Derivation of Critical Infrastructure Accessibility Index Using GIS-MCDA and Network Analysis: Case Study of Sarajevo

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Abstract: This study explores the accessibility of critical infrastructures (CRITIS) in urban planning, focusing on the City of Sarajevo. CRITIS, essential for societal functioning, encompasses diverse services vital to social, economic, political, health, educational, and administrative systems. The authors leverage geographic information system (GIS) tools to construct an accessibility model for Sarajevo, analysing the spatial availability of critical functions. Six groups of CRITIS indicators, composed of 29 CRITIS elements, were used in the derivation of critical infrastructure accessibility index. The methodological framework was based on implementation of network GIS analysis, interpolation method (IDW) and GIS multi-criteria analysis, which could be applicable to similar research studies. Local communities concentrated in the strict urban core (Ferhadija, Baščaršija) have the best accessibility of CRITIS, while peripheral local communities with a large area, such as Mošćanica and Reljevo, have the lowest. Results suggest a zonal categorization of the urban area, providing valuable insights for spatial planning and future urban development management. The study reveals that the highest value of CRITIS accessibility doesn't necessarily align with the most densely populated areas at local community level.

1 INTRODUCTION AND BACKGROUND

Though lacking a singular and universally accepted definition, critical infrastructures (CRITIS) (Luiijf et al., 2009) can be elucidated through a fundamental set of services that constitute the lifeblood of seamless economic and societal functioning. According to Murray (2012) it encompasses a diverse array of means facilitating the operation of social, economic, political, health, educational, and cultural systems. Numerous studies and scholarly works delve into the capacity of a state or society to enhance the functionality of essential infrastructural systems, often with the primary objective of formulating measures to protect and fortify specific infrastructural components crucial to national security (Croope and McNeil, 2011). The formulation of strategies for this purpose proved highly beneficial during crises such as the COVID-19 pandemic and various environmental or natural disasters, including floods and earthquakes. Consequently, the past decade has witnessed a proliferation of research on the vulnerability and resilience of critical infrastructure, exemplified by works from Huff et al. (2019), Milanović et al. (2017), Svegrup et al. (2019) and Niu et al. (2022). Although Bosnia and Herzegovina lacks an advanced critical infrastructure protection system, there has been a growing recognition in both public and academic spheres of the necessity to establish such a platform (Smajić and Bajramović, 2024). Given that urban areas remain focal points for human settlement, critical infrastructure assumes paramount importance within cities due to its multifaceted nature and the substantial user base reliant on its services. Urban planning, in this context, places particular emphasis on investigations into the accessibility of specific functions (Neuman, 2012, Šiljeg et al., 2018), with accessibility being a determinant of equal access and opportunity, where transport infrastructure assumes a pivotal role. The vulnerability of these systems emerges as a significant planning challenge, as highlighted by Tsenkova (2012), particularly in the cities of Southeastern Europe, where susceptibility is compounded by limited access to education and healthcare. Such a situation result from the rapid

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urban development of the formal city and strong centralization, relegating smaller settlements to the periphery. Sarajevo, the capital of Bosnia and Herzegovina and the most administrative, political, cultural and financial centre of the country, is no exception. The city has undergone substantial spatial transformations in urban content and significant alterations in urban morphology, owing to its turbulent historical and social development, as well as the impacts of economic and induced demographic transitions (Pobrić, 2002; Gül and Dee, 2015; Čakarić and Idrizbegović Zgonić, 2020). The dynamic nature of these alterations underscores the necessity to investigate the availability of infrastructural facilities considered vital for urban functioning. Given the absence of a universally applicable set of criteria for ascertaining infrastructure criticality, such criteria are tailored to the socio-economic characteristics of the observed area. Cikotić et al. (2018) assert that energy plants, information technology, finance, healthcare, food services, water, transport, and government are among the most prevalent critical infrastructure components, subject to national, regional, and local spatial scales vulnerability assessments. Contemplating the essential services requisite for seamless daily operations and drawing insights from recent pandemic conditions, the authors of this study have incorporated elements from the transport, administrative, health, educational, and communal sectors in their analysis of the spatial availability of critical infrastructure.

Leveraging Geographic Information System (GIS) tools for the spatial delineation of essential, critical functions, the principal objective of this study is to construct an accessibility model of critical infrastructure (CRITIS) for the City of Sarajevo. The aim is to comprehend the extent to which residents and all service users can effortlessly access goods, services, and activities. Ford et al. (2015) posited that accessibility to services constitutes a crucial component in developing a sustainable transport system, functioning as a highly important intermediary between services and the population. Consequently, spatial accessibility encompasses both service availability and travel impedance, with travel distance and suitable transportation emerging as common indicators of accessibility (Yin, 2010; Šiljeg et al., 2018; So, 2016).

GIS provides an expansive array of tools for analysing availability, vulnerability, resilience, and control, particularly in CRITIS (Wolthusen, 2005; Milanović et al., 2018). This underscores the applicability of geographic solutions in addressing contemporary urban challenges. The novelty of this study lies in its innovative utilization of the GIS multi-criteria model to construct a comprehensive accessibility model of critical infrastructure in a case study of a transitional city with atypical urban development, thereby offering valuable insights for informed decision-making in urban planning.

2 STUDY AREA

The territorial scope of this research is limited by the administrative boundaries of Sarajevo (141 km²), which has a population of 275,524 people, according to the last 2013 census (BHAS, 2016). It comprises four urban municipalities (from east to west): Stari Grad, Centar, Novo Sarajevo and Novi Grad. The historical centre of Sarajevo is located in the eastern part of the urban area, in the municipality of Stari Grad (Old City), while newer neighbourhoods line up to the west. The terrain morphology primarily determines the urban development and sprawl of Sarajevo, so the majority of the city population is concentrated in the Miljacka River valley and on the nearby hills. On the other hand, the surrounding mountains, such as Trebević and Ozren, are virtually uninhabited.

Sarajevo is a typical example of a transitional city. It experienced most of its spatial and population growth in the socialist period, during the second half of the 20th century. The event of the 1984 Winter Olympics was a particularly significant stimulation for urban growth and infrastructure modernisation. However, the process of further development of critical infrastructure was interrupted by the 1992-95 war and post-war economic underdevelopment. Hereby, this study is the first attempt at methodologically based research on disparities of urban development of critical infrastructure in the capital city of Bosnia and Herzegovina.

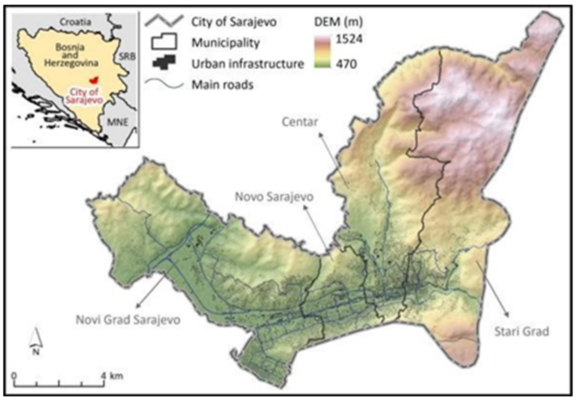

Figure 1: Geographical location of City of Sarajevo and its administrative division.

3 MATERIALS AND METHODS

The methodology is based on an integrated application of network GIS analysis (closest facility), interpolation method of time cost attribute and GIS multi-criteria analyses (GIS-MCDA).

The methodological framework can be divided into seven steps (Fig. 2): (1) determine the main GIS-MCDA objective (2) selection of appropriate groups and elements of CRITIS; (3) acquisition of GIS and non GIS data; (4) application of closest facility tool within Network analyst; (5) interpolation of travel time cost attribute using inverse distance weighted (IDW) method; (6) aggregation of the accessibility raster models using weighted sum tool; and (7) delineation of hot-spots and deprivation zones of CRITIS using Zonal statistics tool.

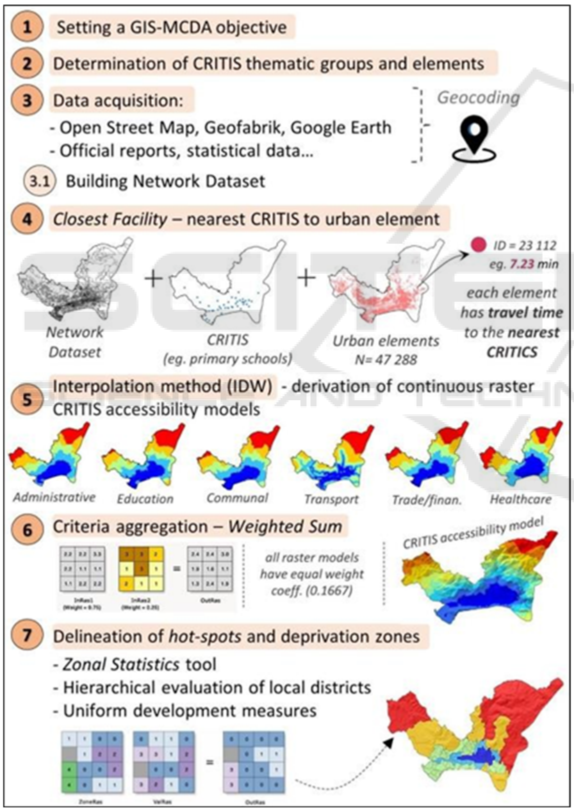

Figure 2: Methodology workflow.

3.1 Selection of CRITIS

CRITIS encompasses components of the urban system that constitute essential foundations for the operational integrity and safety of urban environments, particularly during periods of imminent peril (Yang et al. 2023). These infrastructural systems assume a pivotal role in facilitating the fulfilment of imperative social, economic, organisational, and other functions crucial for the routine activities of the urban populace (Petrović et al, 2018). The absence of a uniform system for selecting indicators for critical infrastructure allows the authors arbitrariness to the extent that follows the logic and nature of urban functions and the socio-economic status of the city.

In selecting infrastructure systems as critical, the authors primarily decided on educational and health infrastructure due to their fundamental roles in ensuring societies' well-being, resilience, and functionality. Educational institutions are primary contributors to human development in a sphere of workforce preparation, innovation and social development (Grigore, 2021), while health infrastructure, including hospitals, clinics and public health systems, provides medical services and plays a critical role in safeguarding public health (Sänger, et al-, 2021, Scholz et al-, 2022). In many works, the transport network is undeniably treated as a vital part of critical infrastructure (Theoharidou, 2012; Borghetti and Marchionni, 2023), enabling basic services for the movement of people, goods and information, and in the context of the availability of all other functions, it plays an intermediary role. Administrative functions involve critical decision-making processes at various levels of government. These decisions impact the overall well-being of a nation, its citizens, and its infrastructure, which is reason why many authors (Żaboklicka, 2020) find it critical. Due to their essential role in providing services such as water supply, gas and telecommunication, utilities are considered as CRITIS (URL 1, URL 2).

Although it certainly belongs to the critical domain, the connection of households to electricity, water, sewerage and similar networks was not taken into consideration within this research, since it is considered that almost all the city's population has access to this type of infrastructure. Instead, the work is focused on the discovery of spatial disparities in the accessibility of those functions, which are characterised by a certain degree of physical distance, but are also necessary for the daily life of people, as well as the sustainability of the social system. In the context of the accessibility of communal services, treated facilities where fees for the aforementioned services are regulated, and which are considered inevitable for their users. Finally, banks, malls, supermarkets and hypermarkets as key chains for the supply of commercial and banking services are classified in the group of trade/financial indicators of CRITIS. Table 1. shows all CRITIS groups and elements for which accessibility analysis is done.

Table 1: CRITIS thematic groups and elements.

Group	CRITIS	Source
Educational	Primary school	URL3, Google Earth (GE)
	Secondary school	URL3, GE
	Kindergartens	Geofabrik, GE
Administrative	Offices for social help and employment	URL 4, GE
	Ministries	URL 5
	Police stations	GE
	Courts	GE
	Local communities	GE
	Administrative authority	GE
Healthcare	Hospital 1rank	URL3, GE
	Hospital 2rank	URL3, GE
	Hospital 3rank + health homes	URL 3, GE
	Pharmacy	Geofabrik, GE
	District outpatient clinics	URL 3, GE
Trade / Finance	Large stores	Geofabrik
	Marketplace	GE
	Banks	Geofabrik
Traffic	Bus terminal	Ministry of Transport
	Minibus stations	Ministry of Transport
	Tram stations	Ministry of Transport
	Trolleybus stations	Ministry of Transport
	Railway stations	Ministry of Transport
	Main roads	Geofabrik
	Post office	Google Earth
Communal	Communal cash register	URL4, GE
	Firefighters	URL4, GE
	Electro distribution	URL4, GE
	Heating plants	URL4, GE
	Community and building managers	URL4, GE

3.2 Data Acquisition

GIS and "non" spatial data were acquired to create the CRITIS accessibility index for the city of Sarajevo. GIS data was mostly acquired from OSM sources, Geofabrik, and official state sources (layer of local communities, and four urban municipalities). "Non-GIS data (addresses of schools, hospitals, banks, etc.) were geocoded using My Maps and Google Earth and then with KML to layer tool converted into GIS data.

After harmonisation, all data were organised into a unique GIS database in the projection coordinate system WGS 1984 UTM Zone 33N. To improve the interpolation model with the extrapolation method (Marić and Šiljeg, 2017), the data were also acquired for neighbouring zones outside the city boundaries. Namely, a buffer zone of 400 m was created around that polygon, which consists of four urban municipalities (Stari Grad, Centar, Novo Sarajevo, and Novi Grad). Within that expanded polygon, a raster accessibility model of the CRITIS was created. After aggregating all models, clipping of the extended model was performed according to the borders of the administrative territory of the city of Sarajevo.

Network analyses were made based on the network dataset, which was created from the road layer downloaded from Geofabrik. Before the derivation of the network dataset, a topological check was made using the Planarize lines tool. Then, for each element, the attribute of the road that needs to be covered (length) and the speed of movement, which in this case is 5 km/h, or the average walking speed of a person, is calculated. From the calculated length and movement speed, the attribute of time (min) that needs to be spent to overcome a certain element of the path is calculated.

3.3 Closest Facility Analysis

Based on the derived network dataset, geocoded locations of CRITIS, and the layer of residential buildings that represent the location of the population in the city of Sarajevo, the Closest facility analysis was performed using the Network Analyst extension within ArcMap 10.8.1. The closest facility solver measures the cost of travelling between incidents and facilities and determines which are closest to each other. When finding the closest facilities, you can specify how many to find and whether the direction of travel is towards or away from them. It displays the best routes between incidents and facilities, reports their travel costs, and returns driving directions.

Residential buildings representing the locations of residents were acquired from Geofarbrik (layer: gis osm buildings a free 1) and then converted into points. In the analysis, "facilities" represented a specific element of the CRITIS infrastructure (e.g., primary schools), while "incidents" was a layer of residential buildings (n=47,288). The cost attribute was time of travel in min. For each residential building, a time of travel attribute was calculated, i.e. how many minutes should be spent walking to reach the specific CRITIS element.

3.4 Interpolation Method

To perform raster continuous models of CRITIS accessibility, it was necessary to implement a specific interpolation method (IM). The input data were elements of residential buildings (n= 47 288). For each of them the cost attribute of travel time was calculated. The IDW (Inverse Distance Weighted) interpolation method was used, which explicitly assumes that things that are close to one another are more alike than those that are farther away. The measured values closest to the prediction location have more influence on the predicted value than those farther away. It gives greater weights to points closest to the prediction location, and the weights decrease as a function of distance. When implementing interpolation methods, the same user- defined parameters (search distance, power setting, etc.) were set for each element of a specific CRITIS group. For all raster models, a spatial resolution value of 10 m was set. After generating the continuous raster models of CRITIS accessibility, it is possible to create isochrones, i.e. lines connecting points (places) that can be reached from a specific place in the same average time.

3.5 Interpolation Method

In total, 26 accessibility CRITIS models were derived. They were clustered into six groups. In the first step, models were aggregated within each thematic group (education, health, administration, etc.) using the Weighted sum tool. Each model had an equal weight coefficient. This resulted in six thematic accessibility CRITIS models. This was followed by a new aggregation where each thematic CRITIS model had a weight coefficient of 0.16667. The final CRITIS accessibility model was converted into a range of values from 0 to 1, where a lower value represents better accessibility, i.e. shorter travel time to CRITIS. This was done using the tool Fuzzy membership and linear function.

3.6 Delineation of Accessibility Zones

Delineation of CRITIS accessibility zones was done following two approaches: (1) boundaries of local districts and; (2) elements of residential buildings. In the first approach, the final CRITIS model overlapped with the polygonal layer of the local district (n=76) within Sarajevo. For each district using the Zonal statistics tool, the mean values of the pixels located within the boundaries of that district were calculated. This made a certain generalisation of the availability CRITIS model according to the boundaries of the local districts. The availability zones thus follow the boundaries of local districts. They were classified into five classes (extremely accessible, accessible, neither accessible nor inaccessible, inaccessible, moderately inaccessible) using the Jenks (natural breaks) classification method (Fig. 2). In the second approach, the final CRITIS model overlapped with the residential buildings layer (points). Then, using the Extract value to point tool, the CRITIS accessibility attribute was derived for each object (point). Then the objects were classified into five classes using the Jenks classification method, similar to the first approach. Descriptive statistics then were derived for both approaches.

4 RESULTS AND DISCUSSION

4.1 CRITIS Models

Examining the spatial dynamics of Sarajevo reveals disparities between the urban core and the semi-urban periphery, particularly evident when scrutinizing the accessibility of critical infrastructure. This analysis delves into key sectors such as educational facilities, public transport, commercial services, administrative hubs, healthcare, and communal infrastructure. The examination unveils distinct patterns that underscore the challenges faced by residents of the outskirt parts of the city compared to those in city center. The study results are predominantly conveyed through cartographic representations, encompassing 29 basic thematic maps. Additionally, these are synthesized into six aggregated maps based on distinct indicator groups. Spatial inequalities between the urban core and the semi-urban periphery of Sarajevo are very evident when it comes to the analysis of the availability of educational infrastructure (Figure 3). The distribution of secondary schools particularly contributes to this, since their deficit has been established even in densely populated areas of the municipality of Novi Grad, while there are none of them in the outer parts of the city. The availability of primary schools is somewhat more even, which is especially visible in the northwestern city periphery. Neighborhoods in this part of Sarajevo are once again neglected regarding availability of kindergartens. A very similar spatial pattern is observed when analyzing the public transport infrastructure (Figure 3). In this regard, the flat part of the city is particularly privileged, where all the tram, trolleybus and railway stations are located, while the hilly neighbourhoods primarily rely on bus and minibus lines.

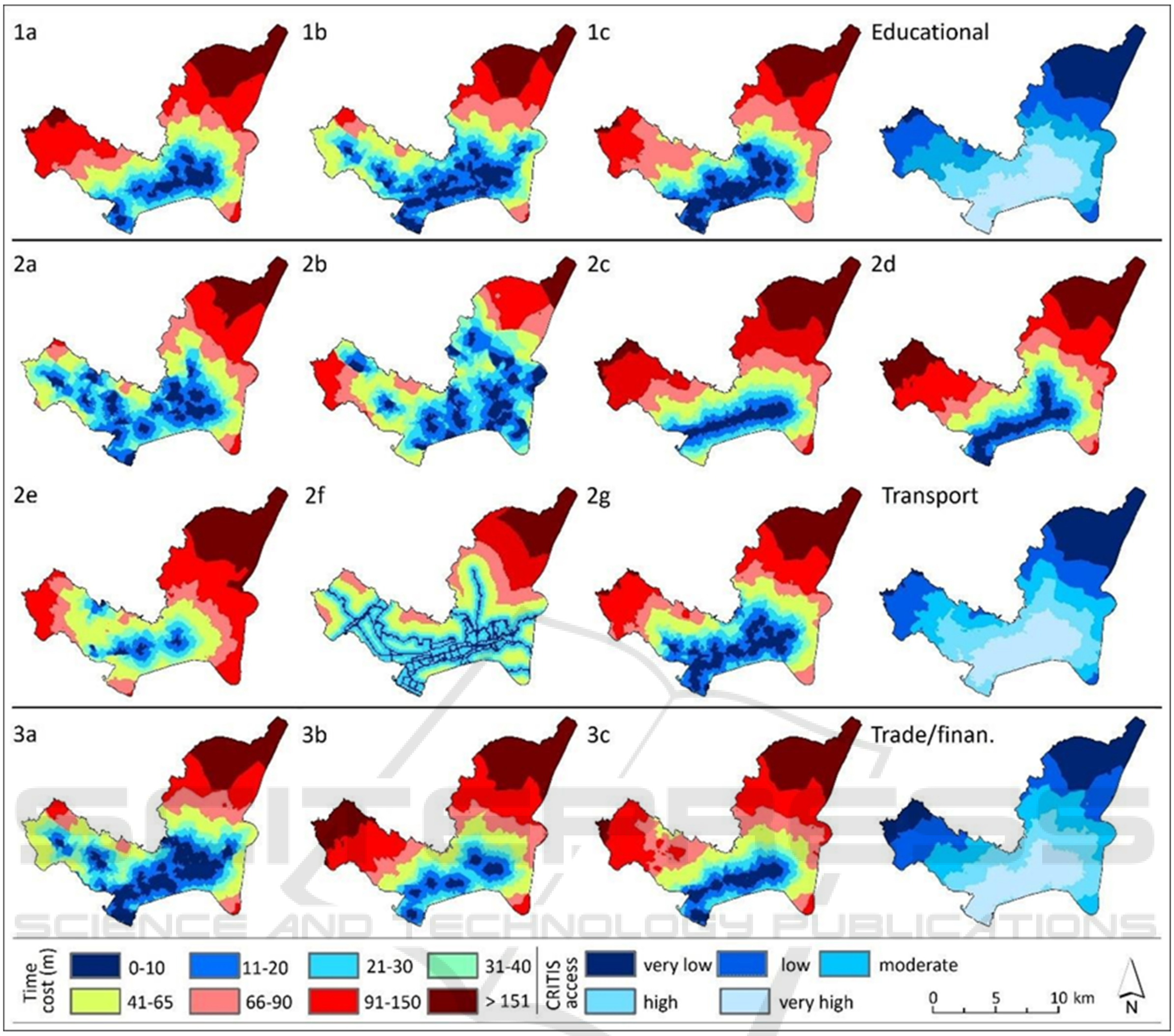

Figure 3: Accessibility model of 1a) secondary schools; 1b) primary schools; c) kindergartens and final educational acessibiliy model; accessibility model of 2a) bus terminal; 2b) minibus station; 2c) tram stations; 2d) trolleybus stations; 2e) railway stations; 2f) main roads; 2g) post office and final transport accessibility model; accessibility model of 3a) large stores; 3b) marketplaces; 3c) banks and final trade/financial acessibility model.

The stretch of most of the main roads is also determined by the morphological characteristics of the terrain, and is highly correlated with the density of other urban contents. Post offices are relatively evenly distributed in highly urbanized parts of all four city municipalities, but there are practically none on the city's outskirts.

Access to basic commercial and financial services also differs significantly in the peripheral compared to the central parts of the city (Figure 3-3). While supermarkets are somewhat more widely dispersed across the city, banks are primarily concentrated along the main axis of Sarajevo's urban development, in the east-west direction.

Market locations are relatively few, which is why the model of their availability shows spatial fragmentation.

The administrative infrastructure (Figure 4) is primarily located in the central part of the city, and secondarily in highly urbanized parts of other city municipalities (Stari Grad, Novo Sarajevo and Novi Grad). The semi-urban periphery is particularly marginalized in this regard. A significant exception is the administrative functions at the level of local communities, which were primarily formed so that the inhabitants of individual urban neighbourhoods could more easily articulate their infrastructure needs.

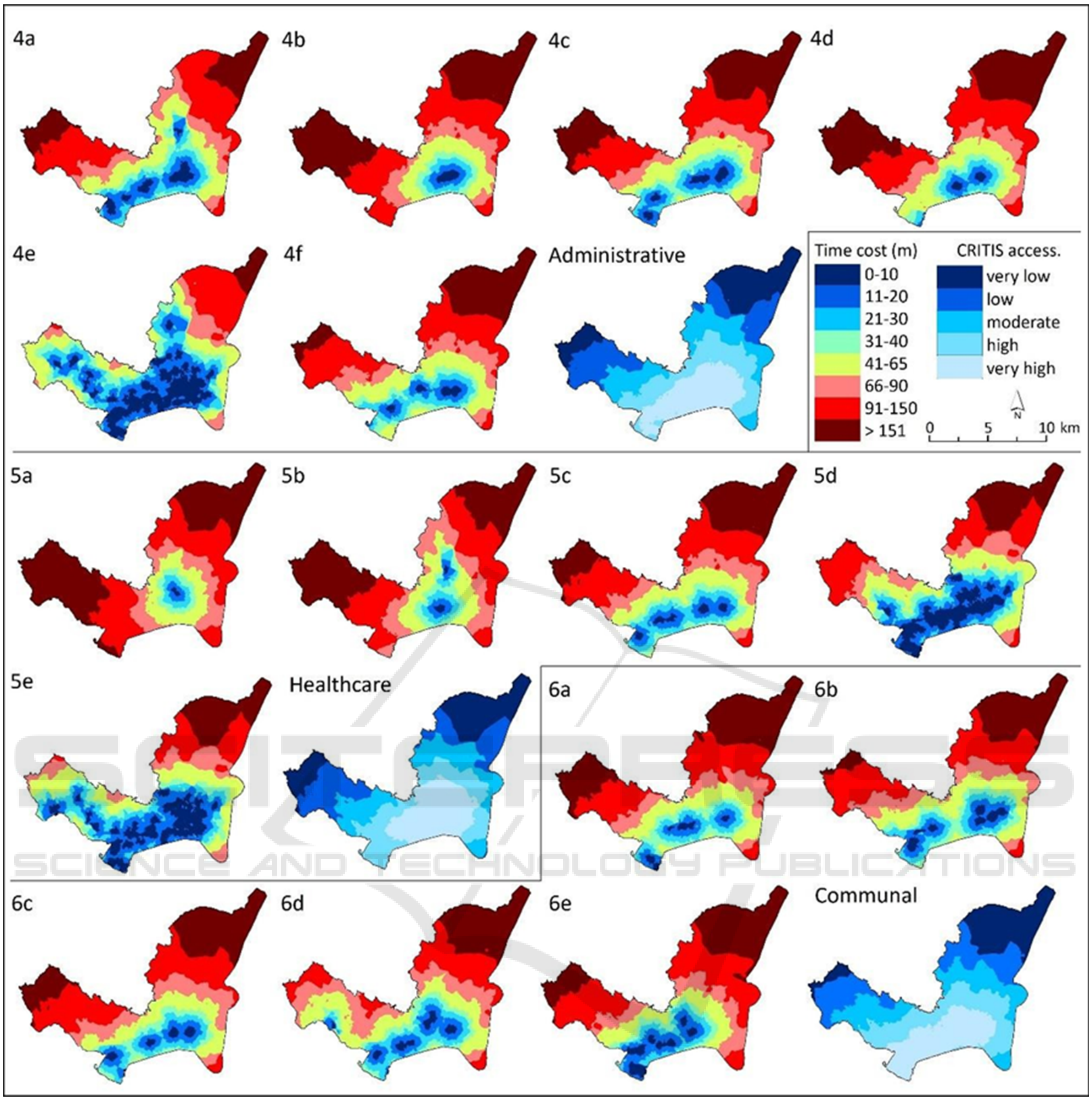

Figure 4: Accessibility model of 4a) social help and employment; 4b) ministries; 4c) police stations; 4d) courts; 4e) local communities; 4f) administrative authority; and final administrative accessibility model and 5a) hospital 1_rank; 5b) hospital 2_rank; 5c) hospital 3_rank; 5d) pharamcy; 5e) district outpatient clinics; and final healthcare accessibility model and 6a) communal cash register; 6b) firefighters; 6c) electro distribution; 6d) heating plans; 6e) community and building managers and final communal accessibility model.

Healthcare, as an extremely important element of critical infrastructure, is organized on four levels – clinical center, other hospitals, health centers and local clinics (Figure 4). Since the facilities of the two highest levels of this organizational structure are located exclusively on the territory of the municipality of Centar, even the urbanized parts of Novi Grad in the west are characterized by an unsatisfactory degree of availability of these services due to physical distance. The city's population is served by five health centers, and the large spatial imbalance is partially mitigated by the distribution of a larger number of local clinics. The analysis also took into account the availability of pharmacies, which emphasized the very unfavourable position of the northwestern outskirts of Sarajevo. Modeling of communal infrastructure availability confirmed similar spatial patterns as in the case of other elements of critical infrastructure (Figure 4). The only thing more pronounced is the slightly better infrastructure coverage of Dobrinja, as the city's largest district, which is located on the far southwestern outskirts of the city of Sarajevo.

4.2 Final CRITIS Accessibility Model

Figure 5 shows the final model of the CRITIS accessibility and the derived zones of accessibility following the two mentioned approaches. Descriptive statistics are provided in Table 2 and 3, where it is stated how many residents and residential buildings can be found in the derived zones, depending on the used approach.

The five local districts with the best accessibility of CRITIS infrastructure are (1) Ferhadija; (2) Baščaršija; (3) Center Trg Oslobođenja; (4) Mjedenica and (5) Džidžikovac Koševo I. These five local districts have a total of 9369 inhabitants with a total area of 1,037 km², which gives 9,035 population per km². These are the local communities of the central business district where the main city functions are concentrated. It is also the main traffic and historical center of Sarajevo.

The five local districts with the lowest accessibility of CRITIS infrastructure are (1) Naselje Heroja Sokolje; (2) Pionirska Dolina Nahorevo; (3) Reljevo; (4) Dobroševići and (5) Moščanica. These five local districts have a total of 20428 inhabitants with a total area of 80.02 km², which gives 255 population per km². These are peripheral hillside local communities, with a relatively low population density and a significant distance from the urban center. Low CRITIS accessibility (CA) represents a significant and long-recognized problem by the local population with a negative effect on their quality of life (URL 6, 7, 8).

Table 2: Results of CRITIS accessibility (CA) for first approach (local districs).

CA	Population		Area (km²)		Local district	
	Total	%	Total	%	Count	%
1	84359	30.6	7.85	5.7	26	34.2
2	123032	44.7	16.70	12.0	35	46.1
3	21382	7.8	8.40	6.1	5	6.6
4	33974	12.3	35.17	25.4	6	7.9
5	12778	4.6	70.53	50.9	4	5.3
Total	275525		138.66		76	

1 - very high, 2 - high; 3 - medium; 4 - low; 5 - very low

Table 3: Results of CRITIS accessibility for the second approach (residential buildings).

CA	Residential buildings	
	Total	**%**
1	15008	31.76
2	17429	36.88
3	7094	15.01
4	4052	8.57
5	3675	7.78

On the basis of the derived multicriteria index, it was established that about 30% of the urban population of Sarajevo falls into the most favourable category of infrastructural availability. These are residents of the city core in the municipalities of Centar and Stari Grad, then the highly urbanized neighbourhoods of Novo Sarajevo, and a smaller part of Novi Grad. On the other hand, some 17% of the population of Sarajevo has low or very low availability of critical infrastructure. The largest number of inhabitants from these categories inhabit the northwestern periphery of the city territory (part of the municipality of Novi Grad), that is, primarily the local communities of Dobroševići, Naselje Heroja Sokolje and Reljevo. The situation is similar in the hilly northeastern parts of Sarajevo (e.g. the village of Nahorevo), but the population concentration in these areas is still significantly lower.

The findings for the City of Sarajevo unveil interesting patterns, revealing that the highest concentration of service supply does not necessarily coincide with the most densely populated areas. It is known that the largest population concentration pertains to the southwest part of the urban area (the southern part of the municipalities of Novo Sarajevo and Novi Grad). However, the accessibility of critical infrastructure in this part of the city only partially fulfils the needs of its residents. This issue needs to be further explored through future research, which would treat population density as a key variable. Simultaneously, there is a need to differentiate weights for different types of infrastructure. In this study, equal weights were utilized for methodological transparency, eliminating subjective assessments of the significance of individual infrastructure elements. However, it is evident that there is a need for an objective and methodologically grounded differentiation in this field. Additionally, parallel research of this type is necessary in other cities to optimize the spatial CRITIS model through different case studies, aiming for its universal validity.

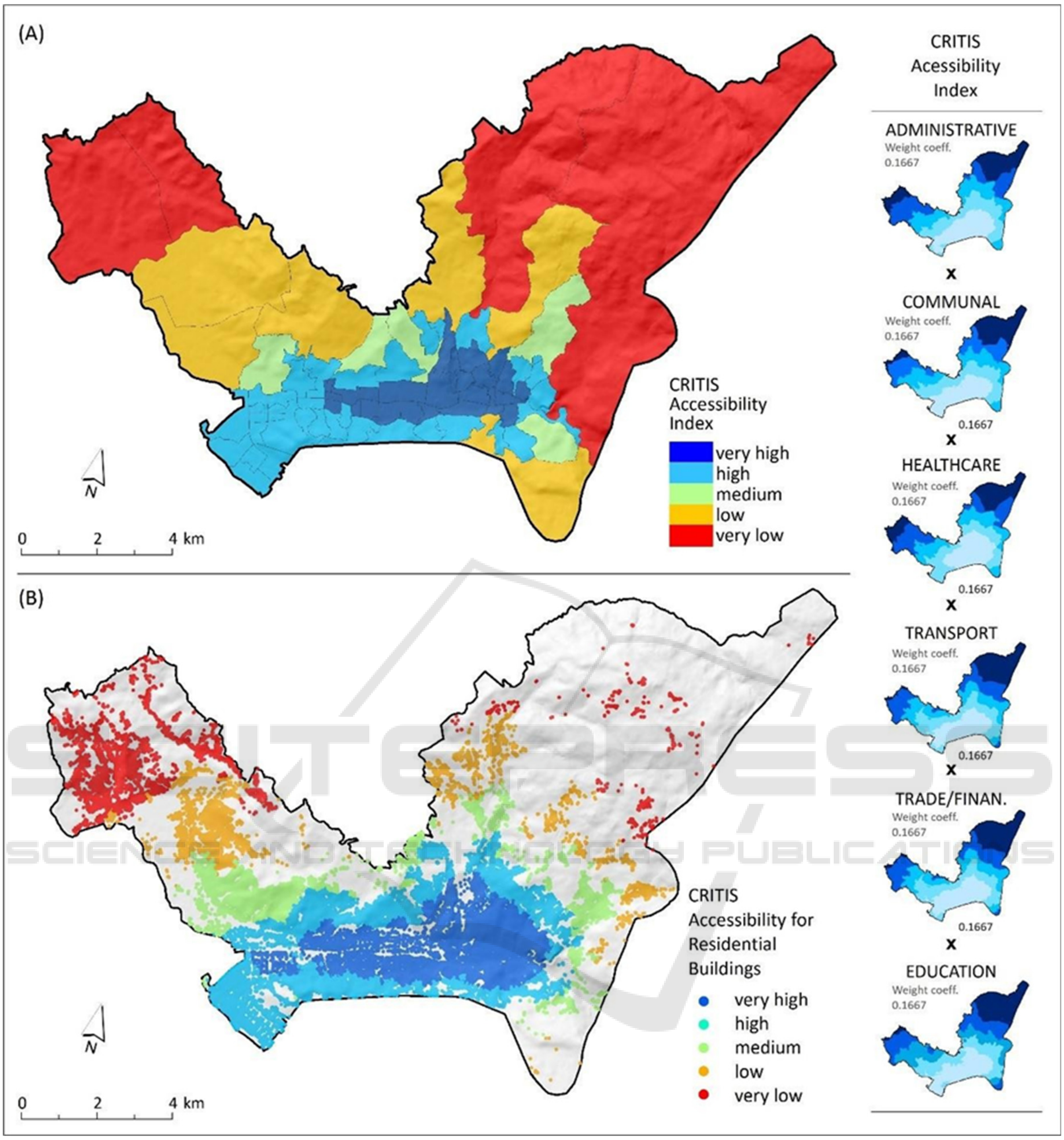

Figure 5: (A) CRITIS accessibility index for local district; (B) CRITIS accessibility for residential buildings.

5 CONCLUSION

The CRITIS accessibility model applied in this case study resulted in the creation of a composite index, whereby equal weights were assigned to administrative, communal, healthcare, transport, trade/financial and educational infrastructure. In this way, a specially designed methodological approach for examining infrastructural disparities within the urban zone of Sarajevo was tested, which can be used in other examples of cities of similar size, status, historical background and/or urban patterns. The obtained results are promising, since they clearly indicate the zonal categorization of the studied urban area, which can be widely used in spatial planning, that is, in the future management of urban development. Recommendations for further improvement of this model primarily include research on the correlation of CRITIS availability with population concentration, introduction of differentiated weights, more detailed analysis of individual elements of critical infrastructure, potential inclusion of additional and review of existing criteria, comparative field research, as well as comparative analyzes with other cities. While Bosnia and Herzegovina is still in the initial phases of developing its critical infrastructure protection system, this model serves as a solid foundation for further expansion and implementation across other cities in the country.

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REFERENCES

Borghetti, F., Marchionni, G. (2023). Cross-border critical transportation infrastructure: a multi-level index for resilience assessment, *Transportation Research* Procedia,69,77-84, https://doi.org/10.1016/j.trpro. 2023.02.147.

Čakarić, J. & Idrizbegovic Zgonic, A. (2020). Nameless Settlements of Sarajevo. IOP Conference Series Materials Science and Engineering. 960. https://doi.org/10.1088/1757-899X/960/3/032020.

Cikotić, S., Smajić, M., Delić, H., Subašić, N, 2018: *Nacionalna sigurnost i privatna zaštita, Fakultet političkih nauka*, Univerzitet u Sarajevu, Sarajevo, Bosna i Hercegovina.

Croope, S. Mcneil, S. (2011). Improving Resilience of Critical Infrastructure Systems Postdisaster. Transportation Research Record: *Journal of the Transportation Research Board.* 2234. 3-13. 10.3141/2234-01. https://doi.org/ 10.3141/2234-01.

Ford, AC., Barr, SL., Dawson, RJ. James, P. (2015). Transport accessibility analysis using GIS: Assessing sustainable transport in london. *ISPRS International Journal of Geo-Information.* 4(1):124-149. https://doi. org/10.3390/ijgi4010124.

Grigore, L. M. (2021): *Education as a critical infrastructure. Strategies XXI* – Command and Stuff College. 17. 404-407; https://doi.org/10.53477/2668-2028-21-53.

Gül, M., Dee, J. (2014). Sarajevo – A city profile, *Cities*, 43 (152-166). https://doi.org/10.1016/j.cities.2014.11.018.

Huff, J., Medal, H., Griendling, K. (2019). A model‐based systems engineering approach to critical infrastructure vulnerability assessment and decision analysis. *Systems Engineering*, 22(2), 114-133. https://doi.org/10.1002/sys.21460

Luiijf, E., Nieuwenhuijs, A., Klaver, M., van Eeten, M., & Cruz, E. (2009). Critical information infrastructure security, *8th International Workshop, CRITIS 2013, Amsterdam,* The Netherlands, September 16-18, 2013.

Marić, I., Šiljeg, A. (2017). Application of Huff model in analysing market competition–example of shopping centres in the settlement of Zadar. *Geoadria*, 22(1), 41-64

Milanović, J. Zhu, Wentao. (2017). Modeling of Interconnected Critical Infrastructure Systems Using Complex Network Theory. *IEEE Transactions on Smart Grid. PP.* 1-1. https://doi.org/10.1109/TSG. 2017.2665646.

Ministry of Transport of Sarajevo Canton, 2014: Network of public passenger transport lines in Sarajevo Canton (https://ms.ks.gov.ba/sites/ms.ks.gov.ba/files/010420 14%20Muamer%20Kukan_mreza%20linija.pdf, accessed in November 28, 2023)

Murray, T. G (2012). Critical infrastructure protection; The vulnerability conudrun, *Telematics and Informatics*, 29., https://doi.org/10.1016/j.tele.2011.05.001

Neuman, M. (2012). Infrastructure planning for sustainable citie. *Geographica Helvetica.* 66. 100-107. https://doi.org/ 10.5194/gh-66-100-2011.

Niu, D.; Wang, L.; Li, W.; Ma, Y. (2022). An International Comparative Study on the Resilience of Urban Communities after COVID-19 Pandemic: A One- Year Case Study between Lanzhou, China and Sarajevo, Bosnia and Herzegovina. *Int. J. Environ. Res. Public Health* 2022, 19, 14458. https://doi.org/10.3390/ ijerph192114458.

Petrović, N., Stranjik, A., Peternel, R. (2018): Generic Resilience Indicators of Critical Infrastructures. *Annales of Disaster Risk Sciences*. ADRS, 1 (1.), 97-103.

Pobrić, A. (2002). Osnovne značajke i posljedice migracijskih kretanja u Bosni i Hercegovini. *Migracijske i etničke teme*, 18 (4), 349-364.

Sänger, N., Heinzel, C. Sandholz, S. (2021). "Advancing Resilience of Critical Health Infrastructures to Cascading Impacts of Water Supply Outages— Insights from a Systematic Literature Review" Infrastructures 6 (12). https://doi.org/10.3390/infrastructures6120177

Scholz, C., Schauer, S., Latzenhofer, M., 2022: The emergence of new critical infrastructures. Is the COVID-19 pandemic shifting our perspective on what critical infrastructures are? *Int J Disaster Risk,* 83, 103419. https://doi.org/10.1016/j.ijdrr.2022.103419.

Smajić, M., Bajramović, Z. (2024): Risks and Vulnerability of Critical Infrastructure in Bosnia and Herzegovina-Assessment and Protection, *Contemporary Macedonian Defense*, 23(45): 9-18.

Šiljeg, S., Marić, I., Nikolic, G. Šiljeg, A. (2018). Accessibility analysis of Urban Green Spaces in the settlement of Zadar (Croatia). *Šumarski List*. 142. 487-496. https://doi.org/10.31298/sl.142.9-10.4.

So, S. W. (2016). *Urban Green Space Accessibility and Environmental Justice: A GIS-Based Analysis in the City of Phoenix, Arizona*, Doctoral dissertation, University of Southern California, Los Angeles.

Svegrup L., Johansson J., Hassel H. (2019). Integration of Critical Infrastructure and Societal Consequence Models: Impact on Swedish Power System Mitigation

Decisions. *Risk Anal.* 39(9):1970-1996. https://doi.org/10.1111/risa.13272.

Theoharidou, M., Kandias, M., Gritzalis, D. (2012). Securing Transportation-Critical Infrastructures: Trends and Perspectives. In: Georgiadis, C.K., Jahankhani, H., Pimenidis, E., Bashroush, R., Al-Nemrat, A. (eds) Global Security, Safety and Sustainability & e-Democracy. e-Democracy ICGS3 2011 2011. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, 99. https://doi.org/10.1007/978-3-642-33448-1_24

Tsenkova, S. (2012). Urban planning and informal cities in southeast Europe. *Journal of Architectural and Planning Research.* 29. 292-305.

URL 1 - https://aspr.hhs.gov/cip/Pages/default.aspx (accessed in November 28, 2023)

URL 2 - https://www.coresecurity.com/industries/energy-and-utilities (accessed in November 28, 20

URL 3 - https://ustanove.transparentno.ba/bs-Latn-BA (accessed in December 10, 2023)

URL 4 - https://mrsri.ks.gov.ba/javne-ustanove/lista (accessed in December 10, 2023)

URL 5 - https://vlada.ks.gov.ba/ministarstva (accessed in December 10, 2023)

URL 6 - https://avaz.ba/kantoni/sarajevo/360505/dok-se-politicari-brinu-o-nazivu-skole-daci-pjesace-po-9-kilo metara (accessed in December 10, 2023)

URL 7 - https://avaz.ba/kantoni/sarajevo/664191/ocajni-mjestani-naselja-reljevo-apeliraju-na-nadlezne-vise-od -godinu-nemamo-vode?amp=1 (accessed in December 10, 2023)

URL 8 - https://www.fokus.ba/vijesti/bih/djaci-iz-sarajev skog-naselja-pjesace-do-skole-i-po-cetiri-kilom etra-u-jednom-pravcu/2757803/ (accessed in December 10, 2023)

Wolthusen, S. D. (2005). GIS-based command and control infrastructure for critical infrastructure protection. *First IEEE International Workshop on Critical Infrastructure Protection (IWCIP'05*), Darmstadt, Germany, 2005, pp. 8 pp., doi: https://doi.org/10.1109/IWCIP.2005.12.

Yang, Z.; Barroca, B., Laffréchine, L., Weppe, A., Bony-Dandrieux, A. & Daclin, N., 2023: A multi-criteria framework for critical infrastructure systems resilience, International *Journal of Critical Infrastructure Protection,* 42, 100616, https://doi.org/10.1016/j.ijcip.2023.100616.

Yin P. (2010). Urban–rural inequalities in spatial accessibility to prenatal care: A GIS analysis of Georgia, USA, 2000–2010. *GeoJournal.* 84(3):671-683. https://doi.org/10.1007/s10708-018-9884-1.

Żaboklicka, E. (2020). Critical infrastructure in the shaping of national security. *Security and Defence Quarterly*, 28(1), 70-81. https://doi.org/10.35467/sdq/118585