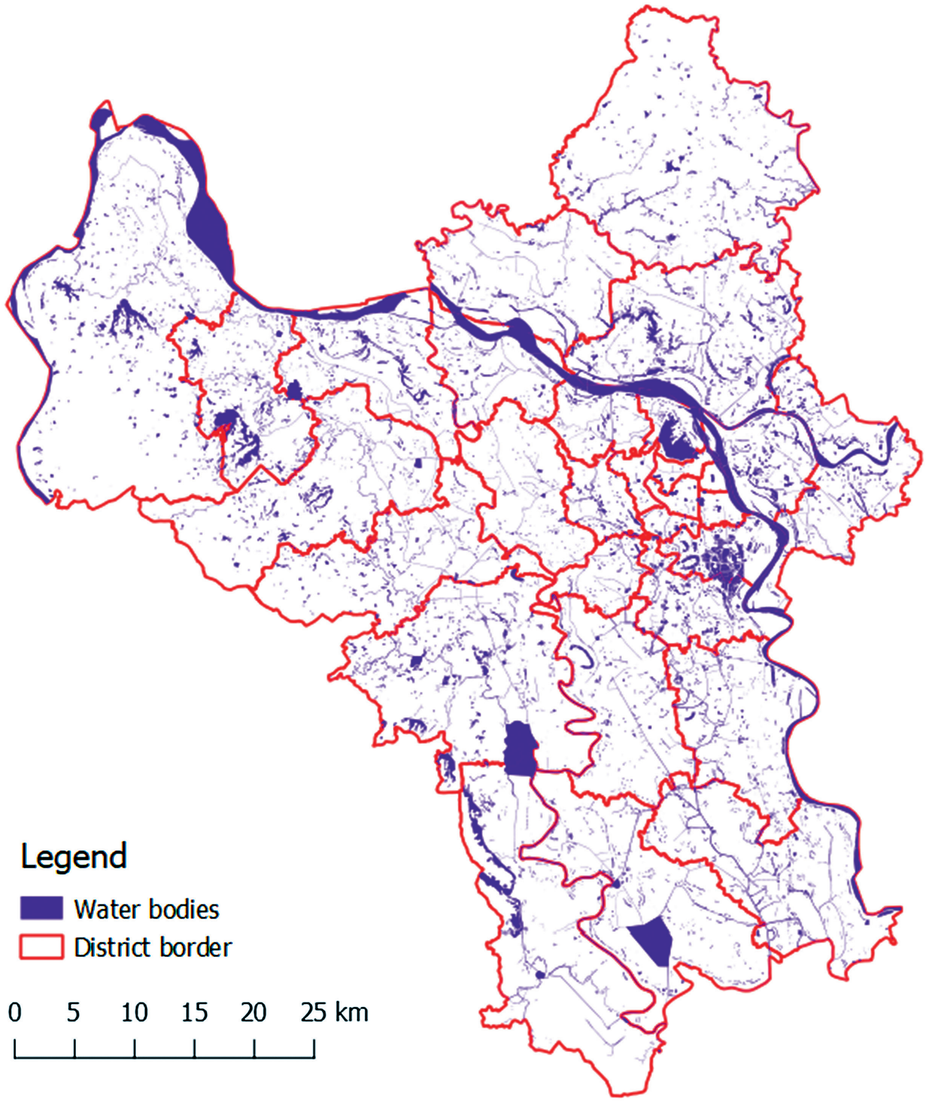

Fig. 4. Water bodies and Hanoi districts' borders
Rys. 4. Wody powierzchniowe i granice administracyjne dystryktów Hanoi

4. RESULTS

The structure of the bus network with the residential area was analyzed two-ways. First, the localization of the bus stops was analyzed. Second, the coverage of the bus routes was analyzed. In both approaches, two buffers with different radii were applied. The buffer radius represents the distance a passenger has to walk to get to the public transport. Due to the topography and road network, the X meter buffer around the point of a bus stop doesn't mean that walking X meter is enough to get to this bus stop. Therefore citizens living within the buffer may be forced to walk further. The buffer values were assumed for the ideal scenario, where there are no obstacles. One has to remember that area within X meters walking distance is smaller than X meter buffer.

Based on the studies for others cities in developing countries, the walking distance of 500m to the bus stop was chosen (Johar et al., 2015). Another buffer, 1000m, was used to analyze the less urbanized, rural districts of Hanoi. Figure 5 and Figure 6 present the coverage of the area for 500m buffer.

For each district, the residential area covered by the bus stop buffer was computed. The results are presented

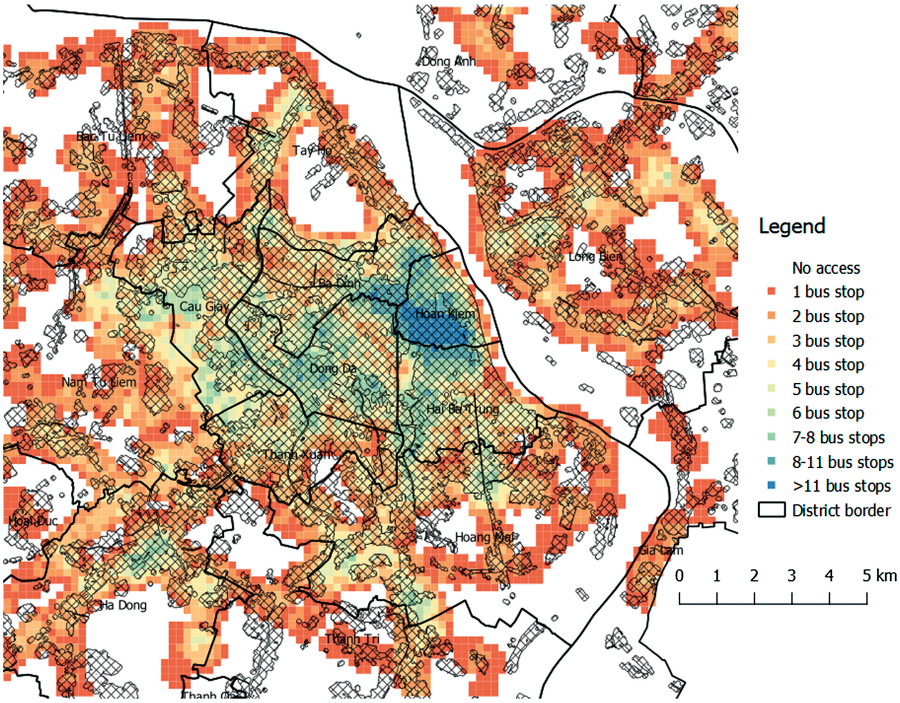

Fig. 5. Access to bus stops (up to 500 m) and residential areas (hatched) – Hanoi's downtown districts
Rys. 5. Dostęp do przystanku autobusowego (mniej niż 500m) z zaznaczonymi obszarami mieszkalnymi (kreskowanie) – miasto Hanoi

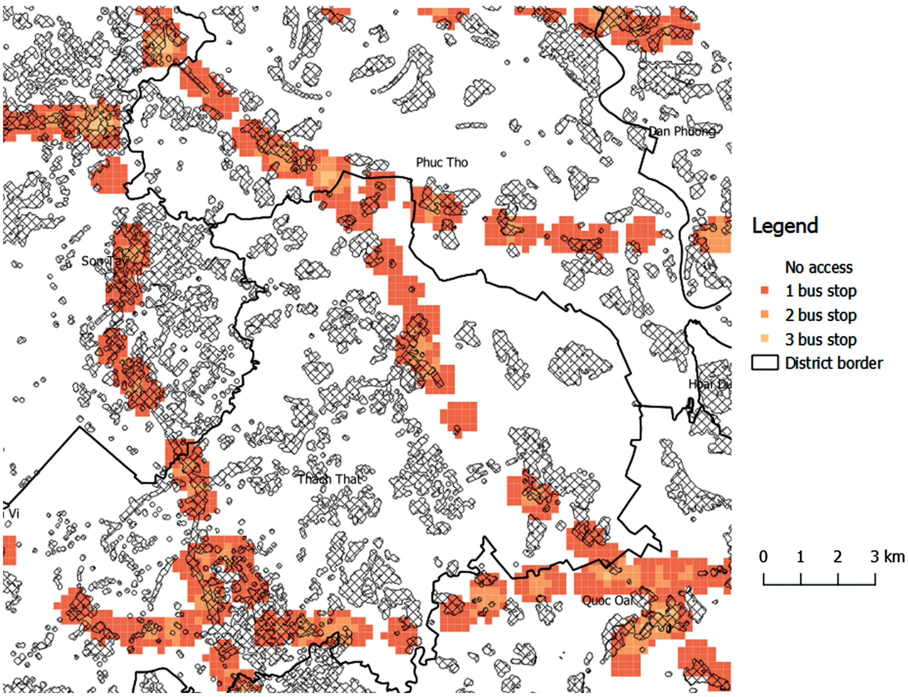

Fig. 6. Access to bus stops (up to 500 m) and residential areas (hatched) - Western districts
Rys. 6. Dostęp do przystanku autobusowego (mniej niż 500 m) z zaznaczonymi obszarami mieszkalnymi (kreskowanie) – zachodnie dystrykty prowincji Hanoi

Tab. 3. Residential area within 500 m and 1 km to the bus stop (percent)
Tab. 3. Powierzchnia obszarów mieszkalnych w zasięgu 500 m i 1 km do przystanku autobusowego (procent)

District Name	Residential area coverage (buffer 500m) [%]	Number of people outside the 500m buffer	Residential area coverage (buffer 1000m) [%]	Number of people outside the 1km buffer
Ba Dinh	97.2	6323	97.3	6221
Ba Vi	2.8	235888	6.2	227484
Bac Tu Liem	77.8	71021	95.6	14253
Cau Giay	96.2	9450	97.8	5442
Chuong My	21.1	205987	33.4	173784
Dan Phuong	37.1	78517	61.4	48221
Dong Anh	48.6	193586	76.7	87961
Dong Da	96.9	12822	96.9	12822
Gia Lam	45.0	138265	68.1	80142
Ha Dong	71.5	71522	87.2	32054
Hai Ba Trung	95.8	15956	96.8	12276
Hoai Duc	33.3	125986	58.3	78731
Hoan Kiem	97.8	3850	97.8	3850
Hoang Mai	78.1	78374	89.4	38073
Long Bien	75.4	67409	91.0	24765
Me Linh	20.2	149708	35.5	121012
My Duc	10.2	150587	22.7	129588
Nam Tu Liem	74.6	59156	93.9	14234
Phu Xuyen	27.1	132346	41.8	105557
Phuc Tho	18.5	126132	48.4	79849
Quoc Oai	20.4	116707	40.1	87878
Soc Son	34.4	166728	62.4	95410
Son Tay	24.0	138113	49.0	92742
Tay Ho	84.8	17451	90.4	11039
Thach That	17.7	122586	35.9	95493
Thanh Oai	22.2	110906	44.4	79310
Thanh Tri	50.8	118580	75.9	58024
Thanh Xuan	91.8	21311	95.5	11548
Thuong Tin	25.6	154774	49.6	104788
Ung Hoa	26.9	141656	41.7	112945
	Average = 50.8	Sum = 3041698	Average = 66.0	Sum = 2045497

Table 4 Residential area within 1km to the metro station (percent)
Table 4 Powierzchnia obszarów mieszkalnych w odległości do 1km do planowanej stacji metra

	Line 2A		Line 3	
District Name	**Residential area [%]**	**Population [p]**	**Residential area [%]**	**Population [p]**
Ba Dinh	22.5	51423	50.9	116303
Bac Tu Liem	n.a.		16.8	53916
Cau Giay	2.6	6589	51.1	128327
Dong Da	48.0	195918	35.0	142940
Ha Dong	53.0	132909	n.a.	
Hai Ba Trung	n.a.		2.4	9088
Hoai Duc	n.a.		0.3	513
Hoan Kiem	n.a.		26.3	46796
Nam Tu Liem	5.5	12894	19.4	45240
Thanh Tri	1.8	4435	n.a.	
Thanh Xuan	56.8	147071	n.a.	
		Sum = 551240		Sum = 543123

in Table 3. The coverage of the whole Hanoi province is about 50–65%, depending on the assumed walking distance. Outside the 500m and 1km buffers live over 3 million and 2 million people respectively.

Table 4 presents the districts' residential area percent within the 1km range to the station. When the metro routes go across the districts, the coverage is about 50 percent. Close to the intersected districts' borders, the buffer overlaps the neighbor districts like Hai Ba Trung and Hoai Duc. The total population within 1km walking distance is about 1.1 million, what is a half of the whole population in those districts.

5. SPATIAL ANALYSIS

All identified downtown districts (over 25000 pop. per km^2) has coverage over 90% of the residential area. For this group, the lowest coverage is in Thanh Xuan. The small town/suburbs districts have the coverage over 50% for 500m buffer and over 75% for the 1km buffer. The rural area has coverage in the range of about 10–50% and 20–75% respectively for 500m and 1km buffers. The Ba Vi district is an exception, where only about 3% and 6% of the houses are in the range of bus stops. That also means that averagely 94–97% inhabitants of this district don't have access to the public service.

The residential areas outside the buffer zone were computed. The percent of the districts' residential area not covered with bus service (1km buffer) is presented in Figure 7. The worst coverage of the network is in the western districts – Ba Vi, Thach That and My Duc. To evaluate the distance to those buildings, the distance map was generated. Examples for the Ba Vi district and the southern districts are presented in Figure 8 and Figure 9.

The Ba Vi district is the only one district, where most of the inhabitants have to walk over 5km to the nearest bus stop, and from the western part of the district over 10km. In the south-west districts, where the network is denser, only the borderlands areas aren't within the 5km distance. But both those examples exceeded the walking distances presented by the scientists. Therefore, assuming 1km walk distance for the rural areas, the network density has to be increased. In contrary, in the Hanoi downtown (south part of Hoan Kiem district) within 500m distance there is

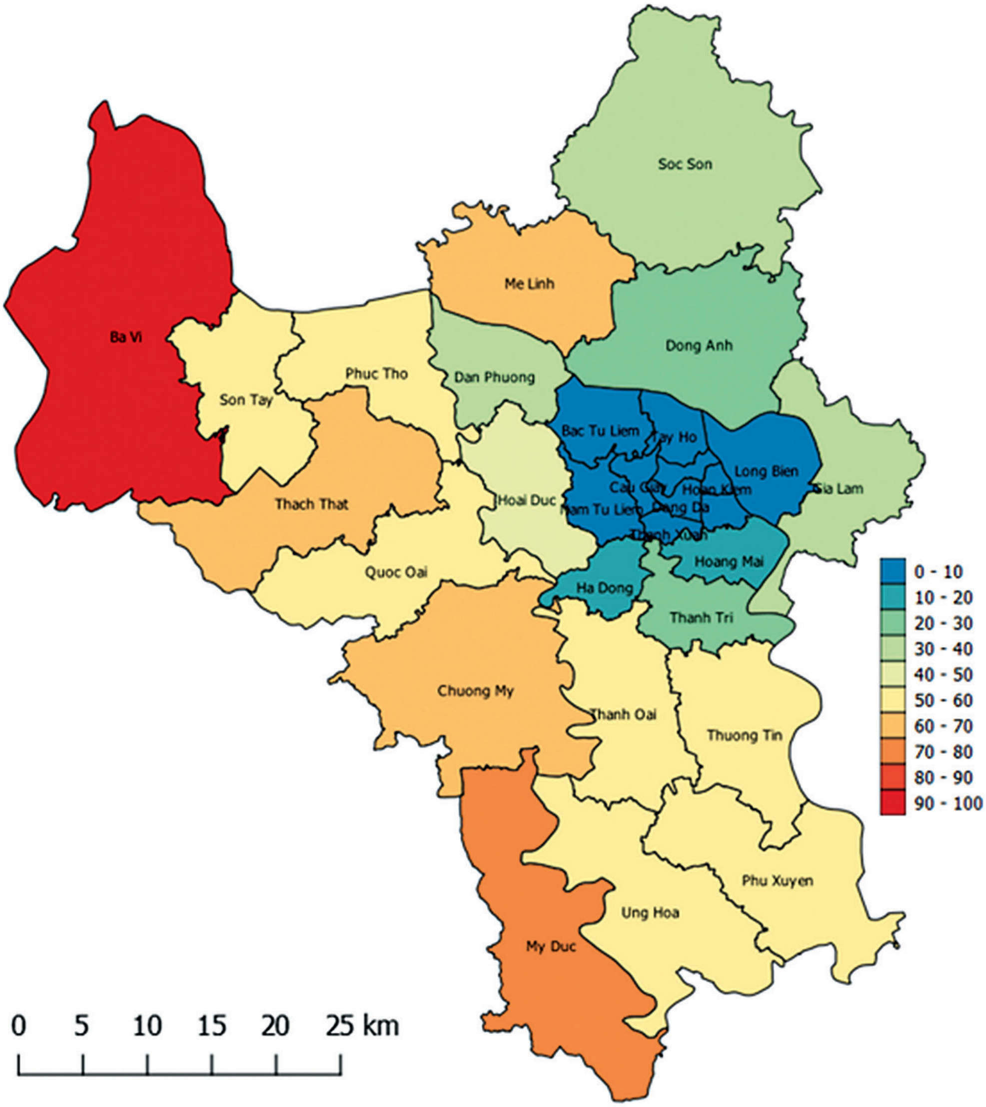

Fig. 7. Percent of the residential areas in distance greater than 1 km from the bus stop
Rys. 7. Procent obszarów mieszkalnym leżących dalej niż 1 km od przystanku autobusowego

over 10 bus stops (Figure 5), and within 1000m almost 50 bus stops.

In the next step, the gaps in the bus stop network were identified. For all bus lines, the buffers 500m and 1km were applied. The bus stops buffers were compared with bus routes, and the difference was intersected with residential areas. The final result contained buildings within the walking distance to the bus line, but without bus stop, where passengers could use the service. Over 50 areas with a population over 1000 people were identified, where 3 areas had equal to or more than 3500 people. Those blind spots are the best places to put new bus stops, to increase the coverage of the analyzed network.

The population covered by the rapid transit is about 50 percent. Therefore, the bus network is essential to complement the transport service. The best practice is placing the bus stop close the rapid transit stations to ease passengers transfer. The 100m and 200m buffers representing the transfer distance were applied. Accordingly, 11 and 6 metro stations don't have access to any bus stop. The reorganization of the bus stop locations around metro stations is an essential problem to increase efficiency and attractivity of public transport.

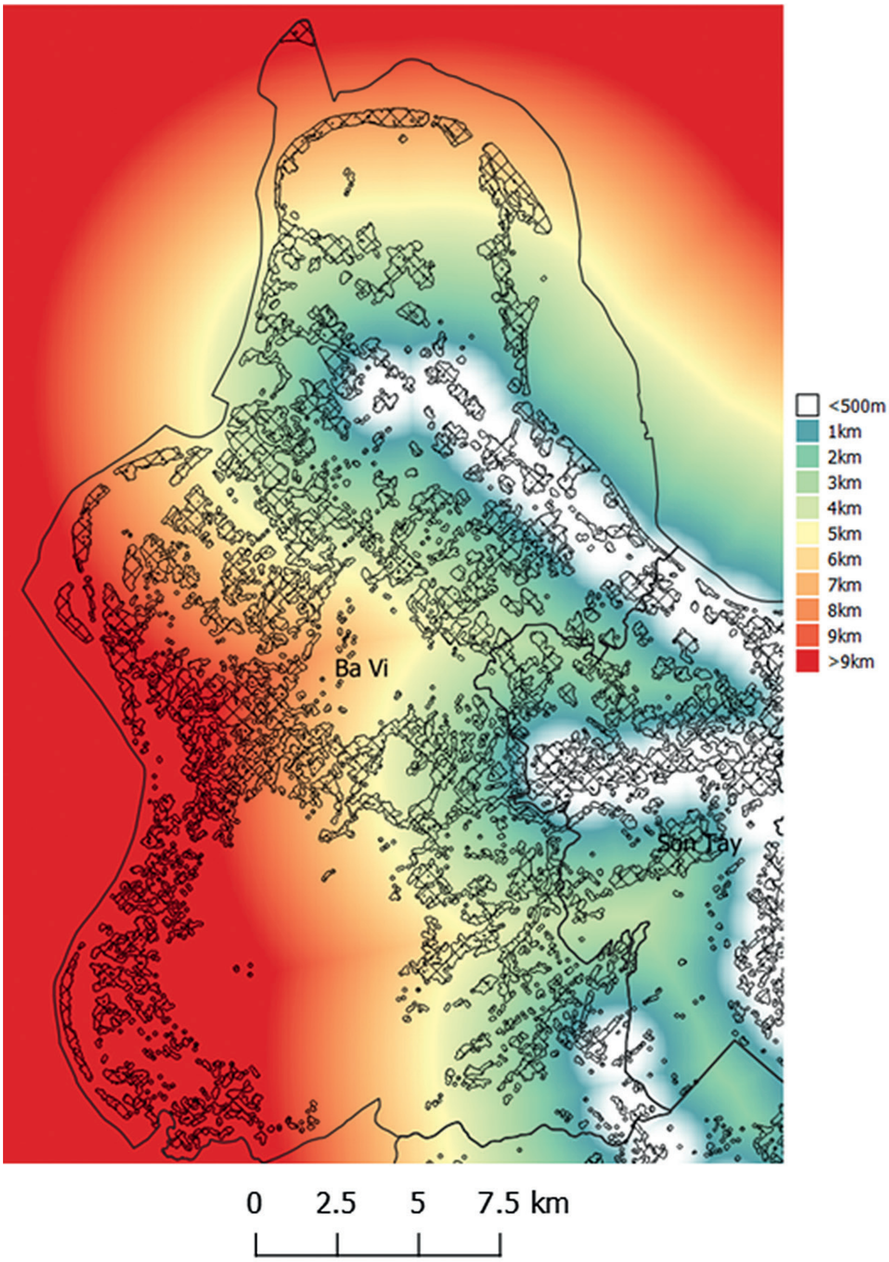

Fig. 8. Ba Vi district bus stop proximity map with marked residential areas
Rys. 8. Mapa odległości od tras linii autobusowych dla dystryktu Ba Vi wraz z zaznaczonymi obszarami mieszkalnymi

6. CONCLUSIONS

Application of the GIS tools in the analyzes of the public transportation network allows fast identification of the not-covered spots. The analyzes conducted for the Hanoi Bus Network identified at least 3 populous areas without the access to the network.

The best coverage is in the downtown, where over 90% of the population has access to the bus stop within 500m. In contrary, in rural districts under 50% of inhabitants has access to the bus stops, even with the increased walking distance.

Bus service is slow and its operation depends on the traffic, especially in peak hours. But it is necessary to

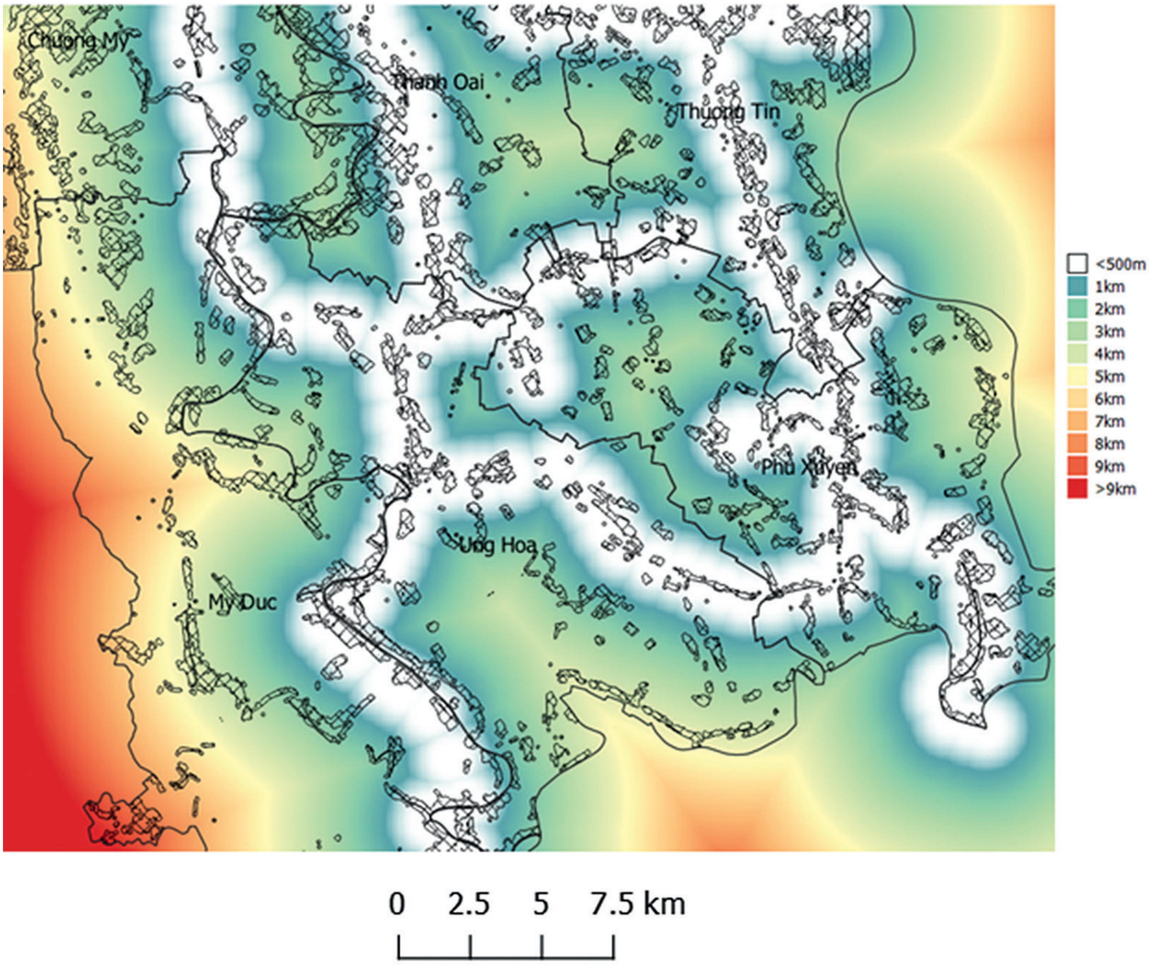

Fig. 9. Southern districts bus stop proximity map with marked residential areas
Rys. 9. Mapa odległości od tras linii autobusowych dla południowych dystryktów wraz z zaznaczonymi obszarami mieszkalnymi

complement the rapid transit system. The Hanoi metro system, contemporary under construction, enforces the changes in the location of the bus stops. At least 6 metro stations don't offer the possibility of transfer to the bus network.

The dense network of a rapid public transportation is the best solution for growing metropolises. And it is the only solution for streets overcrowded with cars and motorcycles. The change from the car-based city into public transport-based city demands to develop of the public services network and changing citizens' habits. In some cultures, the way of traveling is an important part of the lifestyle. It is difficult to change it, but in the end, it would result in the cleaner and more friendly city.

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