Summary

The main scope of this study was to develop a pluvial flood risk evaluation model and its implementation for two urban areas: Gdansk cities and Krakow cities.

For this purpose, using easy and free-to-source data, were available from state administration offices, which were produced through a sequence of tools in a GIS environment. The choice of appropriate data and tools made it possible to identify areas prone to pluvial floods and to assess the risk in these areas. The model was qualitatively assessed with historical events based on emergency calls and interventions of fire brigade occurring between 2010 and 2017 recorded by the National Headquarters of the State Fire Service. The model also considers the morphological characteristics of urbanized areas as well as tangible and intangible goods in these areas.

The flood risk assessment model in urbanized areas uses multi-criteria comparative analysis (WAP) and analytic hierarchy process (AHP). Determining the size of the risk and its spatial distribution in Gdansk and Kraków is a problem of spatial information, which is why this issue was solved with the use of WAP. The comparison of multidimensional objects involved organizing them using the WAP method, which utilized a set of diagnostic features. A grid mesh with a spatial resolution of 500 m x 500 m was adopted as the multidimensional object, and linear ordering was employed to determine the objects' hierarchy. A synthetic variable was used to calculate the values, which were based on observations of the diagnostic features characterizing these multidimensional objects. Non-pattern methods were used to calculate the value of the synthetic variable, which was a function of normalized input variables and aggregated using the arithmetic mean.

Using the linear ordering method, made it possible to rank the multidimensional objects based on their level of pluvial flood risk. This allowed to identify the areas in Gdansk and Kraków that posed the greatest hazard during rainfall.

The model assumes that risk is a function of hazard, vulnerability, exposure and susceptibility. The model was developed in such a way as to best correspond to the key elements of the city expressed through the assessment of sensitivity relating to natural and pseudo-natural characteristics related to morphological and anthropogenic features.

The study analyzed how prone cities are to pluvial flooding by looking at their morphological features, which included the topography (the existence of areas without outflow, flat areas with a low slope (less than 2%), from which the water drains away so slowly that its quantity may be hazardous, areas with large terrain height differences) and sealing of the area, resulting from anthropogenic transformations. In the sensitivity assessment, the results of a survey were used, in which respondents were asked to assess the impact of morphological features of the terrain and land cover on the occurrence of pluvial floods in urban areas. Based on the feedback from the respondents, it seems that "areas without outflow" have the highest effect on the occurrence of pluvial floods among the morphological features. On the other hand, when it comes to land cover, "compact and dense urban development" have been indicated as the most significant factor. The results were used to determine the weighting factors for the indicators describing the morphology and sealing of the area.

The level of exposure of cities was examined about four categories (in the AHP method these are the main criteria) significant from the point of view of potential damage: "Human life and health", "Economic activity", "Transport and telecommunications infrastructure" and "Cultural heritage". The level of exposure of cities was examined about four categories (in the AHP method these are the main criteria) significant from the point of view of potential damage: "Human life and health", "Economic activity", "Transport and telecommunications infrastructure" and "Cultural heritage". For each of them, prepared the sets of features, and the values of indicators describing a given exposure category were calculated. The assessment of the exposure of urbanized areas to pluvial floods also allowed to assess the potentially negative effects of flooding in these areas. An integral part of the exposure assessment was a survey conducted for the AHP method. Respondents were asked to indicate which of the main criteria is more important in the context of protection against pluvial floods because of potential losses and to provide a similar assessment for each of the sub-criteria describing a given main criterion. Respondents were asked to indicate which of the main criteria is more important in the context of protection against pluvial floods because of potential losses and to provide a similar assessment for each

of the sub-criteria describing a given main criterion. As a result, the main criterion "Human life and health" received the highest weight. The importance of the other criteria was rated at a similar level. The results of AHP show that the most important criterion in the assessment of exposure in urbanized areas are “Special areas”, i.e., areas where people who are particularly sensitive to flood risk due to their age and possible mobility restrictions reside. The results of the survey achieved using the AHP method were used to determine the weighting factors for the main criteria and sub-criteria.

The risk assessment was carried out based on maps of the distribution of maximum precipitation quantiles with the duration of precipitation, t=15 min and the probability of exceeding, p=3%, developed as part of the project entitled "Probabilistic models of maximum precipitation with a duration of precipitation and probability of exceeding - Pmax(t,p)". The assessment of the level of vulnerability of the area of Gdansk and Kraków to precipitation floods was the result of the assessment of sensitivity and exposure.

The result of the research was the development of a hazard indicator for each city, integrated indicators: sensitivity, exposure, and vulnerability, as well as an integrated risk indicator. Integral parts of the model are maps of their spatial distribution developed for each of the indicators.

This paper supports the identification and assessment of the consequences of pluvial floods and complements a data-driven approach to identifying areas of pluvial flood hazard and high-exposure areas.

Keywords: a comparative analysis of multi-criteria decision-making methods, analytic hierarchy process, hazard, susceptibility, exposure, vulnerability, risk, pluvial flood, urbanized area