EUROPEAN SPATIAL RESEARCH AND POLICY

Volume 31 2024 Number 1

https://doi.org/10.18778/1231-1952.31.1.05

Marta BOROWSKA-STEFAŃSKA [*], **Krzysztof GONIEWICZ** [**], **Vasile GRAMA** [***], **Marcel HORŇÁK** [****], **Edyta MASIEREK** [*], **Cezar MORAR** [***], **János PÉNZES** [*****], **Alena ROCHOVSKÁ** [****], **Filip TUROBOŚ** [******], **Szymon WIŚNIEWSKI** [*]

SPATIAL MATCHING OF EMERGENCY SHELTERS TO THE DISTRIBUTION OF RESIDENTS IN THE LIGHT OF TRANSPORT BEHAVIOURS OF EVACUEES DURING WAR: THE CASE OF SUWAŁKI

[*] Marta BOROWSKA-STEFAŃSKA, Edyta MASIEREK, Szymon WIŚNIEWSKI, University of Lodz, Faculty of Geographical Sciences, Institute of the Built Environment and Spatial Policy, Kopcińskiego 31 Street, 90-142 Łódź, Poland; e-mails: marta.borowska@geo.uni.lodz.pl, edyta.masierek@geo.uni.lodz.pl, szymon.wisniewski@geo.uni.lodz.pl, ORCIDs: https://orcid.org/0000-0003-2448-4778, https://orcid.org/0000-0002-3148-2503, https://orcid.org/0000-0001-5488-5949

[**] Krzysztof GONIEWICZ, Polish Air Force University, Department of Security Studies, Dywizjonu 303 Street, No. 35, 08-521 Dęblin, Poland; e-mail: k.goniewicz@law.mil.pl, ORCID: https://orcid.org/0000-0003-4368-6850

[***] Vasile GRAMA, Cezar MORAR, University of Oradea, Department of Geography, Tourism and Territorial Planning, 1st, Universitatii St., 410087, Oradea, Romania; e-mails: vgrama@uoradea.ro, cezar.morar@gmail.com, ORCIDs: https://orcid.org/0000-0003-0600-1138, https://orcid.org/0000-0003-0211-5883

[****] Marcel HORŇÁK, Alena ROCHOVSKÁ, Comenius University, Department of Economic and Social Geography, Demography and Territorial Development, Ilkovičova 6 Street, Bratislava 841 01, Slovakia; e-mails: marcel.hornak@uniba.sk, alena.rochovska@uniba.sk, ORCIDs: https://orcid.org/0000-0003-0071-4997, https://orcid.org/0000-0001-6126-7700

[*****] János PÉNZES, University of Debrecen, Faculty of Science and Technology, Institute of Earth Sciences, Department of Social Geography and Regional Development, Egyetem tér 1, 4032 Debrecen, Hungary; e-mail: penzes.janos@science.unideb.hu, ORCID: https://orcid.org/0000-0002-4870-087X

[******] Filip TUROBOŚ, Institute of Mathematics, Lodz University of Technology, 93-590 Łódź, Poland; e-mail: filip.turobos@p.lodz.pl, ORCID: https://orcid.org/0000-0002-5782-6159

Received: 09.10.2023. Revised: 05.01.2024. Accepted: 22.01.2024

Abstract. The aim of the article was the assessment of the spatial matching of existing shelters (supply) to the distribution of residents in Suwałki (demand), considering their declared transport behaviours while evacuating during war. The analysis was conducted based on the locations of existing emergency shelters using data on population distribution (registration data with building accuracy). Spatial alignment was determined using the P-Median problem and E2SFCA. In terms of establishing vehicular or pedestrian travel time, the Manhattan metric based on the urban road network model was utilised. A model of vehicle movement speed was then constructed, while a constant speed was assumed for pedestrian movement. Additionally, survey data on the transport behaviour of inhabitants of Suwałki in the case of war were conducted in 2023. The study concluded that the population residing within the city limits should evacuate on foot, and that prior training on the evacuation process is especially necessary for those who reside in less populated areas of the city. The analyses also showed that existing emergency shelters are overly dispersed, making management difficult for emergency services. Since the current capacity of emergency shelters is not sufficient for the number and distribution of inhabitants of Suwałki, the most practical significance of this article in this respect is to indicate to the authorities the optimal number and location for emergency shelters (to improve the evacuation process).

Key words: emergency shelters, evacuation, transport behaviour, war, Suwałki Gap, surveys.

1. INTRODUCTION

In the face of escalating global conflicts, the protection and safety of civilians have emerged as primary concerns, necessitating innovative approaches in disaster management. The ongoing warfare between Russia and Ukraine has dramatically underlined this reality, casting a harsh spotlight on the inherent limitations and fragility of international laws and conventions during crisis situations. Urban areas have borne the brunt of this conflict, with inhabitants seeking refuge in hastily designated emergency shelters. This stark reality underscores the pressing need for analyses aimed at appropriately preparing cities for passive defence. It calls for comprehensive planning and strategic allocation of emergency shelters for civilians to mitigate the potential devastating impact on both population and property (Bayram, 2016).

In the realm of disaster management, evacuation has long been considered the cornerstone of efforts aimed at protecting people from various calamities, including war (Jha *et al.*, 2004; Na *et al.*, 2012). The main objective of evacuation is to provide safe and efficient means to move people away from areas of immediate danger to designated safe zones following a disaster.

Evacuation planning is an intricate process designed to minimise casualties and property damage resulting from disasters, including war (Jafari *et al.*, 2005). A critical element of this planning involves understanding the spatial mobility of civilians, particularly in relation to the evacuation process during conflict. This process is essential for two key reasons. Firstly, it educates individuals on the steps they need to take to evacuate efficiently and systematically, thereby increasing their chances of survival. Secondly, it provides a valuable roadmap for improvements to be made in crisis management plans, potentially leading to more effective evacuation procedures (Stepanov and Smith, 2009; Borowska-Stefańska *et al*., 2023).

Efficient supply and demand management strategies are crucial for effective evacuation planning and management. The spatial distribution of the existing emergency shelters is directly linked to a city's ability to withstand disasters. Therefore, it is necessary to conduct a comprehensive assessment of the distribution of such shelters to ensure an effective response to disasters. Previous literature has analysed evacuation management in terms of supply and demand. Analyses for this purpose have primarily used information on the population and the capacity of evacuation points. Kulshrestha *et al.* (2011) presented a robust approach to determining the optimal locations and capacities of public emergency shelters. They addressed the uncertainty of demand with respect to the number of evacuees (these studies do not consider the more realistic consideration of the travel choices of evacuees). Zhu *et al.* (2018) proposed a supply-demand relationship by dividing emergency shelter capacity by the total number of evacuees, using the two-stage floating catchment area (2SFCA) method. However, their study showed that the ability of those affected to evacuate to the nearest shelter was limited. This method has been used in the literature to study the accessibility of urban public amenities, such as hospitals (Nakamura *et al*., 2017; Borowska-Stefańska *et al.*, 2017), but they have been underutilised in the examination of the accessibility of emergency shelters.

Previous research has focused on analysing the behaviours of populations during evacuation processes, particularly in relation to natural disasters (Borowska-Stefańska and Wiśniewski, 2018; Fei *et al.*, 2023; Geng *et al.*, 2023). The literature lacks data on the transport behaviours of populations during war and its use in planning the evacuation process. This study contributes to this area. In addition, this is the first study of this type for Suwałki – an important place in the context of a potential war due to its geographical location. War presents unique challenges, which means a bespoke approach is required, highlighting the necessity of research in this area. Borowska-Stefańska *et al.* (2024) examined the transport behaviour of people in four cities (and four countries) affected by war. The research showed that when the inhabitants of these cities wanted to evacuate, they were generally not familiar with evacuation instructions and did not know where emergency shelters were located. In order to properly plan the evacuation process, it is not only important to know the behaviour of the residents, but also to educate them in this regard (Borowska-Stefańska *et al.*, 2024).

The aim of this article is the assessment of the spatial matching of existing emergency shelters (supply) to the distribution of residents in Suwałki (demand), considering their declared transport behaviours while evacuating during war. Effective evacuation planning requires matching shelter capacity to demand in different spatial segments of the city. In order to ensure optimal performance, it is important to not only provide an adequate number of emergency shelters, but also to carefully consider their location in relation to the populations they serve (Huang *et al.*, 2016). Studies have shown that improper planning in this context can lead to severe congestion and delays, significantly affecting the overall efficiency of the evacuation (Sorensen, 2000). The study's innovative stance lies in its commitment to employing a methodological and applied approach. It emphasises the adaptation of elements of spatial development, particularly emergency shelters, to the unique needs presented by the evacuation process. While this research carries global implications, its relevance is especially salient for European countries, particularly those belonging to NATO. It proposes that with the use of comprehensive data and the suggested methodological approach, we can enhance the evacuation process during war. This enhancement would involve the appropriate preparation of both public bodies and residents, along with the optimal placement of emergency shelters. The ultimate goal is to ensure that evacuation during times of crisis is not just a reactive process, but a well-prepared strategy designed to save lives and minimise damage. Through informed decision-making and comprehensive planning, this study illuminates the path towards not just survival, but resilience in the face of war, setting the stage for the robust discussions and analysis that follow.

The manuscript unfolds over six sections. First, an introduction establishes the context and issues to be discussed. Second, a comprehensive review of the theoretical background aligns the study within the wider academic discourse, highlighting contrasting views on disaster management and evacuation planning. The third section provides a detailed exploration of the research area, the Suwałki region, revealing its unique geographic, social, and political characteristics. In the fourth section, the adopted materials and methods are meticulously detailed, explaining how the location of emergency shelters and population data were utilised, and how evacuation was simulated. The fifth section presents and discusses the study results, focusing on the optimal location of emergency shelters and evacuation strategies. The final section concludes the study, summarising key findings and contributions, identifying potential research limitations, and outlining future research avenues.

2. THEORETICAL BACKGROUND

About 3.3 billion of the world's population live in suburban or urban areas, with prospects that this will grow to over 5 billion by 2030 (NRC-Urban-Shelterguidelines_23-11-10_compressed, n.d.). This rapid and uncontrolled urbanisation process, combined with other phenomenon like migration, conflicts, and disasters (natural or man-made) will amplify the human crisis, challenging the fragile urban ecosystems and the sustainable development process, impacting, at the same time, urban economic, social, and environmental health security. In this context, to be able to address conflicts, crises or disasters, cities must be equipped well, aware that a well-planned, self-motivated evacuation greatly reduces damage and casualties. Cities must provide protection and coping mechanisms, as the number of people seeking shelter in urban areas will continue to rise (Luo, 2019). The process of evacuation can be divided into five stages: the decision to evacuate; warning; escape; shelter; and return (Lim *et al*., 2013).

The first three stages of an evacuation are critical. Delays in any of these may result in insufficient time to conduct the planned evacuation, i.e., a situation where not all evacuees reach the desired destination in good time, or even fail to escape the danger areas (Urbina and Wolshon, 2003; Jonkman, 2007; Kolen and Helsloot, 2012; Kolen *et al*., 2013). A key objective of planning an evacuation in emergency situations is to ensure that evacuees leave the affected area as quickly as possible and reach safe locations. Therefore, planning an evacuation should be about minimising the total evacuation time, thereby protecting the health and lives of the population (Dulebenets, 2021).

Evacuation may be classified as voluntary, recommended, and mandatory. No special traffic-related controls or transportation measures are normally taken during voluntary evacuations, people in such cases can even remain in their places of residence if they wish. Recommended evacuation refers to disasters with a higher probability of endangering the population. In this case, decisions of whether or not to leave are left to individuals and limited emergency transportation arrangements are made. Mandatory evacuations represent the most serious type of evacuation, but they are extremely difficult to conduct and, in many countries, are even impossible since relevant provisions do not exist everywhere and people often resist orders to leave their homes (Urbina and Wolshon, 2003).

Moreover, it is important whether an evacuation is conducted (supervised and controlled) by an external entity (emergency services in particular) or by the evacuees themselves, in which case it is called self-evacuation (Kolmann, 2020) and may be performed in an organised manner or spontaneously (Gromek and Kozioł, 2015). Spontaneous self-evacuation happens when there is a direct threat of disaster. A planned (organised) self-evacuation can be implemented before a catastrophe when the probability of a disaster is high. In such situations, people should immediately evacuate to a secure location, utilising their own transportation. Most often, residents will use their own modes of transportation, but if a household does not have access to a car or other means of transportation, a neighbour may be willing to provide assistance. That being said, it is essential to emphasise that the success of self-evacuation depends largely on the individual's resources, including access to transportation and a place of refuge. The primary difference between self-evacuation and coordinated evacuation is that self-evacuation is not managed, supervised, or controlled by authorities, resulting in a spontaneous and unorganised approach that may become chaotic due to poor information and knowledge (Kolmann, 2020). It should also be noted that evacuation may be by vehicular transport, on foot or a combination of the above. Were evacuation transport employed by the organisers of an evacuation, it will primarily be for people unable to evacuate themselves – highlighting the need to know the community in the area. The use of vehicular transport, particularly road and rail, is essential for the organised movement of large numbers of people (or other entities) to be evacuated over longer distances. However, these means of transport are often not available in sufficient numbers to fully meet the needs in question. Therefore, in such cases, a combined method enables the use of available means of transport of an organised nature together with the evacuees' own resources or the use of escape on foot. From the perspective of decision-makers responsible for evacuation management, each of these options has their limitations, which affect the validity, efficiency, and effectiveness of their application (Kolmann, 2021). A number of decisions must be made at the individual level about whether to evacuate, when to evacuate, what to take with, how to travel, what route to travel, where to go, and when to return (Alsnih and Stopher, 2004). As part of an evacuation, the following behavioural analysis questions need to be addressed: (1) how many people will evacuate (evacuation participation rate); (2) at what point residents will evacuate in relation to an evacuation order; (3) what usage rate can be expected for public emergency shelters; (4) how many resident will evacuate to points further afield; (5) how many of the available evacuation vehicles will be used.

City emergency shelters play an important role in protecting people during war, which is why a few important points should be considered regarding their location:

– City emergency shelters should be planned based on their optimum situation for the population using them. Access to these shelters should be devised in such a way that they can accommodate large numbers of people in emergency situations as rapidly as possible.

– Shelters should also be useful in times of peace. Therefore, public service facilities should be planned as shelters, offering protections for citizens during and after disasters.

– In order for residents of cities to access their nearest emergency shelter in case of war, they should be informed of the exact location of said shelters (Shakibamanesh and Fesharaki, 2011; Zhu *et al*., 2023).

In order to obtain all information for planning the evacuation process, it is necessary to know the potential transportation behaviour of residents in affected areas, as well as to be aware of designated shelter locations, to establish evacuation routes, and to determine the number of services participating in these activities (Borowska-Stefańska *et al*., 2024).

3. CHARACTERISTICS OF THE RESEARCH AREA

Suwałki is located in northeastern Poland, near the borders with Lithuania, Russia, and Belarus (Fig. 1). It is the second largest city in the Podlaskie Voivodeship. Transport routes from Berlin (via Warsaw) to St. Petersburg and from Warsaw to Helsinki (the Via Baltica and Rail Baltica routes, which connect the Baltic countries with Western Europe) go through the city. The Suwałki Gap links the Baltic states with Poland and the other NATO countries, while separating Russia's Königsberg region from Belarus (an ally of Russia). It is, therefore, a strategic location in any potential escalation of the current war beyond the territory of Ukraine. Traffic in Suwałki is largely on a radial road system (with not very high technical parameters), as the outer ring road is not fully closed (Fig. 9).

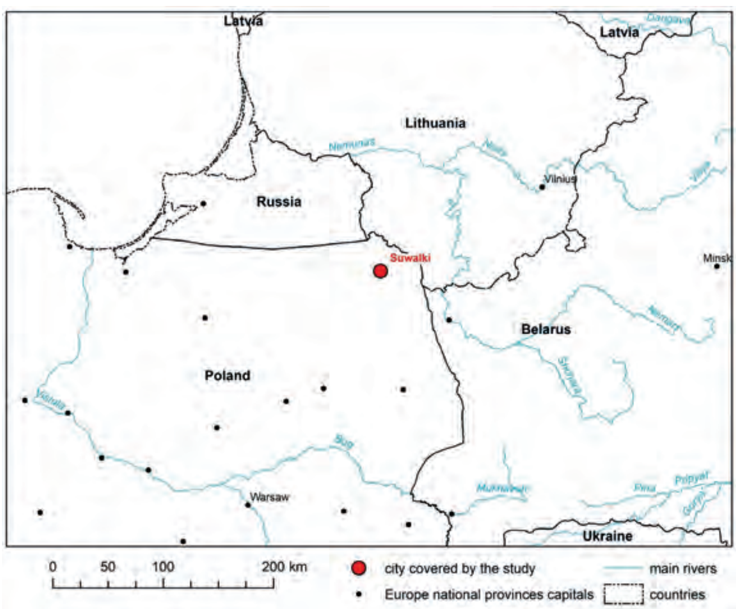

Fig. 1. Location of Suwałki

Source: own work.

Thanks to information obtained from the Suwałki City Hall staff, a total of 8 documents related to the emergency response criteria that the city uses have been identified. 6 of these cover the local level, two of which relate to the operation and organisation of the City Hall itself. The other are plans for crisis management; evacuation and reception of the population; civil defence, and the functioning of the city of Suwałki in a situation of external security threat and war. No documents were identified at the regional level (Table 1).

Table 1. Documents related to emergency situations used by the city of Suwałki

National level	Local level
− Guidelines of the Chief of National Defence of 17.10.2008 on the evacuation of population, animals and property in case of a mass emergency − Instruction on the principles of evacuation of population, animals and property in case of a mass emergency	− Municipal Crisis Management Plan (2022) − Evacuation/Reception Plan for the Population in the City of Suwałki (2021) − Civil protection plan 2012/2022 − Operational plan for the functioning of the City of Suwałki in conditions of external threat to state security and war (2021/2022) − Organisational Regulations of the Town Hall in time of war (2022) − Plan for the technical adaptation of the Town Hall to a command post or relocation at an alternate place during an external threat to security and in time of war, or in the event of any specific threats making it impossible to continue operations at the current location

Source: own work.

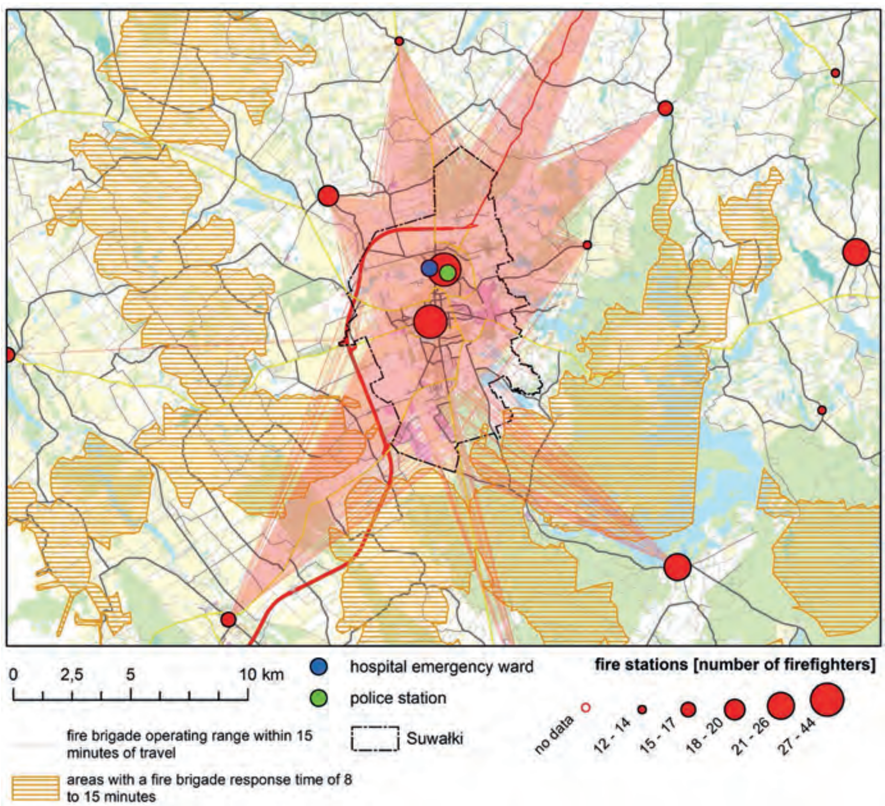

Fig. 2. The location of the city of Suwałki in the supra-local perspective against the background of the spatial range of services provided by the fire brigade

Source: own work.

In Poland, the State Fire Service (SFS) (a professional body established to fight fires, natural disasters, and other local hazards) plays a key role in rescue and civil protection. In the rescue and civil protection subsystem, the SFS is supported by other emergency services, state institutions and NGOs. The SFS, however, most closely collaborates with the Voluntary Fire Service (VFS). As of 31 May 2021, there were two emergency and firefighting units in Suwałki with approximately 70 staff (Fig. 2). This number, however, is insufficient should the need to protect the residents of the city of Suwałki against a major incident arise. These units would then need to be reinforced by firefighters from local VFS stations.

The data retrieved from the Town Hall of Suwałki shows that, as of 19 April 2023, the town had 66,838 residents, including 926 people on temporary stay visas (Table 1). Figure 3 (left) presents the distribution of the town's population, whose pattern of distribution is shaped by a north-south axis, with a particularly high density in the north.

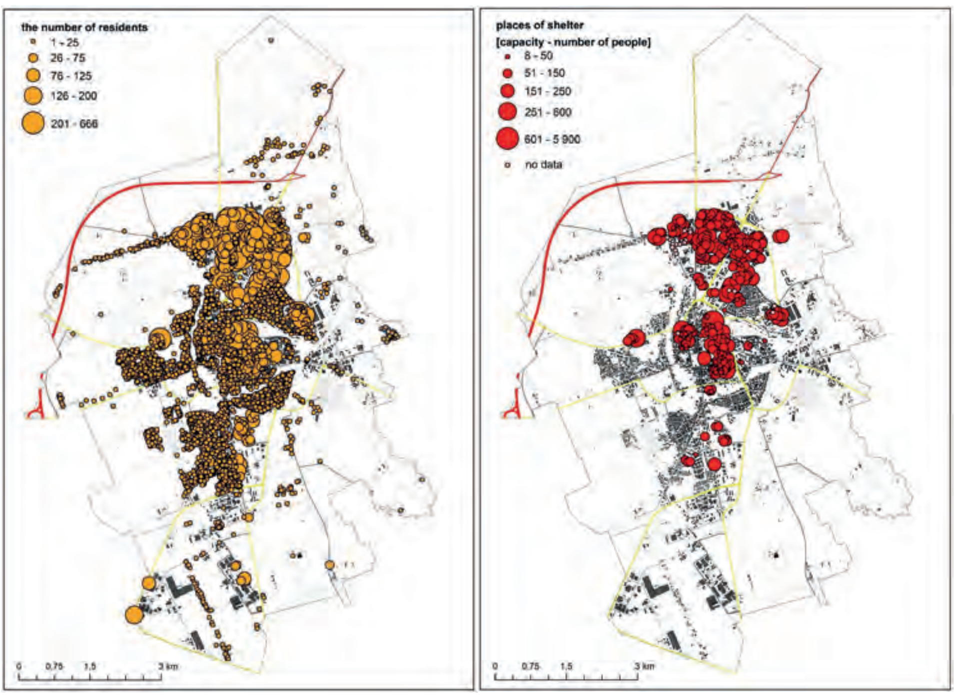

Fig. 3. Distribution of city residents (left) and location of emergency shelters (right) in Suwałki
Source: own work based on data from the Suwałki City Hall.

The existing emergency shelters can accommodate 40,612 people, predominantly in basements of residential and non-residential buildings (several garages have also been designated for this purpose). The largest number are located in the centre and the north of Suwałki, which partially reflects the distribution of the town's population (Fig. 3). These emergency shelters are heavily dispersed (394 different locations across the town), and, on average, a single facility can accommodate 103 people. The total number of emergency shelters designated for the population is inadequate for the number of residents registered in Suwałki (Table 2).

Table 2. Basic quantitative characteristics of variables taken into account in modelling the evacuation process

variables of modelling evacuation	**number/ capacity**	**min.**	**max.**	**arithmetic average**	**standard deviation**
number of city population	66,838	1	666	13.5	35.2
number of postal addresses	4,965	-	-	-	-
existing shelter capacity	40,612	8	5,900	103.0	299.7
number of existing shelters	394	-	-	-	-
capacity of public buildings	79,690	9	157,345	637.5	1581.1
number of public buildings	125	-	-	-	-

Source: own work.

4. SOURCE MATERIALS AND RESEARCH METHODS

The basis for the model of traffic speed used in the research was the preparation of a vector model of the road network. In order to ensure the highest possible level of accuracy of the network, a road network model was built, containing the accurate mapping of the route of roads with categories ranging from national roads, through voivodship, poviat, and commune roads. Each of the sections in the database (as well as its geolocation and attributes containing the category of the road section) was assigned: road class, number of lanes, type of terrain through which it runs according to criteria used in national traffic studies (built-up, undeveloped or mixed), capacity, speed in free traffic, speed limit, frequency of junctions, density of buildings within 100 m, and the number of inhabitants within a radius of 500 m. The combination of these attributes made it possible to build the movement speed model. The basic speeds that were modelled, depending on the attributes assigned to sections, are code speed limits (determined by the relevant standards and the manner of traffic organisation by their managers) and speeds in free traffic (resulting from the technical parameters of the road). It was assumed that as the level of freedom of movement decreases, the speeds observed on the network also drop. The aforementioned level of freedom of movement is affected by the previously mentioned attributes, i.e., the density of intersections on the road section, the density of buildings, and the number of inhabitants in their vicinity. The size of speed reduction on the road network, considering the above-mentioned parameters, was differentiated depending on the categories of roads and the types of land use they ran through (built-up, undeveloped or mixed), which is motivated by different ways of organising traffic. The aforementioned road network and traffic speed model was used, among others, in research related to transport accessibility and the load on the road network (Wiśniewski, 2021, pp. 172–183; Wiśniewski *et al.*, 2020).

For the calculation of travel times, both pedestrian and vehicular, the road and street network of Suwałki was utilised to determine the distance between research points, which were calculated according to the Manhattan metric or urban metric (the sum of absolute differences between the coordinates of points). This distance represents the path that must be traversed between points, using solely the city's street grid. The travel time was determined in accordance with the aforementioned velocity model, while pedestrian movement times were calculated assuming a constant walking speed of 4.5 km/h. Typically, the average walking speed is assumed to be about 1.2 to 1.4 m/s, corresponding to approximately 4.3 to 5.0 km/h. This speed is considered typical for adults moving in unobstructed conditions, though studies indicate that walking speed can vary depending on, among others, age and gender. Older individuals and children typically move slower (0.9 m/s) than the average adult population. In urban conditions with numerous obstacles (such as intersections or crowded sidewalks), the average speed may be lower. Therefore, despite the likely haste during an evacuation process (speed closer to maximum than to comfortable), a decision was made to adopt an intermediate value between threshold values.

In order to determine the transport accessibility of the population at risk to the evacuation sites, vehicular travel or walking times between the designated start and end points were measured in accordance with the speed model. The next stage of the study was to determine the sections connecting the starting points and destinations adopted for the analysis – individual elements of the truss. Spatial adjustment of the distribution of emergency shelters was determined by market areas. To ascertain the spatial differentiation of accessibility to evacuation sites, the Enhanced Two-Step Floating Catchment Area Method (E2SFCA) was used in a modified version to capture the essence of the study as accurately as possible.

In the variant examining the spatial fit of evacuation sites to the population distribution, the focus was on the links between the population distribution and the location of these specific facilities. In terms of availability, the study focuses on determining the level at which the supply of places available in such facilities intended for the evacuated population corresponds to its theoretical demand. By considering both dimensions we were able to develop the most comprehensive analysis of accessibility. This solution also makes it possible to avoid interpretation errors accompanying analyses based on the capacity per inhabitant of a given area. These are studies without a spatial character, e.g., due to not considering the border effect or the inability to determine the relationship between the distribution of facilities and the distribution of population. Based on the classic version of the two-stage floating catchment method (2SFCA), an enhanced version (E2SFCA) was introduced. This version introduces weights to the original method that enable one to distinguish individual time ranges of access to facilities. Thus, this model is based on a more rational assumption of the demand for space in such facilities. This weight is then used to calculate the space needs of individual populations, eliminating classically occurring over-estimations.

The 2SFCA approach was used due to its relative simplicity and intuitiveness, which facilitates its understanding and application. Given the limitations on access to sensitive data (e.g., personal data) concerning the evacuation process, it is beneficial that it does not require complex input data. Moreover, considering the applied nature of the study, the method does not require advanced analytical tools, making it accessible to a wide range of users, including planners and decision-makers. Flexibility is also an important factor. The method allows for adjustments depending on the specifics of the area studied and the data available. It can be used to assess the availability of various types of services, including those as specialised as crisis management. It enables balancing supply and demand in the availability analysis, providing a more balanced view of the situation than those methods that focus solely on one of these aspects. 2SFCA facilitates the modelling of future service availability scenarios, such as the opening of new facilities (e.g., emergency shelters) or changes in population distribution. This allows planners and decision-makers to better assess the potential impact of planned interventions and optimise resource allocation.

The first part of the method is based on determining the area of influence of each object, assuming a borderline value for the travel time (in this study, maximum travel times of 8 and 15 minutes were assumed in the case of the evacuee organising their own transport). For each of the objects, the isochrone of the theoretical travel time are plotted. Then, for the designated zone D, all objects are found and weight assigned to each according to the exponential function. The fundamental component determining the results of the accessibility model is the space resistance function used. Originally, the E2SFCA method proposed by Luo and Qi (2009) used the Gaussian distribution, but in this study it was decided to use the exponential function, the most common in empirical research (Wiśniewski, 2021).

Commuting to a place of refuge or accommodation facility for evacuees was classified as a very short journey. For each of the facilities, an individual TRj indicator was calculated, which is its weight per the summed number of residents (potential evacuees) living in buildings located in the area designated by a given isochrone:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \in D\}} P_k W_r}$$

where:

S_j – weight (capacity) of the object *j*;

W_r – weight consistent with the exponential function for the zone of potential service for people evacuating,

P_k – size of the population *k* of the address point *i* within the scope of the study,

d_{kj} – travel time between object *j* and address point *i* with population *k*.

In the second part of the analysis, attention is focused on the address points of residence of potential evacuees. For each of them, the area is determined, as in the first stage of the analysis, using the adopted limit values of the time of travel to the objects. Then, for each building, the accessibility index is calculated, which is the sum of the products of the R_j values obtained for individual objects and weights W_r in the area of the individual building area and:

$$A_i^F = \sum_{j \in \{d_{ij} \in D\}} R_j W_r$$

The number of analysis variants included in the study is determined by four variables, each of which has a dichotomous nature (Fig. 4.). The first element is the maximum duration of the journey to the facility intended for receiving evacuees, which has two ranges: 0–8 minutes and 8–15 minutes. The second element is the type of refuge. Cases were considered in which the population evacuated to emergency shelters and public buildings. The third variable is the form of evacuation, scenarios of self-evacuation and organised evacuation for people unable to escape independently were included.

In the section of the article focusing on the results, the outcomes of the conducted optimisations of emergency shelter locations, considering the variables mentioned above and in Fig. 4, were presented. These were captured both in cartographic form (limited due to the scope of possibilities considered) and synthetically in the form of a summary table, which includes indicators defining, among other things, time efficiency and effectiveness (the number of residents covered). Maps presented the final results of spatial matching of emergency shelters to residential areas. They did not show the individual phases of the 2SFCA implementation, as this would double the already rich number of figures (supplied separately for the differentiation of demand and supply).

Fig. 4. Variables considered in the process of modelling the optimal arrangement of facilities intended for evacuation

Source: own work.

Considering the research method applied and the variables included in the analysis variation, the optimisation of the location of emergency shelters or facilities that could serve this role was conducted using the location-allocation tool (available in the ArcMap package). The input data for this tool includes service-providing facilities (here, safety during an armed conflict or the threat thereof) and demand points (residences) that consume this service. The goal was to find the facilities that most effectively supply the demand points, considering the competition in terms of demand (for shelter) and supply (for residents). The tool solves this problem by analysing different ways of assigning address points to various facilities. The solution is a scenario in which the greatest demand is allocated to facilities and the costs (time) of travel overall are minimised. Emergency shelters are located (or chosen from actual locations) in such a way that the entire or greatest demand for their space (available places) can be met without exceeding the capacity of any facility. Maximising capacity coverage functions like a P-Median problem but with an additional efficiency constraint. The sum of the entire weighted travel time (the weighting being the demand allocated to a facility multiplied by the time to reach it) between address points and emergency shelters is minimised. For each study variant, default cutoff point values of 8 and 15 minutes of travel time were assigned. If the total demand for emergency shelter spaces by the population that could reach it was greater than its capacity, only those address points were allocated (according to the results of applying 2SFCA) that maximise the total demand while simultaneously minimising the total weighted travel.

In order to determine the characteristics of the evacuation process for residents of Suwałki a survey was conducted. It was performed using the CATI technique on a sample of 400 residents (from 1 March to 12 April 2023), following a prior pilot study. It consisted of three parts: respondents' particulars, questions about awareness of the risk, and knowledge about correct behaviour in case of war. Women aged 18 and over and men aged 60 and over were eligible to participate in the study. Residency, gender, and age were the only criteria for entering the sample, therefore, other characteristics were distributed randomly.

In addition, the person responsible for emergency management in Suwałki was contacted. This was to gather information about the city's preparedness in terms of alerting civilians and conducting the evacuation process in the event of an armed conflict. The relevant person had to fill out a survey questionnaire previously designed by the research team, which was sent to them by email. Thanks to the questionnaire, documents at different levels (local, regional, and national) that deal with emergency management were identified. Information was also obtained on the dispersion of knowledge and evacuation training provided to both residents and emergency management personnel alike, as well as the measures the city has taken to increase the safety of residents should an armed conflict on their territory occur. The questionnaire also attempted to ascertain what kind of support was needed in terms of increasing the safety of residents.

Thus, in the following part of the article, elements considered in the research procedure are presented in the following order: a characterisation of the spatial mobility of residents in the context of evacuation necessities; a description of the city's development and its immediate surroundings, with special attention on the distribution of emergency shelters, residential areas, and the transportation network; and the results of optimising the spatial allocation of emergency shelters in line with the population distribution.

The limitations of the study presented may pertain to:

– Weaknesses in the applied method of accessibility analysis. In E2SFCA, weighting functions are utilised to modulate the impact of distance on accessibility. The choice of the appropriate weighting function and its parameters is crucial for the outcomes, but it can also be a source of subjectivity and uncertainty. Despite improvements, E2SFCA still assumes a degree of uniformity in the interaction space. Although the method accounts for distance weighting, it may not accurately reflect real accessibility patterns, especially in diverse geographical and social contexts.

– Weaknesses in the applied questionnaire study. War is an exceptionally sensitive and emotive subject, which may affect the willingness to participate in the study or the honesty of the responses. Respondents might avoid answering difficult questions or might be reluctant to express their true opinions for fear of repercussions. War is a period of significant changes and uncertainties, meaning that the attitudes and behaviour of the population can change rapidly. The results of a study conducted at one point in time can quickly become outdated due to evolving events.

– Weaknesses stemming from the utilised source databases. Official data is often published with a delay relative to the moment of its collection. This means that it may not reflect the current state of population distribution, especially in dynamically changing urban areas. Official population distribution data often does not account for the mobility patterns of residents, such as commuting to work or seasonal migrations, which is crucial for a full understanding of urban dynamics.

– Weaknesses resulting from the lack of data on the daily mobility of residents. Unfamiliarity with the movement patterns of pedestrians, cyclists or drivers can lead to inappropriate safety infrastructure design, increasing the risk of accidents and collisions.

5. RESULTS AND DISCUSSION

To date, no such sophisticated analysis of the population evacuation process has been conducted for Suwałki. Our study revealed that the vast majority of respondents (over 70%) would self-evacuate if military operations occurred in their town. Most people (86.3%) would choose to self-evacuate by car (Fig. 5). 85.75% of the respondents declared that everyone in their household would be able to self-evacuate. In those households that required assistance, 11.25% said that one person would require to be evacuated by emergency services, in approximately 3% this would be two people. Similar results for self-evacuation in the event of a natural disaster (a flood) were presented by Borowska-Stefańska *et al.* (2023) and Shenhar *et al.* (2008).

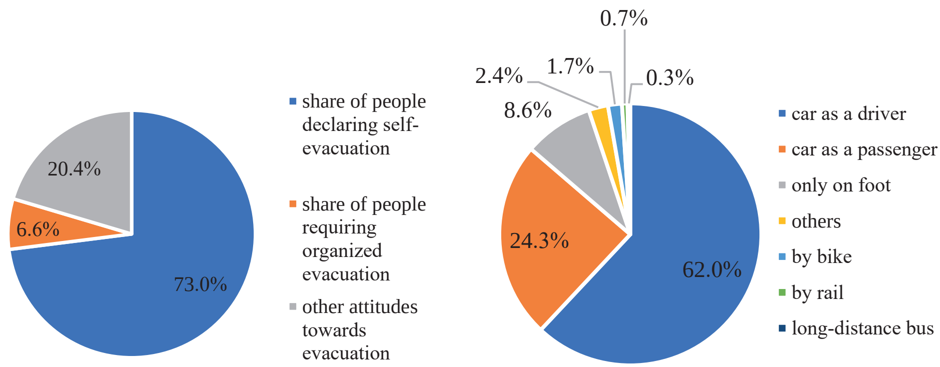

Fig. 5. Declared form of participation in the evacuation process and modal division during its duration

Source: own work.

The survey showed that only 24.5% of the respondents were aware that there were emergency shelters in Suwałki. The rest were either unaware of this fact (47%) or believed that there were none (28.5%). Therefore, most respondents would evacuate to places designated by emergency services (27.2%). Importantly, some respondents stated that they would choose to evacuate to locations outside the city of Suwałki (e.g., to another town) or even abroad (12.2%) (Fig. 6). A telling response was that 389 of the 400 respondents declared that they were unfamiliar with evacuation guidelines in the event of war. The lack of knowledge about evacuation rules in the case of war has also been confirmed by studies conducted in other countries (Borowska-Stefańska *et al.*, 2024). As Shakibamanesh (2015) has indicated, people should know where to evacuate to and without this knowledge the process cannot be properly managed.

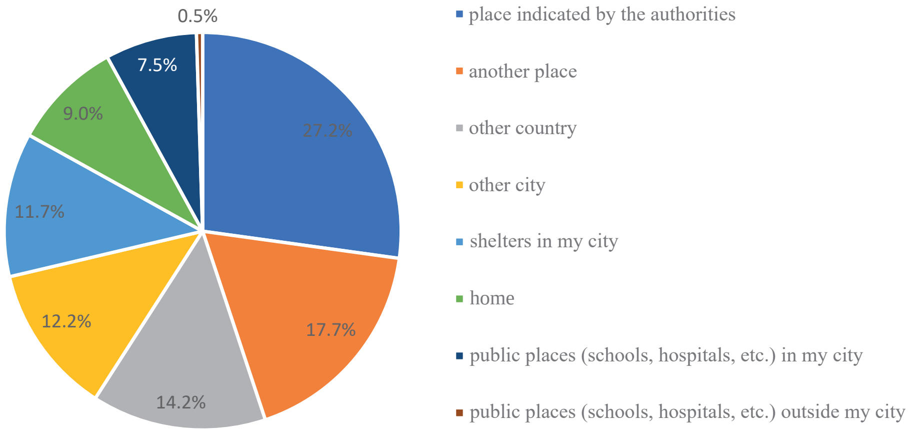

Fig. 6. Declared evacuation destination
Source: own work.

Emergency shelter management is a key part of emergency logistics and disaster operations (Alisan *et al*., 2020a, 2020b). As shown in Fig. 7, the vast majority of residents of the city of Suwałki can reach existing emergency shelters or suitable public buildings within 15 minutes. As regards accessibility on foot alone, both emergency shelters and public buildings (Table 3) can be reached within 15 minutes by 94.1% of all residents. Time is crucial when organising evacuation and rescue operations. If the first emergency services arrive at the areas in question within 15 minutes, it is then possible to provide effective assistance to those in need (Drzymała *et al*., 2014).

The capacity of emergency shelters is, however, insufficient, i.e., on average there are 1.5 inhabitants for every seat in a shelter which can be reached within 8–15 minutes, while the figure for suitable public buildings that could be transformed into additional shelters amounts to 0.8 (Table 3). A number of studies have most commonly used the shortest Euclidean distance, cost distance and road distance method to assess shelter accessibility (Jiang *et al*., 2018). However, while distance analysis alone indicates high emergency shelter accessibility, allocating people at risk to emergency shelter sites using this method alone leads to overcrowding (Su *et al*., 2022).

Based on the survey, it was assumed that 6.6% of the population of the city of Suwałki would require evacuation by the emergency services. A simulation was conducted to see how many ambulances would be required and how long the process would take if assistance was provided to all those in need concurrently. The study revealed that if it was to be provided solely by the emergency services operating in the city of Suwałki, they would need to have at least 10 vehicles at their disposal.

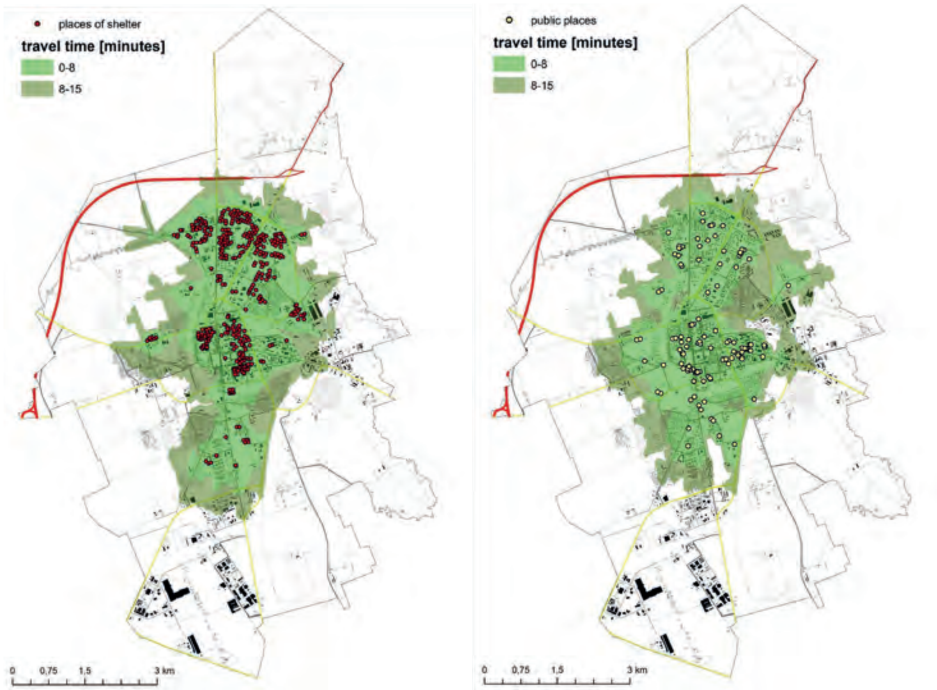

Fig. 7. Spatial differentiation of pedestrian accessibility to places of refuge (left) and public buildings (right)

Source: own work.

Table 3. Current occupancy and coverage of the demand for emergency shelter places

		0–8		8–15		out of protection		on average per emergency shelter/public building		on average per place in an emergency shelter/public building	
		number	share	number	share	number	share	0–8	8–15	0–8	8–15
to public building	postal addresses	2673	53.8%	1670	33.6%	622	12.5%	21.4	34.7	0.0	0.1
	population	50465	75.5%	12420	18.6%	3953	5.9%	403.7	503.1	0.6	0.8
to existing emergency shelters	postal addresses	2862	57.6%	1481	29.8%	622	12.5%	7.3	11.0	0.1	0.1
	population	57027	85.3%	5881	8.8%	3930	5.9%	144.7	159.7	1.4	1.5

Source: own work.

Importantly, to smoothly evacuate all residents in need, each vehicle would have to travel for one hour and each would have to take a different route to avoid creating bottlenecks. As the results of a study by Fei *et al.* (2023) show, while it is important to have an even distribution of emergency services or medical facilities, it is generally important to remember that they are limited in number and can quickly become overloaded without proper management.

Based on the results of the questionnaire survey, a traffic simulation was also conducted to determine the impact of self-evacuation, either on foot or by car, on the urban transport system, for evacuees fleeing outside the city limits. It was possible to identify which roads would require additional measures during evacuation to prevent congestion and to ensure that emergency services could operate along them (by diverting traffic along alternative routes). Figure 8 shows which areas of the city would experience the greatest traffic disruption if not properly managed.

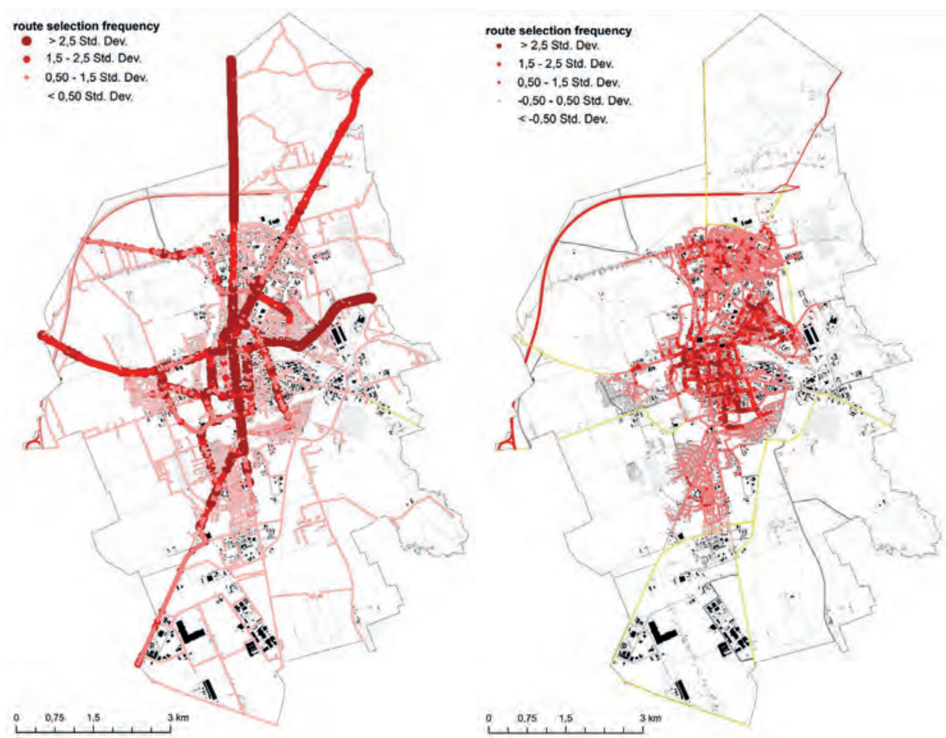

Fig. 8. Spatial differentiation of the load on road junctions resulting from: vehicular traffic of people evacuating outside the city and the activities of emergency services (left) and pedestrian traffic of people moving to emergency shelters in the city of Suwałki (right)

Source: own work.

Research by Borowska-Stefańska *et al.* (2023) revealed that self-evacuation in response to an emergency impacts both the spatial distribution of the load on the road network and travel speeds, although this is also determined to a certain extent by the capacity of the local transport system. It is important that people are kept informed of the available evacuation routes (including evacuation on foot), which would need to be adapted to the prevailing traffic conditions. Otherwise, evacuees will only use "familiar" routes, which may prolong the evacuation process. Therefore, providing up-to-date, reliable and clearly articulated information to road network users would improve the performance of the entire transport system.

Determining the optimal locations of facilities with the amount of assistance elements needed remains an important aspect, while others have focused on determining the optimal locations of facilities with the amount of assistance elements needed (e.g., Kocatepe *et. al.*, 2018). Our research shows the optimum distribution of (existing) emergency shelters that can be reached within 8 or 15 minutes, together with information on the number of postal addresses (properties) they should serve (Fig. 10). This has been determined based on the following: the locations of buildings, the results of the survey, and the population's declaration to self-evacuate (including evacuation to emergency shelters). This reflects the actual situation in the town while excluding those emergency shelters that would take over 15 minutes to reach (i.e., location considered unsuitable). It must be noted that the highest density of emergency shelters is in the central part of the town, as these would possibly have to serve the largest number of postal addresses in the face of evacuation under war footing. It is evident that these places correspond well with the distribution of single and multi-family housing in the north and south of the town. This, in turn, means that shelters in these areas would probably have to serve considerably fewer postal addresses.

It displays the distribution of the lowest required number of emergency shelters for residents of the city of Suwałki (among facilities that are currently designated as emergency shelters) reachable within 8 and 15 minutes, where their actual capacity (not just postal addresses) was considered. Figure 10, however, is extended to include those residents who declared that they would self-evacuate to emergency shelters, or to other places designated by the authorities. These analyses reveal that, as regards the capacity of the places of refuge and their accessibility, emergency shelters located in the very centre of the town are the most important for the protection of the civilian population (excluding those that would serve individual residents only). However, there is an excess of emergency shelters in the centre when the analyses are extended to include further scenarios (self-evacuation to emergency shelters and places designated by emergency services). Then the buildings designated as emergency shelters located to the north and south of the town centre would face greater occupancy.

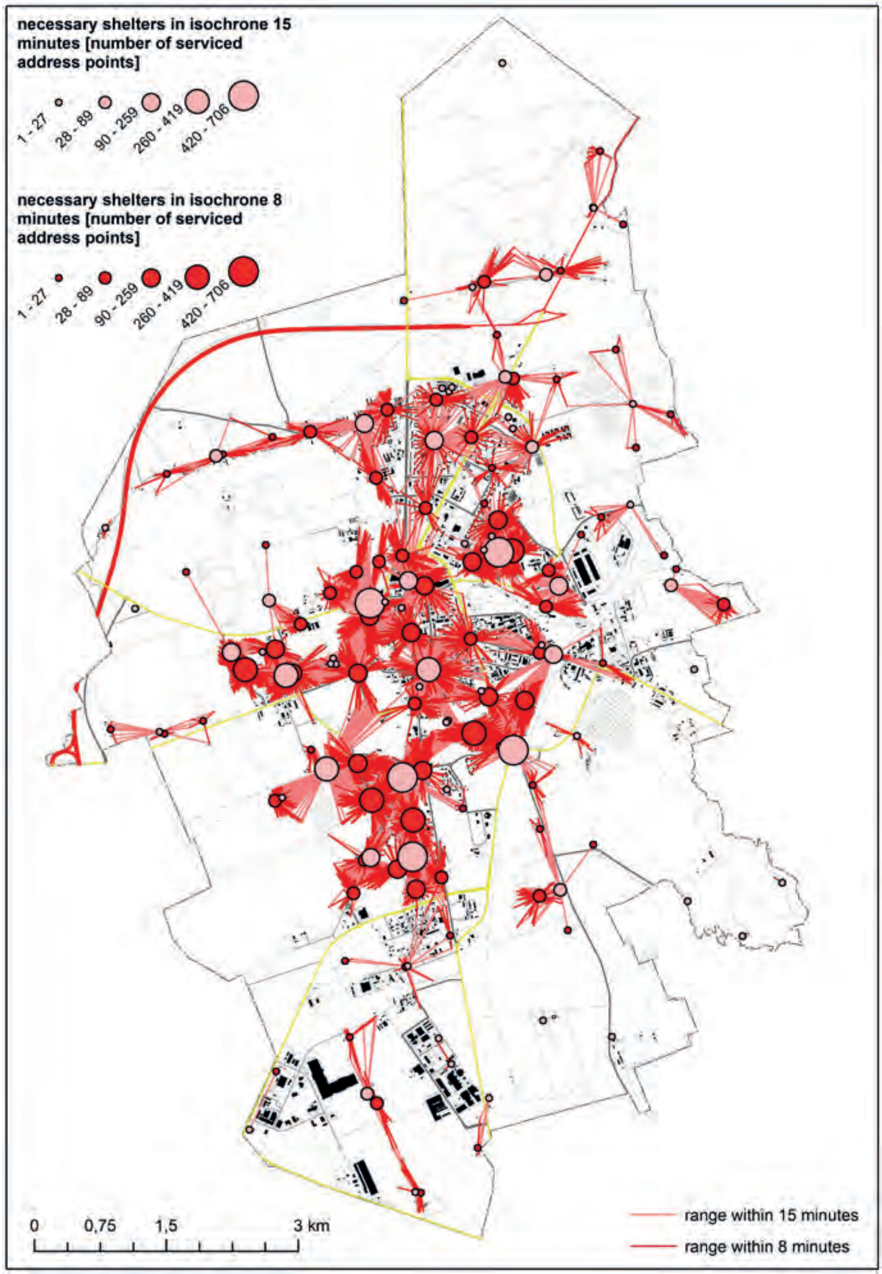

Fig. 9. Spatial arrangement of the required number of emergency shelters (from the set of those currently existing) enabling evacuation in 8 or 15 minutes, together with the number of serviced address points

Source: own work.

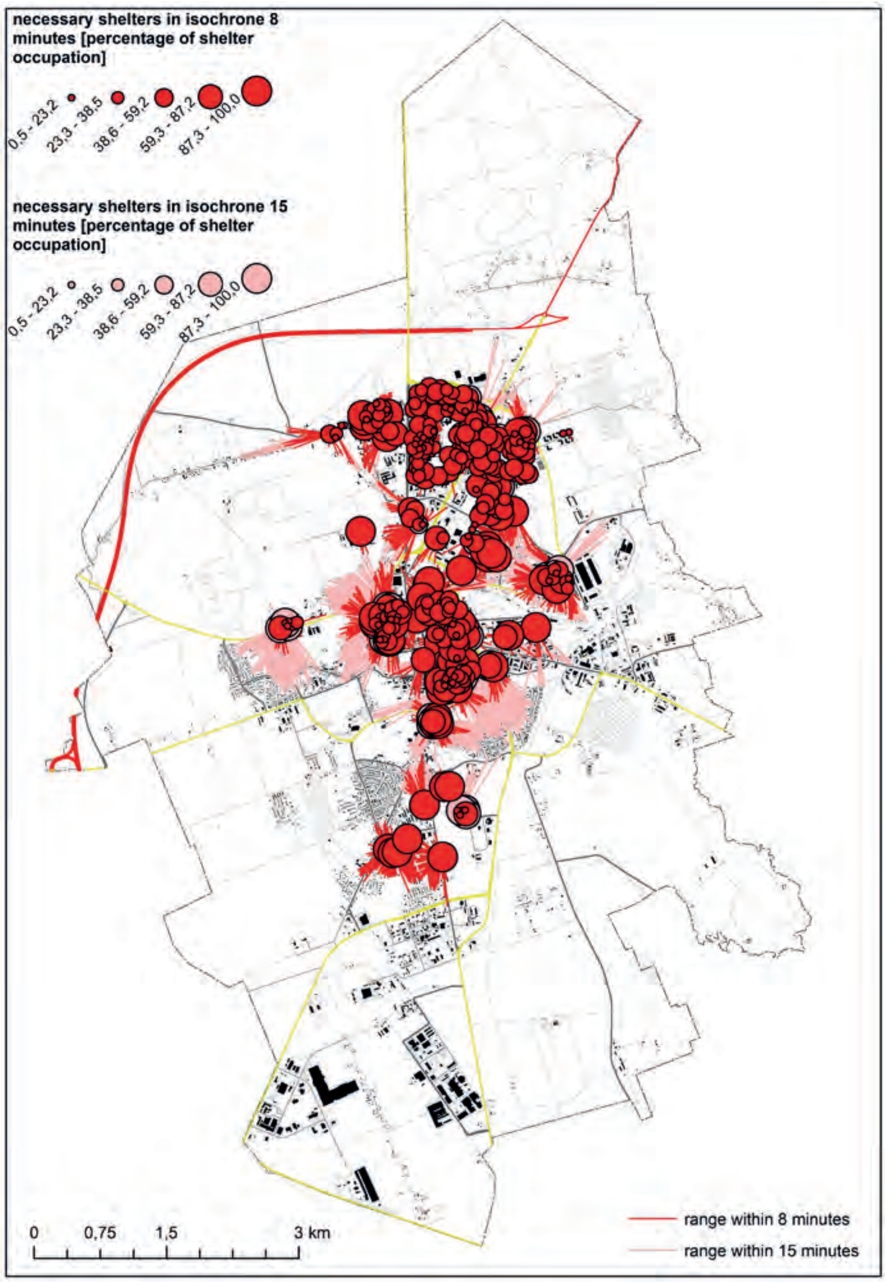

Fig. 10. Spatial arrangement of the required number of emergency shelters (from the set of those currently existing) enabling evacuation in 8 or 15 minutes, along with their occupancy level – extended to include persons carrying out orders from the emergency services

Source: own work.

By dint of having the highest population density, the town centre is the most critical area for the emergency services (firefighters, paramedics, etc.) when it comes to disaster management (Coutinho-Rodrigues *et al.*, 2012). Identifying the most critical sites, whose loss through destruction would be most undesirable, also remains one of the problems associated with emergency shelter management in the planning process (Galindo and Batta, 2013).

Among all existing facilities that either are emergency shelters now or could be transformed into them, locations were selected that residents could reach within the designated time (for each facility the number of people to be accommodated is indicated). 100 locations were proposed that would be reachable by all residents within 8 minutes, and 49 locations within 15 minutes (Table 4). While both variants are workable, it is certainly easier to manage a smaller number of facilities and to protect these buildings in the event of a war. A similar study indicating a proposal for alternative emergency shelter locations in case of war was conducted by Alisan *et al.* (2020b). Figure 11 shows the analyses extended to include those residents who not only declared they would self-evacuate to emergency shelters, but also to additional sites designated by the authorities. However, due to the low-density housing outside its central area, one could state that emergency shelters are basically indispensable throughout these areas. For the extended scenario when there is the need to serve more residents, the number of emergency shelters reachable within 8 and 15 minutes would be identical as in the first variant (Table 4).

Evacuating people to a building that is not classified as a dedicated place of refuge is not a conventional solution. However, with proper identification of the risk and prompt warning, this type of building for evacuation can be effective (Cisek *et al.*, 2018). Figures 12 shows suitable public buildings that have not been designated as emergency shelters in the official evacuation documentation for the city of Suwałki, but could be assigned as temporary emergency shelters. It shows the existing public buildings that should be designated by the authorities as emergency shelters and considers the capacity of these facilities; the residents' expected behaviour and the distribution of people who declared they would self-evacuate to emergency shelters should it be necessary. Residents of the city of Suwałki in need of evacuation should be directed by the emergency services to the designated public buildings. This evacuation would mostly be supervised by emergency response units from outside the town. The minimum number of public buildings reachable by residents within 8 minutes was determined, and it equals 89 (Table 4). As Shakibamanesh (2015) has indicated, emergency shelters should be in public building that also fulfil alternative functions (in times of peace) and the time to reach them should be as short as possible.

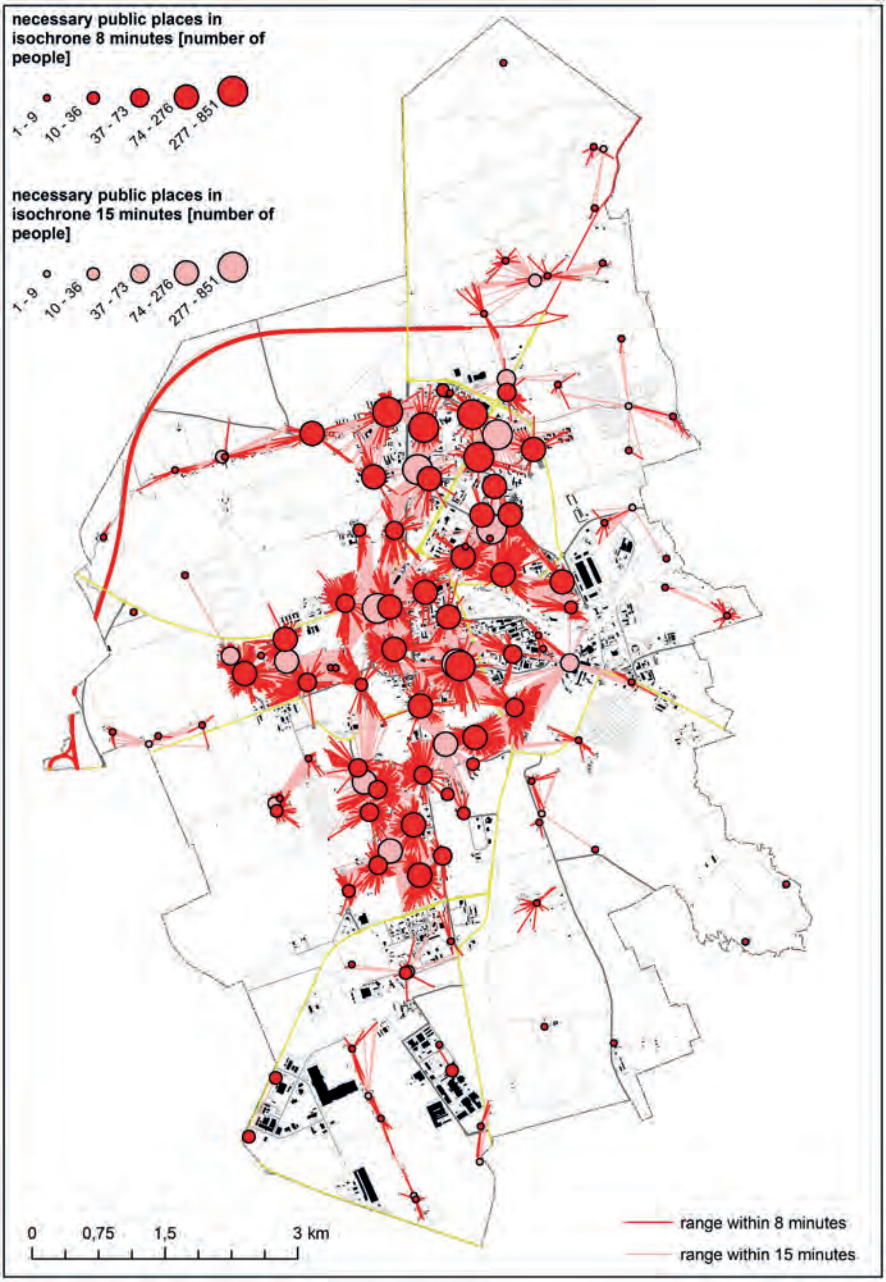

Fig. 11. Spatial arrangement of the required number of new emergency shelters enabling evacuation within 8 or 15 minutes, together with the number of people served – extended to include people following the instructions of the emergency services

Source: own work.

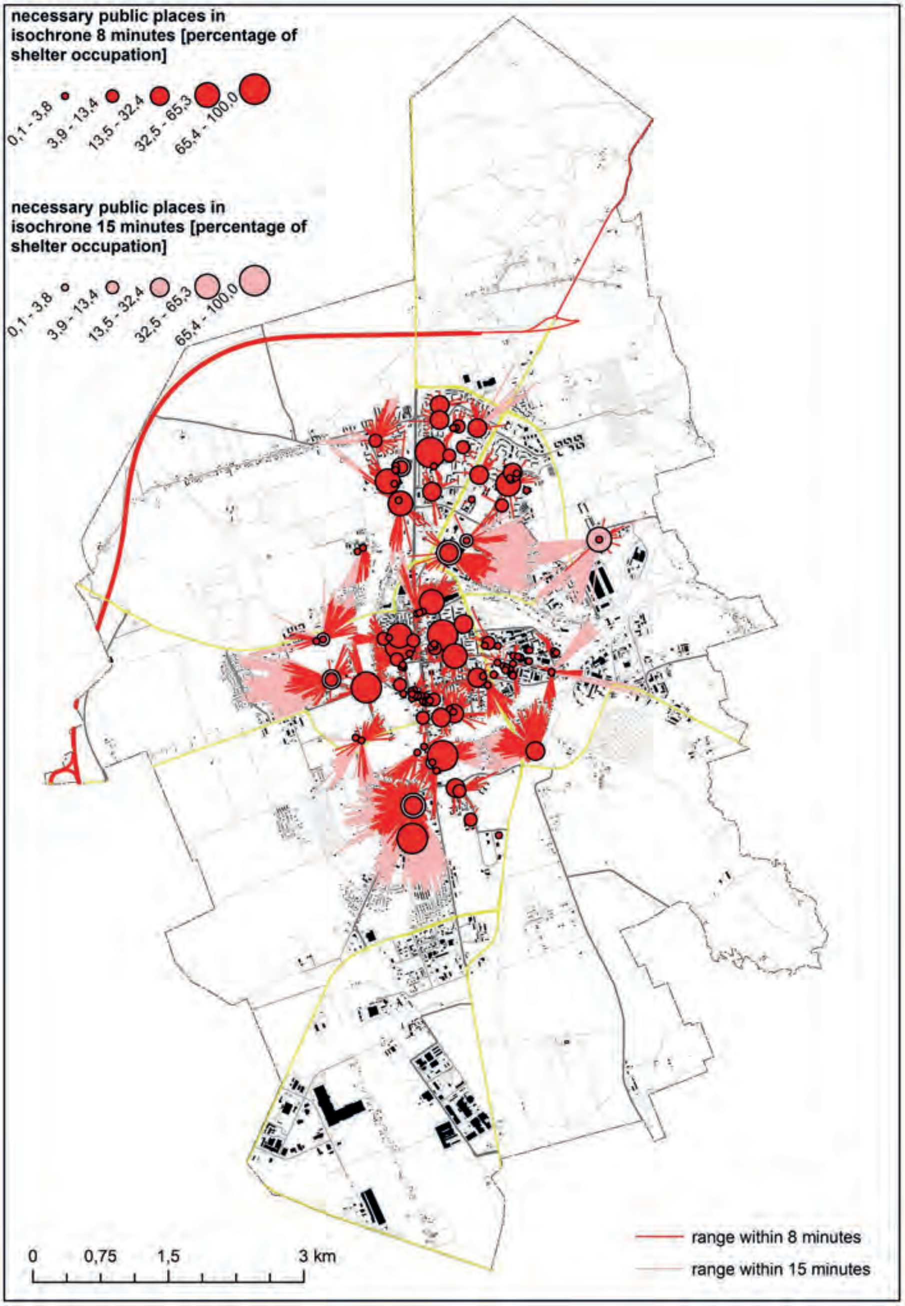

Fig. 12. Spatial arrangement of the required number of public building serving as places of refuge enabling evacuation within 8 or 15 minutes, together with the level of their occupancy

Source: own work.

Table 4. Quantitative characterisation of the effectiveness of the proposed locations of emergency shelters

emergency shelters	**evacuation time [minutes]**	**number**	**capacity [number of seats]**	**share of the maximum capacity [%]**	**number of supported postal address**	**share of serviced postal address [%]**	**number of people served**	**share of the number of people served [%]**	**cumulative evacuation time [minutes]**
new locations of places of refuge [objective: serving the population]	8	100	-	-	4,965	100.0	5,718	100.0	299
	15	49	-	-	4,965	100.0	5,718	100.0	566
new locations of places of refuge [goal: handling postal address]	8	121	-	-	5,840	100.0	-	-	332
	15	64	-	-	5,840	100.0	-	-	599
Existing locations of places of refuge [objective: serving the population]	8	349	38,956	96.0	2,761	55.6	4,811	84.1	174
	15	349	39,092	96.3	4,217	84.9	5,322	93.1	466
Existing locations of places of refuge [objective: serving an extended population group]	8	352	39,555	97.4	2,290	46.1	15,394	81.1	136
	15	354	39,812	98.1	3,348	67.4	16,692	87.9	336
New locations of places of refuge [objective: serving an extended population group]	8	100	-	-	5,840	100.0	18,981	100.0	299
	15	49	-	-	5,840	100.0	18981	100.0	566
Public buildings [objective: serving self-evacuation]	8	86	48,028	60.3	2,282	46.0	2,173	59.5	164
	15	86	48,028	60.3	3,801	76.6	2,764	75.7	441
public buildings [objective: handling organised evacuation]	8	89	49,140	61.7	4,965	100.0	4,411	100.0	86

Source: own work.

6. CONCLUSIONS

Evacuation is a strategy commonly employed as a response to emergencies. Unfortunately, its planning is an extremely complex process, involving many aspects of emergency management, land use, and expected human behaviour in an emergency. It is, therefore, essential to take all measures possible to support and optimise this process, including setting evacuation routes, designating emergency shelters, and properly managing the role of the emergency services. The aim of this article is to assess the spatial matching of existing emergency shelters (supply) to the distribution of residents in Suwałki (demand), considering their declared transport behaviour in the process of evacuation in case of war. The rationale behind this research was to develop and test different scenarios for modelling the location of emergency shelters, considering the distribution of the population and destination buildings, as well as the declared behaviour of residents in the event of a war. The results may serve as a set of recommendations for those in charge of crisis management in the city of Suwałki, its residents, and the emergency services involved in the process of evacuation. Although crisis management plans already exist for the city of Suwałki, they are neither public nor do they contain detailed guidelines. Additionally, the residents do not receive any training on how to act in the event of a war. As a result of the population being unaware of the presence and location of emergency shelters in the city of Suwałki, they would be unsure to where to evacuate. Introducing specific guidelines for emergency services, residents and municipal authorities into crisis management plans could reduce the number of casualties during a war. Moreover, the current capacity of emergency shelters is not sufficient for the number and distribution of inhabitants of Suwałki, therefore, the most practical recommendation in this respect is to indicate to the authorities the optimal number (to improve the evacuation process) and location of emergency shelters. The analyses also revealed how important self-evacuation is, proposing that residents of the city of Suwałki should walk to emergency shelters located within the town limits that are easily reachable on foot within 8 or 15 minutes (as long as the evacuees are properly guided by emergency services and know the specific location of these facilities). Given the size of the city of Suwałki and its layout, residents are advised against using a car for intra-town evacuation. The analyses also revealed that the designated emergency shelters are overly dispersed, making management difficult for emergency services. Their number should, therefore, be reduced in both the centre and also in the northern and southern parts (where they would only serve a limited number of residents). When planning urban land use, dispersed development should be prohibited (here, for the sake of evacuation and its smooth management). Training for residents in wartime evacuation and preparedness should focus on those who live in less densely populated areas and, therefore, may be forced to self-evacuate.

In addition, this training should especially target both the elderly and those who would need to be evacuated by emergency services.

The study clearly underlines that in a war scenario, Suwałki would benefit from external assistance, particularly from the fire brigade, underscoring the urgency for coordinated efforts among these emergency services, especially for rural areas, which would be the primary source of such assistance. In this context, it is particularly unfavourable that at the regional level there are no plans for the evacuation process, an oversight, as this research proves.

This research also underscores the immediacy of implementing these recommendations to fortify the city's crisis response mechanism. Effective spatial planning and targeted resident training could be pivotal in reducing casualties and ensuring swift evacuation, ultimately forging a resilient Suwałki capable of responding to war. This conclusion, therefore, not only offers critical insights for authorities and emergency services but also empowers residents, enabling them to act decisively and confidently in the face of future crises.

Acknowledgments. This article has been supported by the Polish National Agency for Academic Exchange under the NAWA Urgency Grant programme entitled: *Spatial Mobility of the Inhabitants of the Countries of NATO's Eastern Flank in the Event of a Military Conflict on their Territory*.

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