Acta Sci. Pol.
Formatio Circumiectus 23 (2) 2024, 67–82
ENVIRONMENTAL PROCESSES

www.acta.urk.edu.pl ISSN 1644-0765 DOI: http://dx.doi.org/10.15576/ASP.FC/189854

ORIGINAL PAPER Accepted: 10.06.2024

ASSESSMENT OF VULNERABILITY TO FLUVIAL FLOODS: CASE OF MUNICIPALITIES OF THE GIDRA RIVER BASIN, SLOVAKIA

Matej Vojtek[1,2] ✉ 0000-0001-9369-3173, Soheyl Moradi[2] 0009-0003-8372-6957

[1] Department of Geography, Geoinformatics and Regional Development, Faculty of Natural Sciences and Informatics, Constantine the Philosopher University in Nitra, Trieda A. Hlinku 1, 949 01 Nitra, Slovakia
[2] Institute of Geography, Slovak Academy of Sciences, Štefánikova 49, 814 73 Bratislava, Slovakia

ABSTRACT

Aim of the study

The aim of this study is to assess the vulnerability of municipalities located in the Gidra River Basin to fluvial floods. We have calculated a fluvial flood vulnerability index (FFVI) related to the year 2021 for twelve municipalities, which fall into the Gidra River Basin and whose urban area is completely or partially located in the basin, and at the same time a watercourse, belonging to the Gidra River Basin, flows through the municipality.

Material and methods

Three indicators (number of buildings within a 100 m radius from the watercourse; length of roads within a 100 m radius from the watercourse; and number of bridges over a watercourse) representing the economic vulnerability, and seven indicators of social vulnerability (population density of municipalities; share of residents aged 65+ in the total number of residents; share of unemployed residents in the total number of economically active residents; share of households with six and more persons in the total number of households; share of incomplete households in the total number of households; share of residents without education and with primary education in the the total number of residents; and share of residents with disabilities in the total number of residents) were used to determine the respective economic flood vulnerability sub-index (EFVsI) and social flood vulnerability sub-index (SFVsI). We normalized the original values of indicators using the maximum method and treated all of the indicators as equally important. In the last step, we determined the FFVI for each municipality at a scale [0, 1] by an aggregation of the EFVsI and SFVsI, which both had equal weights.

Results and conclusions

The highest values of the EFVsI were recorded in the municipalities of Častá (0.81), Cífer (0.66), and Budmerice (0.64), which are located in central (Cífer) and upper (Častá and Budmerice) parts of the basin. The highest values of SFVsI were recorded in the municipalities of Píla (0.79) and Štefanová (0.76), which are both located in the upper part of the basin. Based on the values of the final FFVI, we can conclude that the highest vulnerability to fluvial floods is found in the municipalities of Častá (0.75), Budmerice (0.67), and Cífer (0.67). On the contrary, the lowest values have been recorded in the municipalities of Ružindol (0.37), Pavlice (0.38), and Jablonec (0.40). The results of this study can be useful for determining the overall flood risk, which is a synthesis of the hazard and vulnerability components. This task is planned for the future research in the study area.

Keywords: fluvial floods, economic vulnerability, social vulnerability, indicators, municipal level

✉e-mail: mvojtek@ukf.sk

INTRODUCTION

Fluvial floods are one of the most common and devastating natural hazards, affecting millions of people and causing significant economic losses every year across the world (United Nations, 2011). The widespread impact of flood events across various regions highlights the need for a comprehensive assessment of flood risk (Lüdtke et al., 2019; Vojtek et al., 2021; Vojtek, 2023). The multidimensional (comprehensive) concept of flood risk is based on two main components: i) the probability of occurrence of flood discharges with different return periods, i.e. the hazard component, and ii) the consequences (impact) associated with the flood event, i.e. the vulnerability component (Gouldby and Samuels, 2005; Solín and Skubinčan, 2013). In this sense, the flood risk is represented by the expected economic, environmental losses or loss of life caused by the flood hazard. The risk is thus expressed as a product of the hazard component and the vulnerability component (Sayers et al., 2003; Adger, 2006). Vulnerability represents the inherent characteristics of economic, social or environmental system that create the potential for harm and can be defined independently of the likelihood of flood hazard occurrence (Sarewitz et al., 2003).

The vulnerability of human settlements to fluvial floods depends on various aspects, such as exposure, sensitivity, and adaptive capacity, which vary across spatial and temporal scales. Exposure refers to the people, infrastructure, and assets located in flood-prone areas. Sensitivity refers to the degree to which these elements are affected by flood events (Nyashilu et al., 2023). Adaptive capacity refers to the ability of these elements to cope with, recover from, and adjust to flood impacts. These factors are influenced by physical, social, economic, and environmental conditions and processes, which shape the multifaceted nature of flood risk and the importance of adaptive measures (Raadgever et al., 2018). Assessing and comparing the vulnerability of different municipalities to fluvial floods is essential for developing effective risk management strategies and policies. However, such assessments are often hindered by the lack of data and indicators that can capture the complexity and diversity of flood vulnerability at the local level (Mai et al., 2020; Mondal et al., 2023).

Economic flood vulnerability relates to the property and infrastructure damage, which can be caused by the floods. Social flood vulnerability is the degree to which people or communities are affected by the impacts of flooding, and it includes loss of life, displacement, health problems, and psychological stress (Chakraborty et al., 2020). It reflects how certain groups within the society – often marginalized due to various inequalities – face increased risk during floods (Ajtai et al., 2023). This concept delves into the dynamic nature of vulnerability, recognizing that exposure, sensitivity, and the capacity to adapt or respond to flood hazard vary significantly across different populations and geographies (Cutter et al., 2003). Some of the factors that influence social flood vulnerability may include age, gender, income, education, ethnicity, health status, social networks, and access to resources and services (Rufat et al., 2015; Sayers et al., 2018). Economic flood vulnerability and social flood vulnerability also depend on the type, frequency, and magnitude of flood events, as well as the spatial distribution and quality of the built environment and infrastructure. Assessing and mapping flood vulnerability can help identifying the most vulnerable areas and support the design and implementation of effective and equitable flood risk management strategies (Chan et al., 2022).

The indicator-based methodology serves as a pivotal tool in the assessment of flood vulnerability, designed to clarify the various indicators contributing to the susceptibility of individuals, infrastructure, and systems to flood-related impacts (Leal et al., 2021; Nguyen et al., 2022). Through the combination and quantification of the indicators, it is possible to calculate a flood vulnerability index that represents the spatial variation of vulnerability across different locales. The strength of the indicator-based methodology lies in its ability to combine diverse datasets, spanning various scales and contexts, thereby facilitating a comparison and ranking of areas based on their vulnerability (Nasir et al., 2019; Nguyen et al., 2022; Vojtek et al., 2023). This methodological framework not only enhances the precision of vulnerability assessments but also supports the targeted allocation of resources and the development of combined mitigation strategies.

The aim of the article is to analyze the fluvial flood vulnerability of twelve municipalities, which fall into the Gidra River Basin. A fluvial flood vulnerability index (FFVI), which is related to the year 2021, was calculated using the spatial multi-criteria analysis and geographic information systems (GIS). The vulnerability assessed in this article is independent of any fluvial flood hazard assessments.

THEORETICAL BACKGROUND

The theoretical exploration of vulnerability concepts, with an emphasis on place-based and indicator-based methodologies, presents a critical perspective through which the vulnerability of varied communities and systems to hazards can be understood and addressed. The place-based methods emphasize the inherent differences in vulnerability across various locations, linking these variations to a blend of environmental, social, and economic factors (Hinkel, 2011; Bera et al., 2020). Conversely, indicator-based methodologies offer a quantifiable approach, deploying measurable metrics that cover the spectrum from physical infrastructures to social networks and governance frameworks (Camacho et al., 2023). This framework aids in pinpointing and mitigating areas of heightened vulnerability, thus enabling targeted resilience-building initiatives (Engle et al., 2014).

Flood vulnerability encompasses the potential for losses or damages arising from flood events, affecting individuals, property, infrastructure, or ecosystems. This concept is evaluated across various spatial scales, aligning with specific analytical objectives and scopes (Leal et al., 2021). A prevalent scale of assessment is the municipal or county level, corresponding to administrative units tasked with local governance, planning, and disaster management (Solín, 2012). Evaluating flood vulnerability at this level of detail facilitates the identification of highly vulnerable areas and populations, alongside the principal drivers of vulnerability. Moreover, it supports the crafting and execution of effective, targeted flood risk reduction strategies (Solín et al., 2018). This research highlights the effectiveness of the indicator-based approach in providing an overview of flood vulnerability, leveraging statistical methods and weighted indicators related to vulnerability assessment. The exposure of populations to flooding, as well as the socio-economic disparities across different regions, plays a pivotal role in shaping vulnerability. Notably, research by Roder et al. (2017) and Santos et al. (2020) has been instrumental in mapping and assessing flood vulnerability using spatial multi-criteria analysis and GIS. These studies illuminate the importance of integrating socio-economic indicators into flood vulnerability assessments, thereby enhancing flood risk management and governance at the municipal level. Additionally, the work of Alabbad and Demir (2022) explores the dimension of social vulnerability, employing exposure and resistance indicators in conjunction with the analytic hierarchy process (AHP) to assess the vulnerability of urban areas to floods. This research highlights demographic elements as critical determinants of vulnerability, clarifying the complex interplay between social structures and flood vulnerability. The utilization of the Social Vulnerability Index (SoVI) further enriches the understanding of flood vulnerability as a multifaceted phenomenon, influenced by both environmental and socio-economic indicators (Tascón-González et al., 2020; Roder et al., 2017).

To sum up, in terms of flood vulnerability, it becomes apparent that various studies have explored the vulnerability of urban and rural communities/municipalities focusing on environmental, socio-economic, and physical aspects. The collective insights from these studies advocate for a comprehensive and multidimensional approach to flood vulnerability assessment, emphasizing the need for tailored strategies that consider the diverse factors influencing flood vulnerability. These previous works provide a foundation for enhancing flood risk management and adaptation practices, as well as underscoring the value of refining indicator-based methodologies for assessing municipal vulnerabilities to floods.

STUDY AREA

The Gidra River Basin is located in the western Slovakia. The length of the Gidra River is 38.57 km and the total area of the basin is 200 km^2. The boundary coordinates of the basin are as follows: northernmost point is 48°26'N, 17°16'E; southernmost point is 48°13'N, 17°37'E; westernmost point is 48°24'N, 17°13'E; and easternmost point is 48°13'N, 17°38'E. The highest point of the basin is located in the Malé

Karpaty mountains, and it is the Jelenec hill (695 m a. s. l.). The lowest point (118 m a. s. l.) is located in the place where the Gidra River flows into the Dolný Dudváh River.

Regarding the geomorphological units, the Gidra River Basin is located across three units. In the north of the basin, it falls within the Malé Karpaty mountains,- the latter form approximately one third of the basin. The largest area of the three units is the Podunajská pahorkatina (hills). In the south of the basin, near the mouth of the Gidra River, there is a third unit called Podunajská rovina (plain), albeit the extent of it is very small compared to the other two units.

The Gidra River springs on the eastern slopes of the Malé Karpaty mountains at an altitude of approximately 547 m a. s. l. on the Baďurka hill, and it flows through the forests of the Kobylská dolina (valley). It continues eastward through the urban area of the Píla municipality and passes the Budmerice water reservoir and the Hájiček pond on the left just before the Budmerice urban area. Then, it flows through the urban area of Budmerice, Jablonec, and Cífer municipalities. Before entering the urban area of Slovenská Nová Ves municipality, the Gidra River flows under the D1 highway. It then flows through Voderady, Pavlice, and Abrahám municipalities. Ultimately, the Gidra River flows into the Dolný Dudváh River in the municipality of Malá Mača.

Ronava stream is a left-side tributary of the Gidra River. It originates in the municipality of Ružindol and then flows through the municipalities of Cífer, Slovenská Nová Ves, Zeleneč, Voderady, and Pavlice. Zadný potok stream flows into the Ronava stream from the right side in the municipality of Ružindol. The Ronava reservoir is located in the municipalities of Cífer, Zeleneč, and Slovenská Nová Ves. It is important to mention that the Ronava and Zadný potok streams do not flow through the urban areas of any of the above-mentioned municipalities. An important tributary of the Gidra River is the Štefanovský potok stream, which originates at an altitude of 695 m a. s. l. in the Malé Karpaty mountains on the southeastern slope of the Jelenec hill. It is a left-side tributary of the Gidra River, into which it flows approximately at river km 25.2. Štefanovský potok stream flows through the municipalities of Častá, Štefanová, and Budmerice. Another left-side tributary of the Gidra River is the Pajdla stream, while the Kamenný potok (stream) is a right-side tributary. .

In this article, we analyzed twelve municipalities that fall within the Gidra River Basin, and whose urban area is completely or partially located within the basin, and at the same time, a watercourse belonging to the Gidra River Basin flows through the given municipality (Fig. 1). Five municipalities are located in the Bratislava Self-governing Region, namely Budmerice, Častá, Jablonec, Píla, and Štefanová. Each of these municipalities is located in the Pezinok District. Seven municipalities belong to the Trnava Self-governing Region, of which five are located in the Trnava District (Cífer, Voderady, Slovenská Nová Ves, Pavlice, and Ružindol) and two in the Galanta District (Abrahám and Malá Mača). Several floods have occurred in the basin between 1996 and 2016, affecting different municipalities, as illustrated in Table 1.

Table 1. Number of flood events in the analyzed municipalities during 1996–2016 (source: Reports on the Course and Consequences of Floods in the Slovak Republic, ME SR, 2011, 2018)

Municipality	Year							
	1996	1997	2006	2009	2010	2011	2016	Sum
Abrahám	–	1	–	–	1	–	–	2
Budmerice	–	1	–	–	1	1		3
Cífer	1	1	1	1	1	–	1	6
Častá	–	–	–	1	1	1	–	3
Ružindol	–	–	–	–	–	–	–	0
Jablonec	1	–	1	1	1	–	–	4

Municipality	Year							
	1996	1997	2006	2009	2010	2011	2016	Sum
Malá Mača	–	–	–	–	–	–	–	0
Pavlice	–	–	–	–	–	–	–	0
Píla	–	1	–	–	–	1	–	2
Slovenská Nová Ves	–	–	–	1		–	–	1
Štefanová	–	–	–	1	1	–	–	2
Voderady	–	–	1	1	1	–	–	3

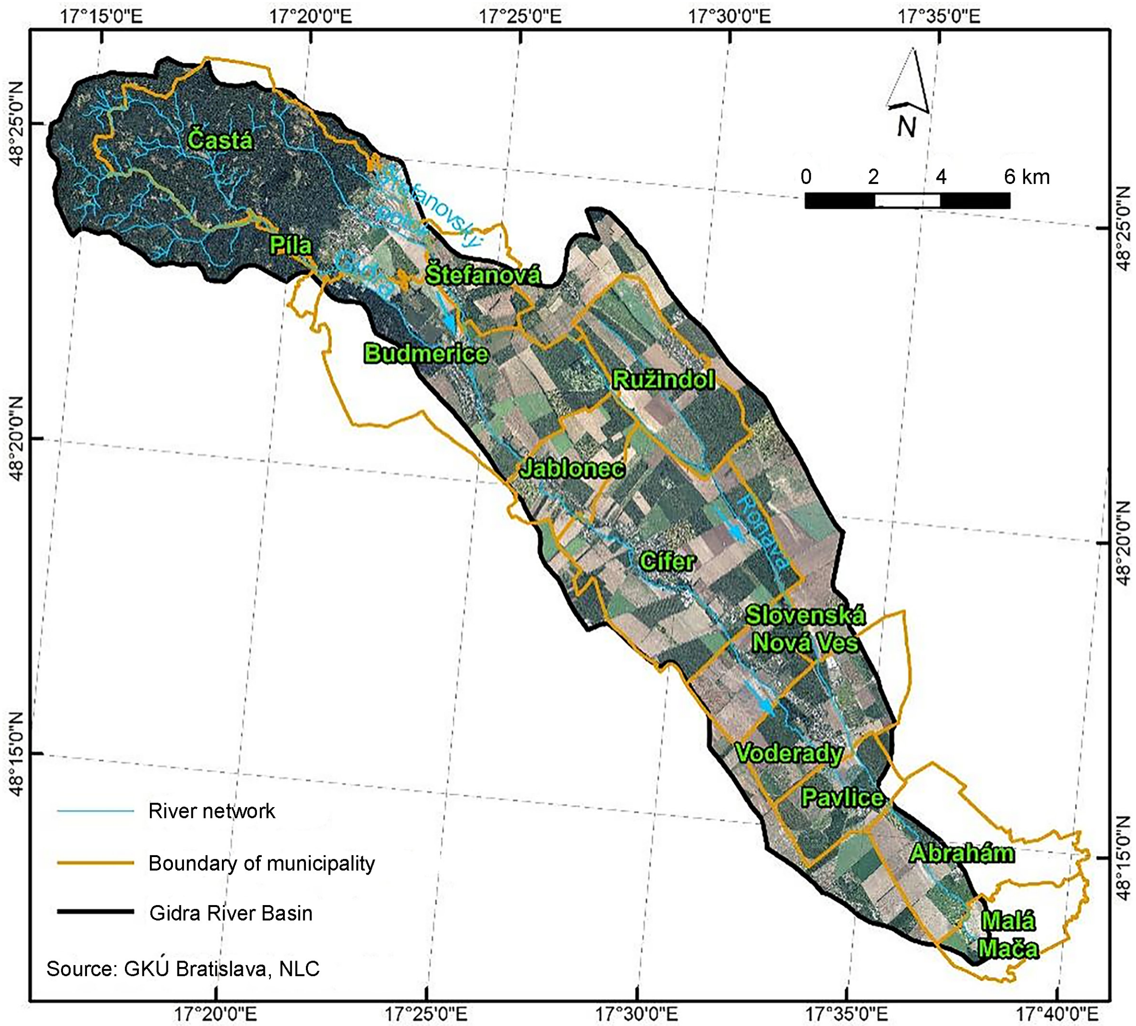

Fig. 1. Study area – Gidra river basin and municipalities within the basin (source: GKÚ Bratislava, NL)

DATA AND METHODS

In this article, we selected three indicators representing the economic flood vulnerability: number of buildings within a 100 m radius from the watercourse, length of roads within a 100 m radius from the watercourse, and the number of bridges over the given watercourse. We chose the constant value of 100 m based on previous expert analysis of the urban areas of municipalities, and the course of the river and streams through these areas. We came to the conclusion that buildings or roads within the stated radius may potentially be affected by fluvial floods. As for the roads, in our analysis we considered only those with paved surface, i.e. asphalt or concrete roads. Source data for creating the economic vulnerability indicators was the ZBGIS database provided by the Geodetic and Cartographic Institute, Bratislava.

Regarding the social flood vulnerability, we chose the following seven indicators: population density of municipalities, share of residents aged 65+ in the total number of residents, share of unemployed residents in the total number of economically active residents, share of residents without education and with primary education in the total number of residents, share of households with six and more persons in the total number of households, share of incomplete households in the total number of households, and the share of residents with disabilities in the total number of residents. The source data for social vulnerability indicators was either retrieved from the DATAcube database for the year 2021, or from the last population census (SODB, 2021), both processed by the Statistical Office of the Slovak Republic. The ten vulnerability indicators used in this study were selected based on the literature survey and similar studies (Chakraborty et al., 2020; El-Zein et al., 2021; Isia et al., 2023; Roldán-Valcarce et al., 2023), data availability, and also based on the concept of vulnerability, where the selected indicators reflect different aspects of vulnerability (sensitivity, resilience, resistance). In particular, the selected indicators are related to the exposure (sensitivity) of infrastructure/people to fluvial flooding and to the ability of residents to anticipate (be aware), cope with, resist or recover (adaptive capacity) from the negative impact of floods.

The source data were processed in MS Excel and ArcGIS software. For the calculations, we used the vector-based analysis. After we processed the original vulnerability indicators, we normalized them so that all indicators have the same scale [0, 1]. The maximum method was used for data normalization, which is expressed by the following Equation (1):

$$x_j^{'} = \frac{x_j}{\max(x_j)} \tag{1}$$

where x'_j is the scaled value of the j-th indicator; x_j is the original value of the j-th indicator; and $max(x_j)$ is the original maximum value of the j-th indicator.

The economic and social vulnerability indicators were separately aggregated into the partial economic flood vulnerability sub-index (EFVsI), and social flood vulnerability sub-index (SFVsI), by summing the respective weighted indicators. We used equal weighting of all indicators, i.e. each indicator was multiplied with equal weight in order to maintain the scale [0, 1]. In case of calculating the EFVsI, we used the weight of 1/3 for each of the three economic vulnerability indicators while for SFVsI we used the weight of 1/7 for each of the seven social vulnerability indicators. In this way, we treated each indicator as equally important when calculating the respective index. The following formulas were used for calculating the EFVsI (Equation 2) and SFVsI (Equation 3):

$$EFVsI = \Sigma_j \frac{x'_j\,1}{3} \tag{2}$$

$$SFVsI = \Sigma_j \frac{x'_j\,1}{7} \tag{3}$$

where *EFVsI* and *SFVsI* are the economic flood vulnerability sub-index and social flood vulnerability sub-index, respectively; and x_j' is the normalized j-th indicator in the scale [0, 1].

To calculate the composite fluvial flood vulnerability index (FFVI) at the scale [0, 1], we used the following Equation (4):

$$FFVI = EFVsI \times \frac{1}{2} + SFVsI \times \frac{1}{2} \tag{4}$$

where *FFVI* is the fluvial flood vulnerability index; *EFVsI* is the economic flood vulnerability index; and *SFVsI* is the social flood vulnerability index. The EFVsI and SFVsI in this equation had an equal weight of 1/2.

RESULTS

Economic vulnerability indicators

We analyzed three indicators in terms of the economic flood vulnerability. In case of the number of buildings within a 100 m radius from the watercourse, the highest values were recorded in the municipalities of Budmerice (1095 buildings) and Častá (930 buildings). On the other hand, no buildings are located within 100 m distance from the watercourse in the municipality of Ružindol. Only 32 and 39 buildings were recorded in the municipalities of Pavlice and Jablonec, respectively (Fig. 2). As for the length of roads within a 100 m radius from the watercourse, the highest values were recorded in the municipalities of Častá (58.9 km) and Cífer (29.9 km). The lowest values were recorded in the municipalities of Pavlice (2.4 km) and Štefanová (4.3 km) (Fig. 2). The highest number of bridges is found in the municipality of Cífer, while only one bridge is located in the municipalities of Štefanová and Jablonec each (Fig. 3).

Social vulnerability indicators

Altogether, seven indicators of social flood vulnerability were analyzed in this sub-section. The highest population density has been recorded in the municipality of Píla (724 residents per km^2), which has the lowest extension (0.48 km^2) from all of the studied municipalities. The lowest values of population density have been recorded in the municipalities of Štefanová (58 residents per km^2) and Slovenská Nová Ves (66 residents per km^2) (Fig. 4). The highest share of persons aged 65+ in the total number of residents has been recorded in the municipalities of Abrahám (20.9%) and Pavlice (18.2%). The lowest value of this indicator has been recorded in the municipality of Slovenská Nová Ves (13.3%) (Fig. 4).

Regarding the share of unemployed residents in the total number of economically active residents, the highest values thereof have been recorded in the municipalities of Jablonec (6.9%) and Štefanová (6.0%). Conversely, the lowest values of this indicator are found in the municipalities of Slovenská Nová Ves (1.8%) and Malá Mača (2.8%) (Fig. 5). Furthermore, the share of residents without education and with pri-

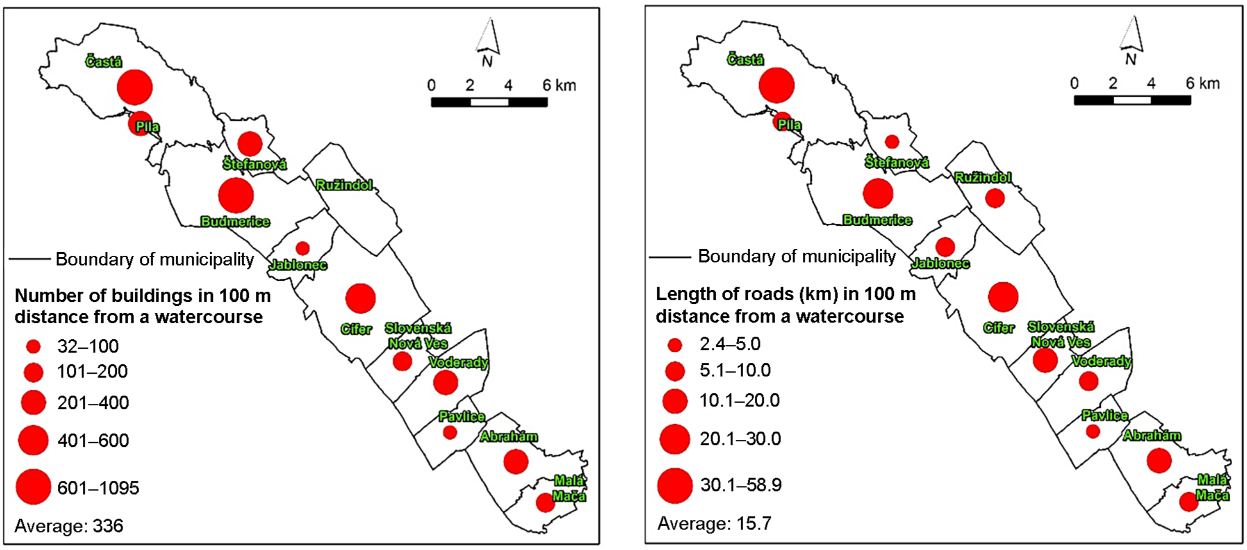

Fig. 2. Number of buildings (left) and length of roads (right) within a 100 m radius from the watercourse in the municipalities of the Gidra River Basin (source: ZBGIS)

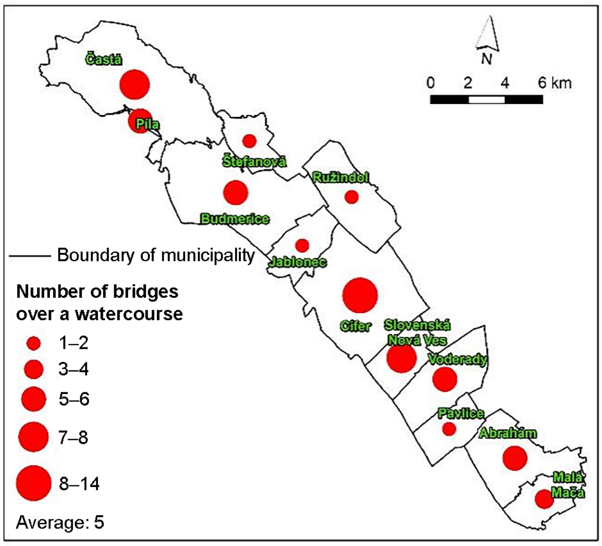

Fig. 3. Number of bridges over the watercourse in the municipalities of the Gidra River Basin (source: ZBGIS)

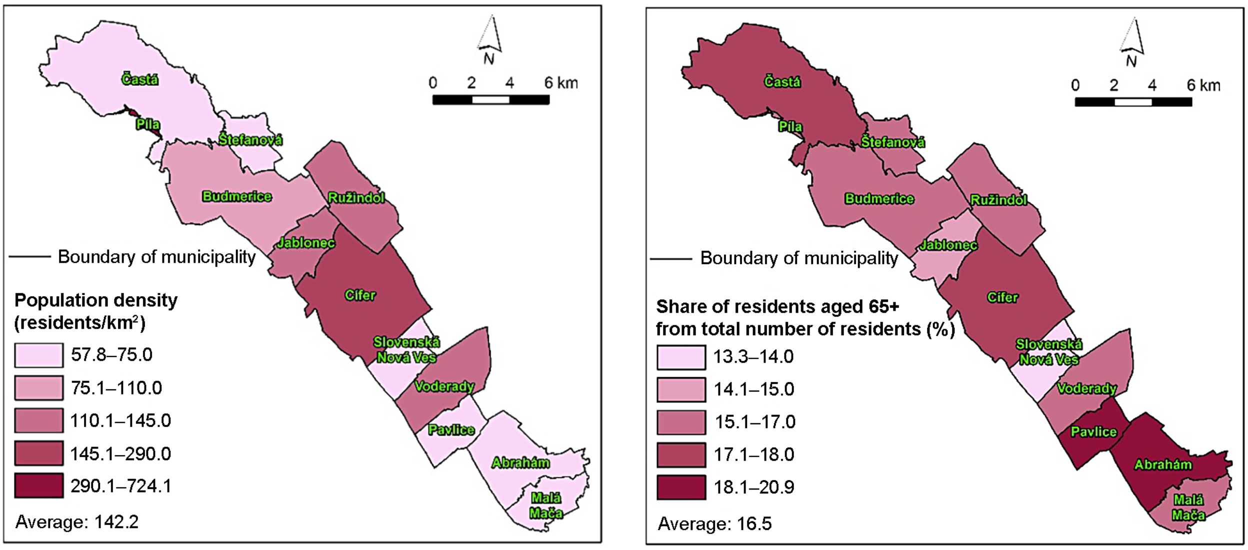

Fig. 4. Population density (left) and the share of persons aged 65+ in the total number of residents (right) within the municipalities of the Gidra River Basin (source: Statistical Office of the Slovak Republic)

mary education is the highest in the municipalities of Štefanová (19.8%), Jablonec (18.2%), and Malá Mača (18.0%). The lowest value of this indicator is found in the municipalities of Píla (14.3%) (Fig. 5).

In case of indicators representing the households, we can see that the highest share of households with six and more persons in the total number of households has been recorded in the municipalities of Štefanová (11.5%) and Pavlice (10.0%). The lowest values of this indicator have been recorded in the municipalities of Abrahám (5.3%) and Slovenská Nová Ves (5.6%) (Fig. 6). Regarding the share of incomplete households in the total number of households, the highest values have been recorded in the municipalities of Cífer (17.1%) and Voderady (16.6%), while the lowest values are found in the municipality of Píla (11.6%) (Fig. 6). The highest value of the share of residents with disabilities in the total number of residents is found in the municipality of Abrahám (8.6%). Conversely, the lowest share of this indicator has been recorded in the municipality of Štefanová (5.9%) (Fig. 7).

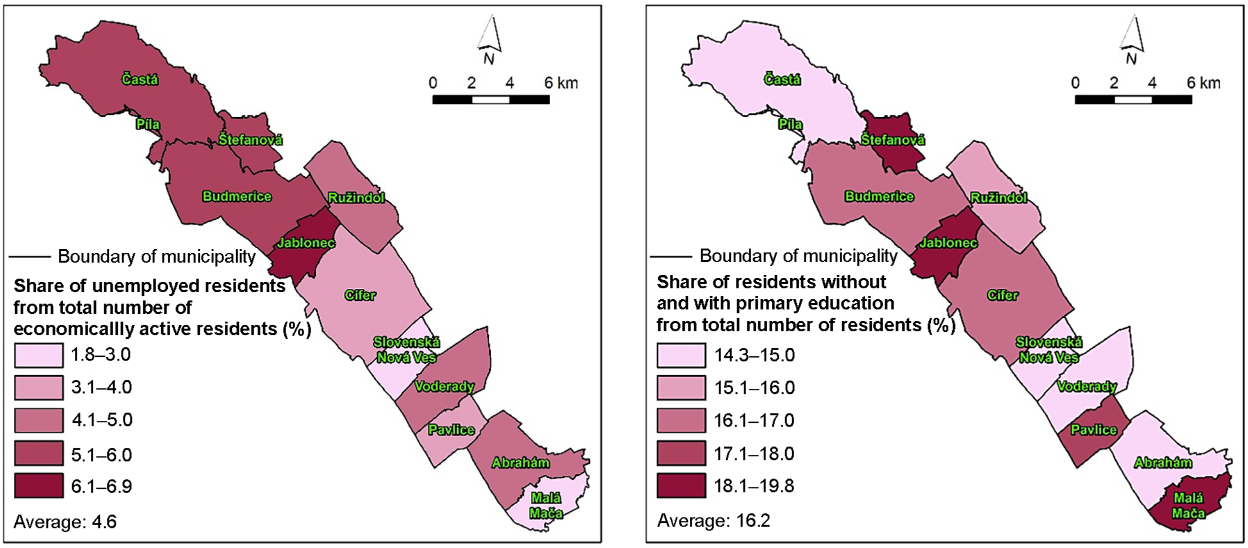

Fig. 5. The share of unemployed residents in the total number of economically active residents (left) and the share of residents without education/with primary education in the total number of residents (right) within the municipalities of the Gidra River Basin (source: Statistical Office of the Slovak Republic)

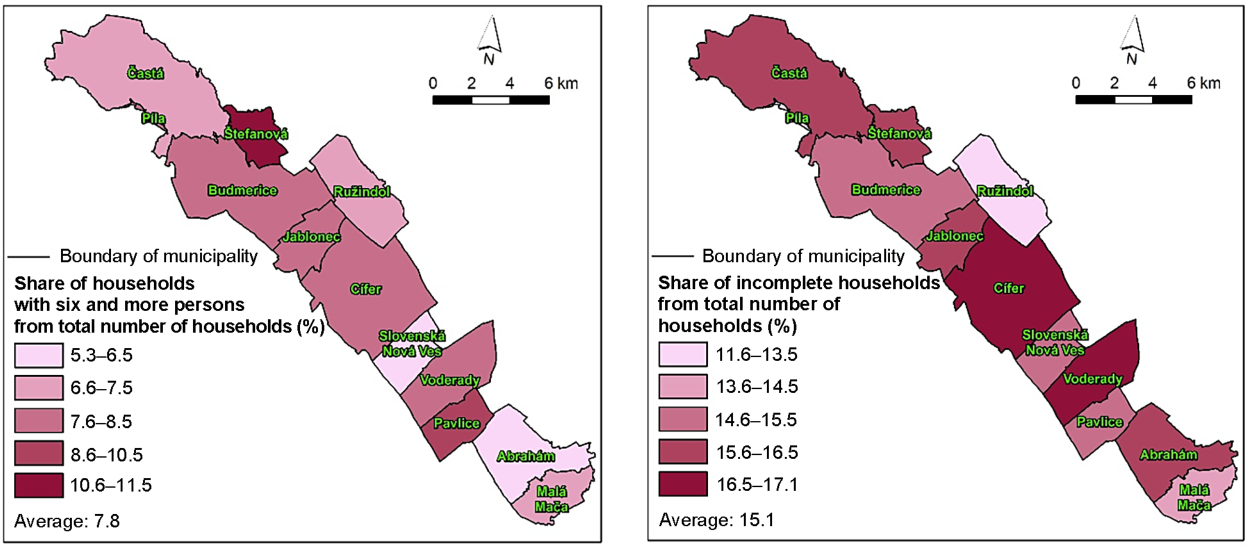

Fig. 6. The share of households with six and more persons (left) and the share of incomplete households (right) in the total number of households within the municipalities of the Gidra River Basin (source: Statistical Office of the Slovak Republic)

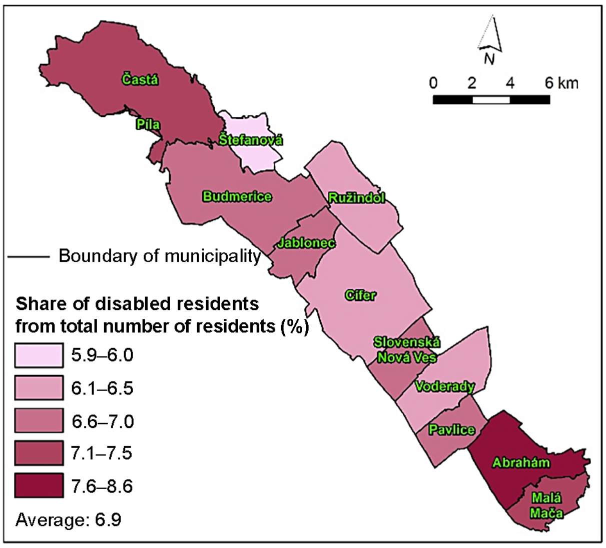

Fig. 7. Share of residents with disabilities in the total population within the municipalities of the Gidra River Basin (source: Statistical Office of the Slovak Republic)

Fluvial flood vulnerability index

Using the three economic vulnerability indicators, we calculated the economic flood vulnerability sub-index, which is shown in Fig. 8. The highest values of the EFVsI have been recorded in the municipalities of Častá (0.81), Cífer (0.66), and Budmerice (0.64). Conversely, the lowest values have been recorded in the municipalities of Jablonec (0.07), Pavlice (0.07), Ružindol (0.08), and Štefanová (0.12) (Fig. 8). Based on the seven social vulnerability indicators, we calculated the social flood vulnerability sub-index. From Fig. 8, we can see that the highest values have been

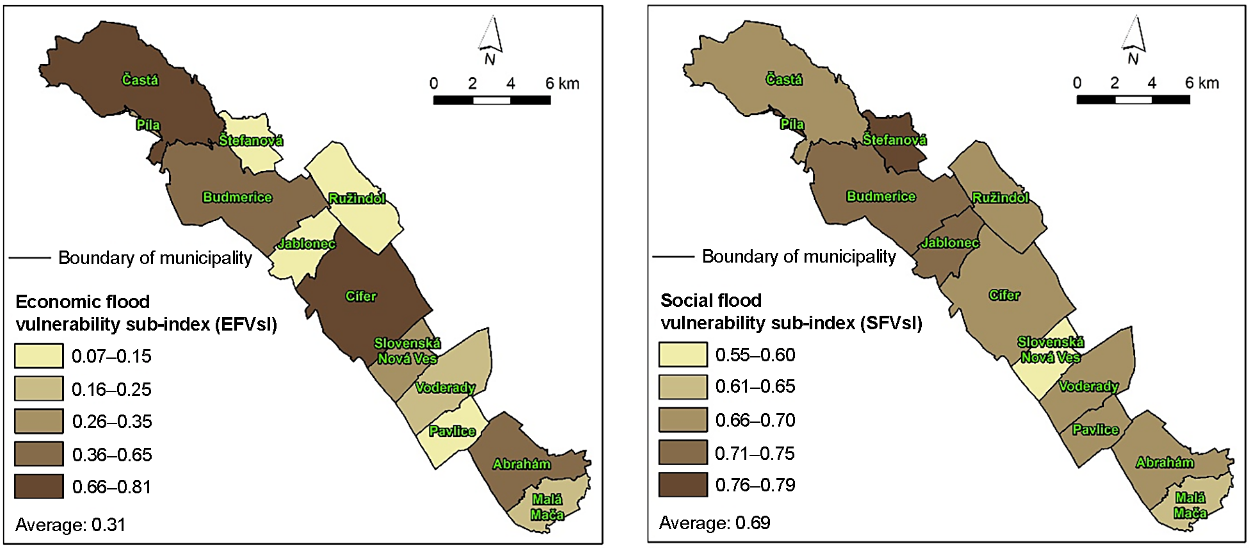

Fig. 8. Economic flood vulnerability sub-index (left) and social flood vulnerability sub-index (right) in municipalities of the Gidra River Basin (source: own elaboration)

recorded in the municipalities of Píla (0.79) and Štefanová (0.76), whereas the lowest value has been recorded in the municipality of Slovenská Nová Ves (0.55). The values of EFVsI and SFVsI presented in Fig. 8 were divided into five intervals based on the average value, which falls within the boundaries of the middle interval.

Fig. 9 presents the composite fluvial flood vulnerability index (FFVI), which was composed of the equally weighted EFVsI and SFVsI by their multiplication. The values of FFVI presented in Fig. 9 were divided into five intervals based on the average value, which falls within the boundaries of the middle interval. The highest values of FFVI have been recorded in the municipalities of Častá (0.75), Budmerice (0.67), and Cífer (0.67). Conversely, the lowest values are found in the municipalities of Ružindol (0.37), Pavlice (0.38), and Jablonec (0.40).

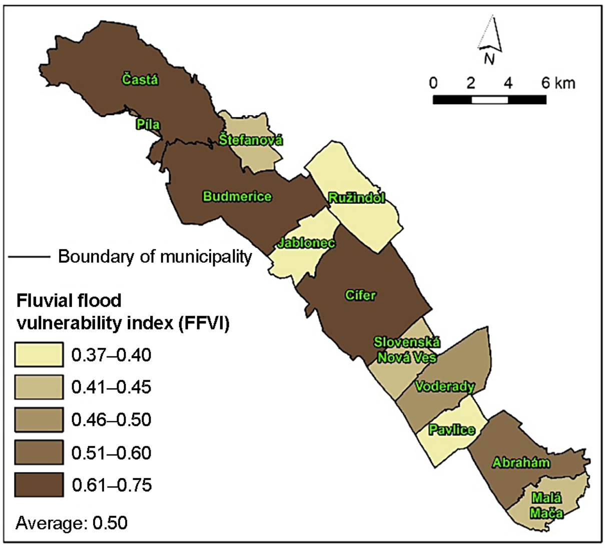

Fig. 9. Composite fluvial flood vulnerability index in the municipalities of the Gidra River Basin (source: own elaboration)

DISCUSSION

This study assessed the vulnerability of the Gidra River Basin municipalities to fluvial floods using the fluvial flood vulnerability index (FFVI) for the year 2021. The highest fluvial flood vulnerability has been recorded in the Častá, Budmerice, and Cífer municipalities, and this is reflected in both the economic and the social vulnerability factors. The methodology involved normalizing various economic and social indicators to a 0–1 scale, highlighting the comprehensive approach to vulnerability assessment. This place-specific vulnerability assessment enhances existing research by offering a localized vulnerability index, which aids in deepening the comprehension of flood risks at the municipal level (Vojtek et al., 2022; Vojtek, 2023). The strengths of this research include the comprehensive indicator-based approach and the use of normalized scales for comparability. Limitations might involve the reliance on available statistical and spatial data or potential for indicator bias. The assumption of equal weighting was used in order to maintain the objectivity and not to prioritize any of the indicators. The reason is that the vulnerability indicators represent different aspects of vulnerability concept (sensitivity, resilience, resistance) and from this point of view, we considered them being equally important and thus having equal weight in the composite FFVI. According to a review conducted by Papathoma-Köhle et al. (2019) and Morreira et al. (2021), equal weighting of indicators or sub-indices is one of the most commonly used methods to determine the composite flood vulnerability index. The equal weighting approach was also used in similar studies, such as Weis et al. (2016), Yang et al. (2018), Choi (2019), El-Zein et al. (2021), Nazeer and Bork (2021) or Hinojos et al. (2023).

The vulnerability indicators used within the economic or social components of the FFVI are comparable to those found in similar literature. The same or similar indicators to some of that used in this study, in particular, indicators of population over 65 years, population of persons with disabilities, population density, and education level were used by Isia et al. (2023). El-Zein et al. (2021) used also the indicators of education level, number of household members, and population over 65 years to determine the social flood vulnerability index. Similarly, Ingle and Chattopadhyay (2022) selected indicators of household size, population over 60 years, or education level, among others. Some of indicators used by Roldán-Valcarce et al. (2023) are again comparable to ours: population age 64 years, population density, households with 5 and more people, or number of dwellings. Furthermore, some of the indicators selected by Chakraborty et al. (2020), such as education level, unemployed population, population over 65 years, population of persons with disabilities, household size, single parents, and population density are more or less the same as the ones used in this study. Solín (2012) worked with incomplete families and population aged 65+, among other indicators of economic and social vulnerability, in order to calculate the flood vulnerability of urban areas in the headwater basins of Slovakia. Buildings and bridges were also used as indicators by Solín and Rusnák (2020). Santos et al. (2020) used road density as one of the indicators representing exposure. All in all, the differences among individual flood vulnerability studies, in terms of selected indicators, are usually caused by the data availability, purpose of the study, and selected methodology. The findings from this study highlight the importance of an indicator-based approach for assessing flood vulnerability. By identifying specific areas of high economic and social vulnerability, this approach enables more targeted and effective flood mitigation and adaptation measures. It emphasizes the need for modified strategies that consider the unique characteristics of each municipality, thereby enhancing resilience against fluvial floods. Such a detailed, localized approach could be applicable in similar settings, offering a replicable model.

For future research, areas to explore may include: a) identifying and integrating additional vulnerability indicators, potentially from environmental or infrastructural aspects, in order to enrich the vulnerability assessment framework (Balica et al., 2012; Yang et al., 2021); b) applying the methodology to other river basins or regions to validate its applicability and adaptability across different geographical and socio-economic contexts (Koks et al., 2015; Nasiri et al., 2019); c) investigating the impact of climate and land use change on flood vulnerability, considering future scenarios in urbanization or population development (Zhou et al., 2012; Vojtek and Vojteková, 2016); d) integrating the findings into flood risk management practices, including the development of more effective strategies and spatial planning guidelines, in order to enhance resilience (Vojtek and Vojteková, 2018). For example, the findings could be used to identify and prioritize the most vulnerable areas and to design and implement appropriate measures, such as to reduce the potential impact and damage of fluvial floods; e) exploring the role of community engagement and social capital in reducing vulnerability and improving recovery processes after flood events. For example, future research could examine how the participation, empowerment, and collaboration of local stakeholders, such as residents, businesses, and self-governments, can influence the perception, awareness, preparedness as well as the coping and adaptation of municipalities for fluvial floods.

CONCLUSION

The results of this study referred to the last population census from 2021. However, for future research, we would like to determine fluvial flood vulnerability of the studied municipalities using past census data, i.e. years 2011 and 2001, and compare that with the results obtained in this study. Except the comparison with past census data, we would like to predict the values of vulnerability indicators for future horizons, most likely the year 2031, and find out how the predicted values might influence the resulting FFVI.

This study emphasizes the integration of economic and social vulnerability indicators into the composite fluvial flood vulnerability index. This approach not only pinpoints municipalities with high vulnerability, but also offers an insight into understanding of the drivers of vulnerability. The results of this study can be practically useful for the Preliminary Flood Risk Assessments (PFRA) (ME SR 2011, 2018) in Slovakia, which are being revisited in six-year cycles according to the EU Flood Directive (2007). Whereas the ME SR (2011, 2018) did not consider vulnerability indicators for determining the areas with preliminary risk of fluvial flooding, the methodology and results presented in this study might provide useful information on how to incorporate the vulnerability assessment into the next revisiting cycle of the PFRA. Moreover, the findings of this study help the studied municipalities to understand their vulnerability to fluvial floods and thus develop appropriate measures for reducing that vulnerability. The calculated FFVI can be further combined with the fluvial flood hazard assessment in order to determine the fluvial flood risk index for the studied municipalities, which may have practical application for preparing appropriate flood risk management strategies and measures at the municipal level.

ACKNOWLEDGEMENTS

Funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V03-00085. This research was also supported by the VEGA agency under the grant numbers 1/0103/22 and 2/0016/24.

REFERENCES

Adger, N.W. (2006). Vulnerability. Global Environmental Change, 16(3), 268–281.

Ajtai, I., Horațiu, S., Maloș, C., Botezan, C., Radovici, A., Bizău-Cârstea, M., Baciu, C. (2023). Mapping social vulnerability to floods. A comprehensive framework using a vulnerability index approach and PCA analysis. Ecological Indicators, 154, 110838.

Alabbad, Y., Demir, I. (2022). Comprehensive flood vulnerability analysis in urban communities: Iowa case study. International Journal of Disaster Risk Reduction, 74, 102955.

Balica, S.F., Wright, N.G., van der Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Natural Hazards, 64, 73–105.

Bera, S., Guru, B., Oommen, T. (2020). Indicator-based approach for assigning physical vulnerability of the houses to landslide hazard in the Himalayan region of India. International Journal of Disaster Risk Reduction, 50, 101891.

Camacho, C., Bower, P., Webb, R.T., Munford, L. (2023). Measurement of community resilience using the Baseline Resilience Indicator for Communities (BRIC) framework: A systematic review. International Journal of Disaster Risk Reduction, 95, 103870.

Chakraborty, L., Rus, H., Henstra, D., Thislethwaite, J., Scott, D. (2020). A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice. International Journal of Disaster Risk Reduction, 43, 101394.

Chan, S.W., Abid, S.K., Sulaiman, N., Nazir, U., Azam, K. (2022). A systematic review of the flood vulnerability using geographic information system. Heliyon, 8(3), e09075.

Choi, H.I. (2019). Assessment of aggregation frameworks for composite indicators in measuring flood vulnerability to climate change. Scientific Reports, 9, 19371.

Cutter, S.L., Boruff, B.J., Shirley, W.L. (2003). Social vulnerability to environmental hazards. Social Science Quarterly, 84, 242–261.

El-Zein, A., Ahmed, T., Tonmoy, F. (2021). Geophysical and social vulnerability to floods at municipal scale under climate change: The case of an inner-city suburb of Sydney. Ecological Indicators, 121, 106988.

Engle, N.L., Bremond, A., Malone, E.L., Moss, R.H. (2013). Towards a resilience indicator framework for making climate-change adaptation decisions. Mitigation and Adaptation Strategies for Global Change, 19, 1295–1312.

EU Floods Directive (2007). Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32007L0060 (accessed: February 2, 2024).

Gouldby, B., Samuels, P. (2005). Language of Risk – Project Definitions. http://www.floodsite.net/html/partner_area/project_docs/floodsite_language_of_risk_v4_0_p1.pdf (accessed: May 20, 2024).

Hinkel, J. (2011). “Indicators of vulnerability and adaptive capacity”: Towards a clarification of the science–policy interface. Global Environmental Change, 21(1), 198–208.

Hinojos, S., McPhillips, L., Stempel, P., Grady, C. (2023). Social and environmental vulnerability to flooding: Investigating cross-scale hypotheses. Applied Geography, 157, 103017.

Ingle, K., Chattaopadhyay, S. 2022. A place-based approach to assess the vulnerability of communities to urban floods: Case of Nagpur, India. International Journal of Disaster Risk Reduction, 75, 102933.

Isia, I., Hadibarata, T., Hapsari, R.I., Jusoh, M.N.H., Bhattacharjya, R.K., Shahedan, N.F. (2023). Assessing social vulnerability to flood hazards: A case study of Sarawak's divisions. International Journal of Disaster Risk Reduction, 97, 104052.

Koks, E.E., Jongman, B., Husby, T.G., Botzen, W.J.W. (2015). Combining hazard, exposure and social vulnerability to provide lessons for flood risk management. Environmental Science & Policy, 47, 42–52.

Leal, M., Reis, E., Perreira, S., Santos, P.P. (2021). Physical vulnerability assessment to flash floods using an indicator-based methodology based on building properties and flow parameters. Journal of Flood Risk Management, 14(3), e12712.

Lüdtke, S., Schröter, K., Steinhausen, M., Weise, L., Figueiredo, R., Kreinich, H. (2019). A consistent approach for probabilistic residential flood loss modeling in Europe. Water Resources Research, 55(12), 10616–10635.

Mai, T., Mushtaq, S., Reardon-Smith, K., Webb, P., Stone, R., Kath, J., An-vo, D.A. (2020). Defining flood risk management strategies: A systems approach. International Journal of Disaster Risk Reduction, 47, 101550.

ME SR (2011). Predbežné hodnotenie povodňového rizika v Slovenskej republike. Ministry of Environment of the Slovak Republic. https://www.minzp.sk/files/sekcia-vod/phpr_sr-textova-cast-oprava.pdf (accessed: January 20, 2024).

ME SR (2018). Predbežné hodnotenie povodňového rizika v Slovenskej republike – aktualizácia 2018. Ministry of Environment of the Slovak Republic. http://www.minzp.sk/files/sekcia-vod/hodnotenie-rizika-2018/phpr_sr2018.pdf (accessed: January 20, 2024).

Mondal, B.K., Basu, T., Das, R., Mahata, S., Lee, M.A., (2023). Geospatial assessment of fluvial dynamics and associated flood vulnerability in the Bhagirathi-Hugli Sub-basin in West Bengal, India. Floods in the Ganga–Brahmaputra–Meghna Delta. Cham: Springer International Publishing, 491–527.

Morreira, L.L., de Brito, M.M., Kobiyama, M. (2021). A systematic review and future prospects of flood vulnerability indices. Natural Hazards and Earth System Sciences, 21, 1513–1530.

Nasiri, H., Yusof, M.J.M., Ali, T.A.M., Hussein, M.K.B. (2019). District flood vulnerability index: urban decision-making tool. International Journal of Environmental Science and Technology, 16, 2249–2258.

Nazeer, M., Bork, H.R. (2021). A local scale flood vulnerability assessment in the flood-prone area of Khyber Pakhtunkhwa, Pakistan. Natural Hazards, 105, 755–781.

Nguyen, T.L., Asahi, C., Tran, T.A., Le, N.H. (2022). Indicator-based approach for flood vulnerability assessment in ancient heritage city of Hoi An, Central Region of Vietnam. Natural Hazards, 114(2), 2357–2385.

Nyashilu, I.M., Kiunsi, R.B., Kyessi, A.G. (2023). Assessment of exposure, coping and adaptation strategies for elements at risk to climate change-induced flooding in urban areas. The case of Jangwani Ward in Dar es Salaam City, Tanzania. Heliyon, 9(4), e15000.

Papathoma-Köhle, M., Cristofari, G., Wenk, M., Fuchs, S. (2018). The importance of indicator weights for vulnerability indices and implications for decision making in disaster management. International Journal of Disaster Risk Reduction, 36, 101103.

Raadgever, G.T., Booister, N., Steenstra, M.K. (2018). Flood risk management strategies. Flood Risk Management Strategies and Governance. Cham: Springer International Publishing, 93–100.

Reports on the Course and Consequences of Floods in the Slovak Republic. Ministry of Environment of the Slovak Republic. https://www.minzp.sk/voda/ochrana-pred-povodnami/informacie/ (accessed: January 10, 2024).

Roder, G., Sofia, G., Wu, Z., Tarolli, P. (2017). Assessment of social vulnerability to floods in the floodplain of northern Italy. Weather, Climate, and Society, 9(4), 717–737.

Roldán-Valcarce, A., Jato-Espino, D., Manchado, C., Bach, P.M., Kuller, M. (2023). Vulnerability to urban flooding assessed based on spatial demographic, socio-economic and infrastructure inequalities. International Journal of Disaster Risk Reduction, 95, 103894.

Rufat, S., Tate, E., Burton. C.G., Maroof, A.S. (2015). Social vulnerability to floods: Review of case studies and implications for measurement. International Journal of Disaster Risk Reduction, 14, 470–486.

Santos, P.P., Pereira, S., Zêzere, J.L., Tavares, A.O., Reis, E., Garcia, R.A.C., Oliveira, S.C. (2020). A comprehensive approach to understanding flood risk drivers at the municipal level. Journal of Environmental Management, 260, 110127.

Sarewitz, D., Pielke, R., Jr., Keykhah, M. (2003). Vulnerability and risk: Some thoughts from a political and policy perspective. Risk Analysis, 23, 805–810.

Sayers, P.B., Gouldby, B.P., Simm, J.D., Meadowcroft, I. (2003). Risk, performance and uncertainty in flood and coastal defence – A review. http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD2302_3433_TRP .pdf (accessed: May 20, 2024).

Sayers, P.B., Horritt, M.S., Carr, S., Kay, A., Mauz, J., Lamb, R., Penning-Rowsell, E. (2018). Future flood risk: High resolution spatial flood risk analysis for the UK. Report for the Committee on Climate Change.

SODB (2021). Sčítanie obyvateľov, domov a bytov 2021. Statistical Office of the Slovak Republic. https://www.scitanie.sk/ (accessed: January 10, 2024).

Solín, Ľ. (2012). Spatial variability in the flood vulnerability of urban areas in the headwater basins of Slovakia. Journal of Flood Risk Management, 5, 303–320.

Solín, Ľ., Rusnák, M. (2020). Preliminary flood risk assessment: Case study of systematic processing of available or readily derivable information. Water and Environment Journal, 34(Supplement S1), 683–698.

Solín, Ľ., Skubinčan, P. (2013). Flood risk assessment and management: review of concepts, definitions and methods. Geografický časopis, 65(1), 23–44.

Solín, Ľ., Sládeková Madajová, M., Michaleje, L. (2018). Vulnerability assessment of households and its possible reflection in flood risk management: The case of the upper Myjava basin, Slovakia. International Journal of Disaster Risk Reduction, 28, 640–652.

Tascón-González, L., Ferrer-Julià, M., Ruiz, M., Garcia-Meléndez, E. (2020). Social vulnerability assessment for flood risk analysis. Water, 12(2), 558.

Tate, E., Rahman, M.A., Emrich, C.T., Sampson, C.C. (2021). Flood exposure and social vulnerability in the United States. Natural Hazards, 106, 435–457.

United Nations (2011). Global assessment report on disaster risk reduction (2011): Revealing risk, redefining development. UNISDR Report. https://www.unisdr.org/we/inform/publications/19846 (accessed: January 10, 2024).

Vojtek, M. (2023). Indicator-based approach for fluvial flood risk assessment at municipal level in Slovakia. Scientific Reports, 13, 5014.

Vojtek, M., Janizadeh, S., Vojteková, J. (2022). Riverine flood potential assessment at municipal level in Slovakia. Journal of Hydrology: Regional Studies, 42, 101170.

Vojtek, M., Vojteková, J. (2016). GIS-based approach to estimate surface runoff in small catchments: A case study. Quaestiones Geographicae, 35(3), 97–116.

Vojtek, M., Vojteková, J. (2018). Flood maps and their potential role in local spatial planning: A case study from Slovakia. Water Policy, 20(5), 1042–1058.

Vojtek, M., Vojteková, J., Pham, Q.B. (2021). GIS-Based Spatial and Multi-Criteria Assessment of Riverine Flood Potential: A Case Study of the Nitra River Basin, Slovakia. ISPRS International Journal of Geo-Information, 10(9), 578.

Vojtek, M., Vojteková, J., De Luca, D.L., Petroselli, A. (2023). Combined basin-scale and decentralized flood risk assessment: A methodological approach for preliminary flood risk assessment. Hydrological Sciences Journal, 63(3), 355–378.

Weis, S.W.M., Agostini, V.N., Roth, L.M., Gilmer, B., Schill, S.R., Knowles, J.E., Blyther, R. (2016). Assessing vulnerability: An integrated approach for mapping adaptive capacity, sensitivity, and exposure. Climatic Change, 136, 615–629.

Yang, P., Xia, J., Luo, X., Meng, L., Zhang, S., Cai, W., Wang, W. (2021). Impacts of climate change-related flood events in the Yangtze River Basin based on multi-source data. Atmospheric Research, 263, 105819.

Zhou, Q., Mikkelsen, P.S., Halsnæs, K., Arnbjerg-Nielsen, K. (2012). Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits. Journal of Hydrology, 414, 539–549.

OCENA PODATNOŚCI NA POWODZIE RZECZNE: PRZYPADEK GMIN DORZECZA GIDRY NA SŁOWACJI

ABSTRAKT

Cel pracy

Celem pracy jest ocena wrażliwości gmin położonych w dorzeczu rzeki Gidry na powodzie rzeczne. Obliczono wskaźnik podatności (wrażliwości) na powodzie rzeczne (FFVI), odnoszący się do roku 2021, dla dwunastu gmin położonych w granicach dorzecza Gidry.

Materiał i metody
Do określenia cząstkowego wskaźnika ekonomicznej podatności na powódź (EFVsI) oraz cząstkowego wskaźnika społecznej podatności na powódź (SFVsI) wykorzystano odpowiednio: trzy czynniki podatności ekonomicznej oraz siedem wskaźników podatności społecznej. Pierwotne wartości wskaźników znormalizowano za pomocą metody maksimum – tzn. wszystkie czynniki potraktowano jako równie ważne. W ostatnim kroku określono FFVI dla każdej z badanych gmin w skali [0, 1] poprzez agregację EFVsI i SFVsI, przy czym tu również przyjęto, że każdy ze wskaźników cząstkowych ma jednakową wagę.

Wyniki i wnioski
Najwyższe wartości EFVsI odnotowano w gminach Častá (0,81), Cífer (0,66) i Budmerice (0,64), które położone są w środkowej (Cífer) oraz górnej (Častá i Budmerice) części dorzecza. Najwyższe wartości SFVsI zanotowano w gminach Píla (0,79) i Štefanová (0,76), które leżą w górnej części dorzecza. Na podstawie wartości ostatecznie obliczonego FFVI można stwierdzić, że największą podatnością na powodzie rzeczne charakteryzują się gminy Častá (0,75), Budmerice (0,67) oraz Cífer (0,67). Natomiast najniższe wartości tego wskaźnika notuje się w gminach Ružindol (0,37), Pavlice (0,38) i Jablonec (0,40).

Słowa kluczowe: powodzie rzeczne, podatność (wrażliwość) ekonomiczna, podatność (wrażliwość) społeczna, wskaźniki, poziom gminy (poziom lokalny)