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The impacts of climate change on urban structures in Slovak cities: Identifying vulnerable urban structures

Miroslava Kamenská[1]*

Katarína Smatanová[2]

[1,2] *Slovak University of Technology, Faculty of Architecture and Design, Institute of Urban Design and Planning, Bratislava, Slovakia*

***Corresponding author**
E-mail: miroslava.kamenska@stuba.sk

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Abstract: In the coming decades, our cities will face extreme weather caused by climate change, which they will have to adopt. Adaptation of the urban environment is attracting the growing attention of planners, researchers, and policy makers in Slovakia and around the world. As essential for urban environment, the National Adaptation Strategy identified the adaptation at local level, which represents the participation of municipalities, supports the development of local adaptation strategies and subsequent implementation of actions that provide the cities with stronger sustainability and resilience. Within the last 8 years since the adoption of the national strategy, only 8 out of 141 Slovak cities in total elaborated an adaptation strategy that could be considered for further investigation. Consequently, this paper aims to broaden our knowledge of the two most significant impacts of climate change–heatwaves and floods–on urban structures in Slovak cities and validate the importance of spatial vulnerability analyses as a considerable tool for the expected unified national methodology for developing local adaptation strategies. The study examines analyses of spatial vulnerability to heatwaves in Hlohovec, Košice – Západ, and Trnava, and analyses of spatial vulnerability to floods in Hlohovec and Kežmarok, developed as part of vulnerability assessment within the framework of adaptation strategies of these cities. The analyses selected for comparison allow us to identify vulnerable urban structures and provide a deeper understanding of the causes of vulnerability in Slovakia, which is crucial for the development of adaptation strategies in the future and the building of resilience in Slovak cities. The article provides an exploratory spatial analysis of vulnerability hotspots. Based on the findings, it outlines the principles of spatial planning and urban structures that are resilient to the impacts of heatwaves and floods.

Keywords: climate change, urban adaptation, spatial vulnerability, spatial planning, sustainable development

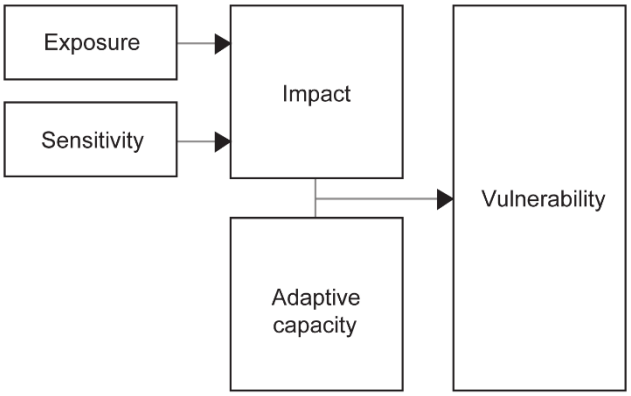
INTRODUCTION

The climate change in Slovakia is characterized by an increase in average air temperature, number of tropical days, extreme weather events, in particular concurrent heatwaves and droughts, sudden and regional floods, decrease in relative humidity and other extreme weather situations (SHI; CCS, 2017; ME SR, 2018). In the urban environment, the increase in the amount of sudden and intense rainfall results in an increased demand for infrastructure. Raising temperatures and heatwaves create urban heat islands, increasing the risk of negative impacts on the quality of life, health, and safety of residents (Pecho, 2016; Hudeková, Paulíková, 2016). To address these challenges, cities initiate the adaptation process, which includes the preparation of the ground, assessment of risks and vulnerability, adaptation strategy with an action plan for its implementation, the implementation of adaptation measures, and subsequent monitoring and rethinking of the effectiveness of the applied measures (ME SR, 2018). As the adaptation process of the urban environment in Slovakia is in an initial phase and the National Action Plan for Implementing the Adaptation Strategy of the Slovak Republic provides for the preparation of a unified methodology for local adaptation strategies, (ME SR, 2021) this work investigates one of the initial parts of this process: vulnerability and risk assessment from the perspective of spatial planning. Spatial planning has been identified as a critical mechanism through which climate change adaptation can be facilitated (Hurlimann, March, 2012). For this reason, the research is expected to fill the gap in understanding the spatial vulnerability of Slovak cities required for the future spatial development of Slovak cities. The presented article is a partial result of doctoral research focused on the study of adaptation of the urban environment to the impacts of climate change in Slovakia. One of the objectives of this research is to identify strategic areas of intervention. Partial research presented in this paper thus focuses on the identification of such spaces in terms of urban planning and design typology. This classification consequently serves as a basis for finding appropriate solutions within the valid framework of urban planning in Slovakia.

METHODS

This study examines selected parts of strategic documents–climate adaptation strategies–analyses for specific impact of climate change, heatwaves or floods. These documents, elaborated by multi-disciplinary teams mainly consisting of climatol-

ogists and other professionals using a specific analytic method, identify spaces in the cities that are the most vulnerable and hence require a particular attention and approach from the side of urban design professionals. In addition to the attempt to match these spaces with the classification provided by urban typology to enable the targeting of urban design responses more systematically, this paper also seeks to validate the importance of spatial vulnerability analyses as a tool that can be applied in the unified methodology for the development of local adaptation strategies in the future, as a potential tool to be used within the valid processes and framework of urban planning. The research aims to identify the most vulnerable spaces in Slovak cities. For identification of such spaces, we will use the information from the vulnerability analyses. The analyses examined were prepared by Carpathian Development Institute (CDI), a leader in adaptation planning in Slovakia, applying a unique method in Slovak adaptation strategies that illustrates the data and results of the vulnerability assessment, based on the international methodology recommended by Intergovernmental Panel on Climate Change (IPCC, 2007). (Diag. 1)



Diag. 1. Methodology of vulnerability assessment according to recommendations of IPCC used by Carpathian Development Institute in examined cities. (Author: Miroslava Kamenská, based on the methodology of CDI and IPCC (IPCC, 2007; CDI, 2020, 2015, 2014))

This method of vulnerability assessment has three core elements: exposure, sensitivity, and adaptive capacity, supplemented by the climate characteristics of the city (IPCC, 2007; CDI, 2020, 2015, 2014). In assessing spatial vulnerability, Carpathian Development Institute divided the analysed area into squares of 200x200 meters or 300x300 meters and provided a quantitative analysis of each square by exposure and sensitivity of the parts. In the final output, the squares were categorized into 3 levels of severity represented by 3 colours on the grid of squares (CDI, 2020, 2015, 2014, 2015, 2018). The adaptive capacity element could not be expressed quantitatively; it was assessed with a descriptive analysis. The organization elaborated 5 of 8 adaptation strategies in total available in Slovakia.

For the purposes of this article, 4 cities have been selected: Hlohovec (CDI, 2020), Kežmarok (CDI, 2015a), Košice – Západ (CDI, 2014) and Trnava (CDI, 2015b), with an existing individual analysis of the specific impact of climate change, heatwaves or floods. The fifth city, Prešov, (CDI, 2018) has integrated the spatial analysis of heatwaves and floods into one spatial analysis, which disabled its objective comparison with other cities. The identification of the most vulnerable areas was carried out in the environment of free map services (OSM). The study uses spatial vulnerability analyses from the adaptation strategies of the selected cities and own qualitative analyses of urban structures (Smatanová, Vitková, Šeligová, 2018) in relation to identified impacts of climate change obtained with field research and observation of affected areas.

RESEARCH

Hlohovec

The urban structure of Hlohovec is predominantly composed of a block structure with residential houses (from 1 to 3 floors) with pitched roofs and private gardens inside the blocks. The southern part of the city is composed of prefabricated apartment building structures (from 8 to 14 floors) positioned in green areas. The division line between these two parts is formed by the main road communication connecting the two close regional centres Trnava and Nitra. Along this axis, the historic centre, main square, and widespread public amenities are located. In terms of spatial vulnerability to heatwaves, the most critical areas are parts of the city centre providing public amenities, which represent spots with increased concentration of citizens during the day. The central area is in close contact with the residential area of prefabricated apartment buildings and its schools, restaurants, and grocery stores. The public spaces along the main axis and the pedestrian zone are unshaded, with many paved areas and no fluent vegetation. Traffic and parking possibilities are priority functions of the street profile in this area. Among the most vulnerable spaces identified, there were the train and bus station and their surroundings with wide open space without shading, trees, and vegetation. (Fig. 1)

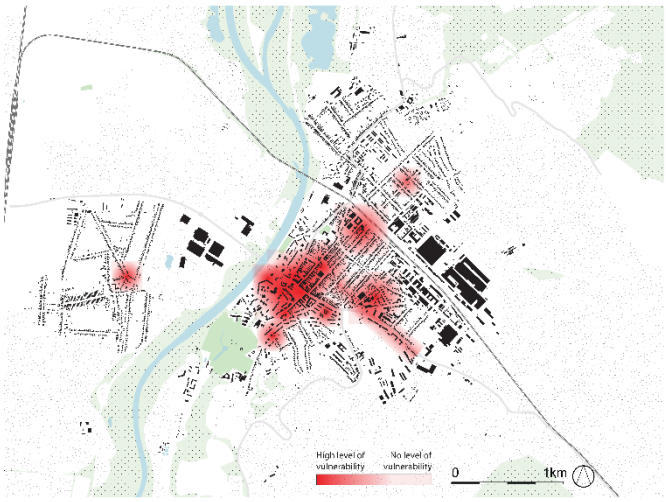


Fig. 1. Spatial vulnerability of Hlohovec to impacts of heatwaves. (Author: Miroslava Kamenská, based on data from CDI (CDI, 2020))

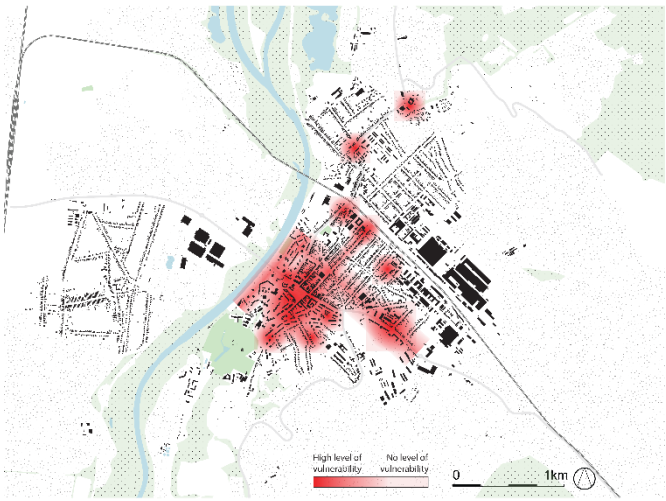


Fig. 2. Spatial vulnerability of Hlohovec to impacts of floods. (Author: Miroslava Kamenská, based on data from (CDI, 2020))

The spatial vulnerability of Hlohovec to floods shows that not only the waterfront area of the river Váh is endangered. The city is exposed to surface floods in the event of heavy rains due to large areas of impermeable surfaces with an out-of-date sewer system. The southern residential zone with apartment buildings is endangered by extensive parking capacities, roads, and sidewalks, as well as the city centre. The vulnerability also includes significant traffic infrastructure of the local transportation scheme, including the main train and bus station and the adjacent streets leading to the city centre. In suburban parts of the city, buildings of production facilities and military premises with more than 80% impermeable area put the structures of nearby houses at risk of access interruption in case of surface flooding. (Fig. 2)

Trnava

The city of Trnava has the character of a compact city with a polyfunctional historic city centre, followed by significant residential areas with the structure of prefabricated apartment buildings (from 8 to 14 floors) and the block structure of individual family houses (from 1 to 3 floors). In the southern part of the city, there is a suburban structure in contrast to large-scale industry and shopping areas. As can be seen in Figure 3, the areas most vulnerable to the impacts of heatwaves are predominantly residential mass housing structures of prefabricated apartment buildings. Extensive parking capacities, traffic infrastructure and other paved areas with lack of tall vegetation and shading are typical of these areas. From socio-economical aspects, the vulnerability of this area is also increased by high population density with the presence of the most vulnerable groups and insufficiency of public amenities. Endangered are the areas with kindergartens due to the presence of vulnerable population groups – kids up to the age of 4. On the other hand, schools and large premises of university campuses are vulnerable because of high concentration of citizens and by their surroundings with parking capacities. The area of the city centre is sensitive in part of the pedestrian zone with a high concentration of public amenities and full paved historic public space with a lack of green infrastructure or other shading possibilities. (Fig. 3)

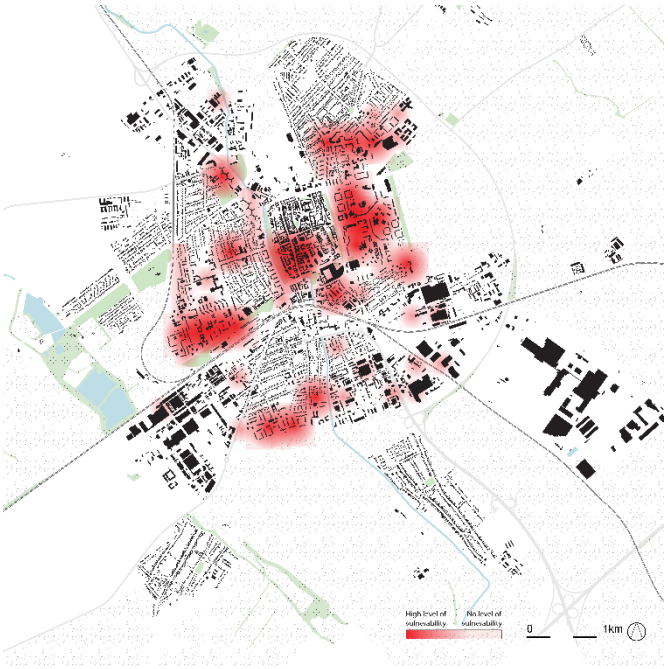


Fig. 3. Spatial vulnerability of Trnava to impacts of heatwaves. (Author: Miroslava Kamenská, based on data from CDI (CDI, 2015b))

Košice – Západ

Západ is the largest city district of Košice, with a dominant residential function, supplemented by public amenities, schools, cultural and healthcare institutions with a developed traffic network located to the west of the central zone. The dominant structure of the district consists of mass housing of prefabricated apartment buildings (from 4 to 14 floors). A tram line and a four to six lane road pass through as a central axis of the territory. The western part of the district is divided with a pine grove and consists of individual and terraced development of family houses and recreational garden houses. The areas most vulnerable to heatwaves in Košice – Západ are the structures of prefabricated apartment buildings, kindergartens, local public amenities, grocery stores, and administrative business premises and their surroundings with extensive roads and parking possibilities without shading. Garage blocks between buildings were identified as a specific element that increases the vulnerability of this residential structure. Also vulnerable is the public space in front of the entrance to the hospital, with poor vegetation and located next to the main crossroad of the central traffic axis. The western part of the district, consisting mainly of family houses, is resistant to the impacts of heat waves at a good level. (Fig. 4)

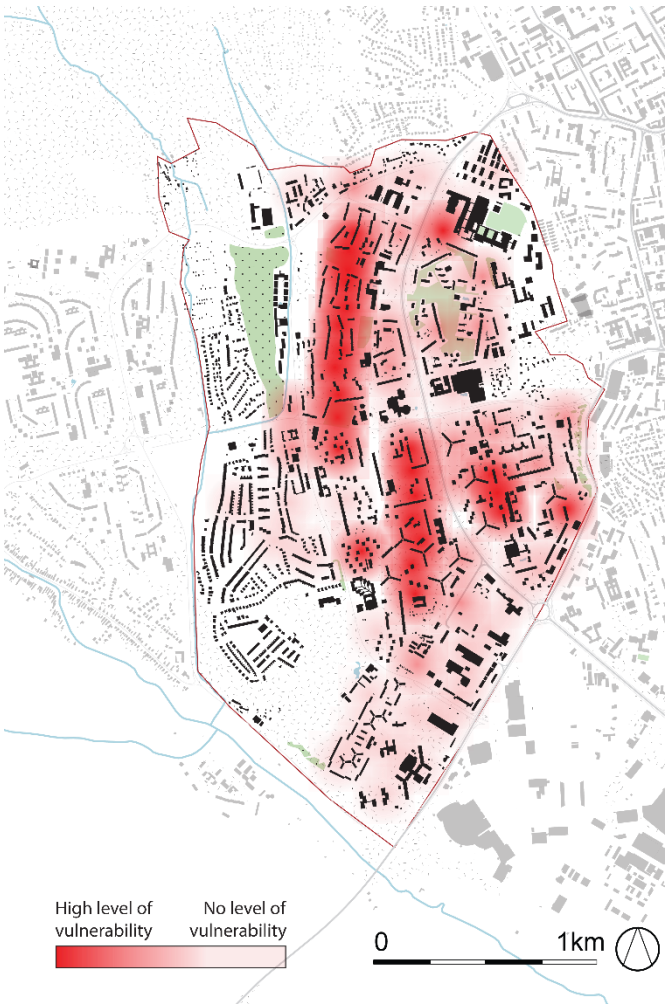


Fig. 4. Spatial vulnerability of Košice – Západ to impacts of heatwaves. (Author: Miroslava Kamenská, based on data from CDI (CDI, 2014))

Kežmarok

Kežmarok is one of the oldest cities in Slovakia. Its urban structure is defined by development along the rivers Poprad and Ľubica. Among these two rivers, there is a polyfunctional historic city centre with a compact structure (from 1 to 4 floors). The

western embankment of the river Poprad is predominated by an industrial and production zone complemented with small residential structures of individual family houses and low-rise apartment buildings (up to 3 floors). To the north and south of the historic centre, the area continues with a mix of low-rise apartment buildings and prefabricated apartment buildings (up to 9 floors). To the east and west, there are individual family houses. Figure 5 shows a strong correlation between the rivers Poprad and Ľubica and their threat to the urban structure as a result of the inappropriate form of embankment and the insufficient flow of the riverbed at snowmelt time in the nearby alpine region. On the one hand, the production and industry facilities in this area are affected by river floods; on the other hand, they are characterised by a high share of impermeable areas and extensive roofs that–without a sufficient sewer system–cause surface floods. Vulnerable to surface floods are areas of parking lots adjacent to shopping amenities, schools, and parking areas in residential zones. The historical central zone with fully paved areas and parking capacities without vegetation and trees to infiltrate rainfall is exposed likewise. (Fig. 5)

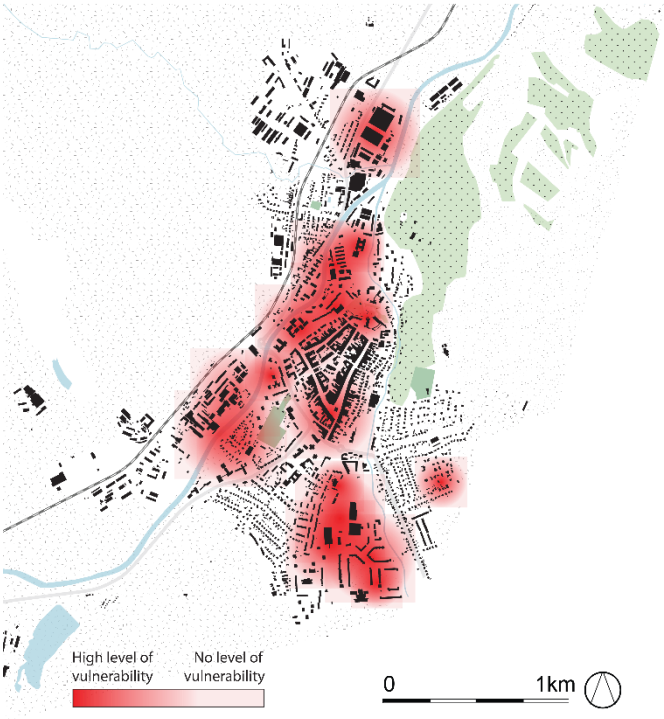


Fig. 5. Spatial vulnerability of Kežmarok to impacts of floods. (Author: Miroslava Kamenská, based on data from CDI (CDI, 2015a))

RESULTS AND FINDINGS

Spatial vulnerability to heatwaves

This study showed the considerable impact of the vulnerability of inhabitants on the vulnerability of urban structures. As was found in the case of all 3 cities covered by the study, the most vulnerable structures are the structures and public spaces with a high concentration of residents. However, the size of evaluated squares of 200x200m does not allow an accurate identification of vulnerable areas, and the generalized orientation of the grid may distort the data. Problems lie in the centres of cities with dense public amenities and a historical footprint with large paved and unshaded areas without vegetation and a lack of trees that could help create the suitable microclimate during heatwaves. Vulnerable territories include transport hubs, train and bus stations, or public transport stops. In the residential zones, there is a vulnerable area in the surroundings of kindergartens, schools, grocery stores or local centres with restaurants and other amenities. As the most vulnerable structure, the mass housing structure of prefabricated apartment buildings was identified. The surroundings of apartment buildings are composed of abundant areas of vegetation and trees. However, in this structure, the extensive traffic network with large unshaded areas of parking capacities, roads, and sidewalks as well as a high concentration of different groups of inhabitants in the area can be observed. Furthermore, the problem lies in the poor technical condition and energy inefficiency of buildings, which cause overheating of indoor spaces. (Tab. 1)

Spatial vulnerability to floods

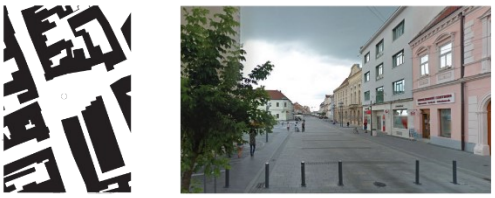
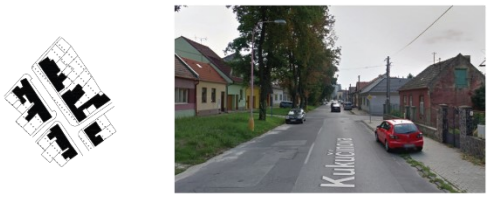
With the arrival of climate change and its consequences, the vulnerability of cities to floods is no longer a problem merely faced by waterfronts, as was found in both cities covered by the study. The vulnerability of the city to floods is characterised by two different scenarios – river floods and surface floods caused by heavy rains and insufficient runoff capacity or the risk of landslides. Analogous to the vulnerability to heatwaves, vulnerability to floods considers the element of vulnerability of inhabitants, but also vulnerability of their property and the threat to urban infrastructure. In the representation of spatial vulnerability, the most vulnerable spaces are the centres of amenities, transport hubs, and the main transportation network. As the case of Hlohovec illustrated, the areas vulnerable to the impact of surface floods are areas with extensive parking lots adjacent to service facilities, grocery stores, schools, administrative buildings, or residential parking areas. Parking lots are made with impervious surfaces and without vegetation that infiltrates rainfall. Additionally, street profiles without vegetation lines or trees capable of infiltration and with insufficient runoff capacity of sewer systems represent the danger for residential and polyfunctional zones, most significantly in areas of accumulated parking capacities. A particular consequence of surface floods for urban structures is the threat of landslides, and–as the case of Kežmarok showed–intense waterflow from the hillsides. Vulnerable to impacts of river floods are residential and industrial structures built in areas adjacent to rivers. The threat in these areas increases with the inappropriate form of the riverbed and embankment. (Tab. 2)

Resilient urban structure

Based on the results shown in previous sections, a significant difference was found between the vulnerability of residential structures. On the one hand, there is the structure of individual or terraced family houses and low-rise apartment buildings with up to 6 floors, which does not show any significant vulnerability to impacts of heatwaves and when family houses are positioned in an environment with sufficient vegetation and evenly distributed parking spots, no significant vulnerability to impact of surface floods occurs. On the other hand, there are mass housing structures with 8- to 14-floor prefabricated apartment buildings that are highly vulnerable to impacts of heatwaves and their surroundings vulnerable to impacts of heatwaves as well as surface floods. Therefore, from the point of view of vulnerability to the impacts of heatwaves, the most suitable urban structure for the development of Slovak cities is the individual or block development of buildings with up to 6 floors, which supports the idea of accessibility and short distances. Supporting polyfunctional structures and mixed use within buildings and within the city could help reduce the concentration of inhabitants in one place, which this research proved to be a problem of the existing structures. It is suitable to use polyfunctional structures both in existing urban structures, and zones with new development. The structure of apartment buildings with up to 6 floors is capable of accommo-

dating more residents in the area than less dense structures of family houses, but does not create hubs with a high concentration of inhabitants like the current construction of prefabricated apartment buildings. It is also important to pay attention to the spaces between buildings. Based on these findings, the structure of terraced houses or individual family houses in the suburbs seems to be resilient to the impacts of climate change. However, with the intensive development, the city area and the demands on mobility increase significantly, making cities more vulnerable through the network infrastructure.

Tab. 1. Urban structures vulnerable and resistant to impacts of heatwaves. (Author: Miroslava Kamenská, Photos: Google Street View)

Examined impact of climate change: *Heatwaves*	
Vulnerable structure	Resilient structure
Pedestrian zone in central area - Trnava  *Pedestrian zone in historic city centre with high concentration of amenities and fully-paved historic public space with lack of green infrastructure or other shading possibilities.*	Polyfunctional buildings with up to 5 floors - KE-Západ  *Residential zone of apartment buildings with 4 to 7 floors with active groundfloor with local amenities.*
Main railway station - Hlohovec  *City´s main railway station surrounded by wide open space without shading and high concentration of inhabitants.*	Residential street with traffic of local importance - Trnava  *Residential street with historic footprint of terraced family houses situated near the city centre. The street is enriched by vegetation line and evenly distributed parking possibilities.*
Prefabricated apartment buildings with local center - Trnava  *Residential area with mass housing structure of prefabricated apartment buildings with 8 to 14 floors with local centre and traffic of local importance.*	Residential street with terraced houses - Košice západ  *Residential street of terraced family houses with front gardens, private gardens and evenly distributed parking possibilities and vegetation.*
Prefabricated apartment buildings - Hlohovec  *Residential area with prefabricated apartment buildings with 8 to 14 floors and their bad technical condition.*	Residential street with individual houses - Trnava  *Residential street with individual family houses with private gardens and front gardens. The street profile is limited to one way and provide parking possibilities for residents.*

Tab. 2. Urban structures vulnerable and resistant to impacts of floods. (Author: Miroslava Kamenská, Photos: Google Street View)

Examined impact of climate change: *Floods*	
Vulnerable structure	Resilient structure
Central area with amenities - Hlohovec  *Historic central zone with high concentration of amenities and public space with fully-paved parking possibilities and lack of vegetation or infiltration surfaces.*	Residential street with mixed structure - Hlohovec  *Residential street with mixed structure of low-rise apartment buildings and individual family houses with private gardens. Street profile is enriched by vegetation line for infiltration.*
Main railway station - Hlohovec  *City´s main railway station surrounded by wide open space with high concentration of inhabitants. Space is fully-paved without possibility to infiltrate the rain water.*	Residential street with mixed structure - Kežmarok  *Residential street with mixed structure of low-rise apartment buildings and individual family houses with private gardens. In the street profile, the traffic is of regional importance.*
River and its adjacent area with mixed structure - Kežmarok  *River and its adjacent area with mixed structure of residential buldings and amenities.The embankment has natural character that cannot manage the critical water level in snowmelt period.*	Residential street with mixed structure - Kežmarok  *Residential street with mixed structure of individual family houses with private gardens and terraced houses with private gardens. The street profile is limited to one-way communication.*
Prefabricated apartment buildings - Hlohovec  *Residential area with mass housing structure of prefabricated apartment buildings with 8 to 14 floors and its surroundings with fully paved parking possibilities.*	Residential street with terraced houses - Kežmarok  *Residential street with terraced houses with front gardens and private gardens. The street profile is characterised by shared communication and front gardens with parking possibilities.*

In terms of vulnerability to impacts of floods, a resilient structure is, on the one hand, the urban structure of family houses with a better ratio between the built-up and undeveloped area, which allows the infiltration of rainwater. However, intensive development requires an increase in demand for the expansion and construction of transport infrastructure. On the other hand, there is the development of apartment buildings with higher density, which represents better accessibility and decrease in individual transport, the building of new transport infrastructure, as well as extensive parking lots. Similarly, as in the case of vulnerability to heatwaves, the support of polyfunctional structures and the mix of functions within buildings and within the city could help reduce the need to develop parking capacities and intensive transport network, which are the most vulnerable areas to the impacts of surface floods in Slovak cities. The question of the vulnerability of historical structures is the subject of monument care and heritage research and in order to be answered, more cultural and social aspects need to be taken into account.

Spatial vulnerability analyses in practice

Taken together, these findings suggest that the spatial vulnerability analysis could be used to contribute to the development of national methodology for local adaptation strategies, which should be currently in the preparation process (ME SR, 2021), with the particular aim of a deeper understanding of the impacts of climate change and the design of solutions for better resilience of Slovak cities. Spatial vulnerability analyses have the potential to be used as a background document for prioritising the implementation of adaptation measures, as a part of background analyses for land use planners, or as subject for further research. To achieve a greater accuracy of the results, the research recommended establishing the use of the square grid with an area of a maximum of 200x200 meters and drawing the dividing lines according to the main composition axis of the urban structure.

CONCLUSION

The presented research focused on the comparison of spatial vulnerability of Slovak cities. It presents selected impacts of climate change with a focus on evaluating the resilience of urban structures. The current study was limited to a small sample of cities due to the limited number of adaptation strategies developed in Slovakia. Despite the differences in population size of the compared sample of cities, establishment period or their location within Slovakia, results show that there is a possibility to identify the characteristics of their spatial vulnerability. Similar results were observed in the vulnerability of urban structures to heatwaves and in the vulnerability of urban structures to floods. In summary, these results show that the most vulnerable urban structures to both impacts of climate change investigated–heatwaves and floods–are the city centres, the residential structure of prefabricated apartment buildings, and extensive parking lots. These results broaden our understanding of the impacts of climate change on Slovak cities. While not all impacts emerge throughout the country as a result of different climate characteristics of cities, it is crucial to address the impacts separately. The results also show the importance of the vulnerability of citizens to the physical environment of the city and how crucial it is to place importance on the form as well as the environment of the urban structure. Considering the limited number of cities examined, further research is needed in the coming years.

Acknowledgements

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