International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13718-13725

Risk Mapping using Spatial Fragmentation of the Risks in Uherské Hradiště

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Abstract

This article describes the application of the risk mapping method using spatial aspects of risks. The method is expanded by the fragmentation of space that is based on the occurrence of threats. The hypothesis of the suitability of risk mapping with the help of spatial fragmentation is verified in the article using a case study. The case study describes the application of the risk mapping method within the territory of the town of Uherské Hradiště. It is implemented using the geographic information system (GIS). The GIS was selected due to its capability of processing spatial characteristics of risks. In addition, one of the main advantages of the GIS tool is its high level of visualization, which provides a clear representation of the outputs. The case study describes the process of the creation of maps of vulnerability, threat and the resulting map of risks.

Keywords: Geographic information systems; Information support; Risk analyses; Crisis management.

INTRODUCTION

Risk analysis is the main tool for identifying individual risks. Risks are identified in order to determine endangered assets and the type of danger. Based on the identification of assets and the type of danger, the appropriate protection of the assets can subsequently be selected [1]. At present, there are many methods of risk analysis. They can be divided into general and specialized analytical methods [2]. General methods are frequently used and can be applied in numerous cases. On the other hand, specialized methods are of limited use and serve primarily to analyze risks in specific areas [3]. Therefore, the concept of risk analysis represents an area with a broad theoretical basis, which enables using adequate methods for specific cases of risk analysis. Similarly, this applies to the analysis of safety risks in towns and villages.

Identifying risks which affect the assets within the territorial units (municipalities) is the basis for the preparation and possible implementation of safety measures to protect the life and health of the population and other assets [4,5]. Risk evaluation is the first step in creating emergency and other plans, implementing preventive measures and performing other activities related to the safety of municipalities [6].

One of the methods of risk analysis is that of “risk mapping” [7]. In order to specify the risks the method of risk mapping is used to determine spatial relationship of threats and assets. This method is based on the mutual intersection of assets and threats, which consequently determines the risk in the given area. The advantage of the risk mapping method is a well-arranged presentation of the resulting risks thanks to a high degree of visualization and spatial expression. Furthermore, the GIS tools are used for risk mapping as they enable processing the spatial data [8]. Recently, the application of the GIS tools has been developing dynamically not only in the area of safety applications but also in many other areas of human activity.

PROBLEM FORMULATION

It is assumed that municipalities need to address the issues of identifying safety risks in their territory. Various analytical methods are currently used for these purposes. However, the use of the vast majority of analytical methods is connected with problems of presenting the resulting risks to both professionals and the general public. It is because the resulting risks are often presented only by stating their type. Information related to the place of occurrence is often unexpressed, or it is expressed only in abstract form, e.g. by stating the designation of objects, address, etc. This way of presenting the risks has a major drawback because it does not provide the full impact of the risks on the territory of the municipality. Risks are often expressed globally without specifying the possible risks (e.g. risk of floods, fire, etc.). At the same time, determining the location of possible risks can make protection more effective, especially by focusing on specific places (space). It also makes it easier to provide information about risks to the population. Above all, providing information is facilitated with a high degree of visualization [7], and thus the time needed to process the information contained in the graphical output is reduced in comparison to text or numerical expressions provided by standard analytical methods. Providing information about the risks and defining the area of their occurrence to the population is therefore a basic problem in the town of Uherské Hradiště (UH). Currently, the only problem that has been addressed is that of the risk of flooding. Other safety risks are not addressed at all. For the territory of UH floods are defined by a map of floodplain zones for various intensity of flooding. These maps mark the flooded territory but they do not include information about other risks in the given space. The method of risk mapping enables the spatial expression of the risks. However, dividing the territory of the municipality according to the level of the existing risk remains difficult. This problem can even be intensified by the possibility of the occurrence of several kinds of risks in one place.

PROBLEM SOLUTION

The problem of dividing the municipal territory into individual quadrants of risk can be solved by means of the method of risk mapping complemented by spatial fragmentation based on the interaction of several types of risks. This enhancement to the method makes it possible to assign a degree of risk to individual parts of the UH territory and subsequently locate individual risk fragments.

*A. **Material and methods***

The fundamental method used in the case study is the method of risk mapping complemented by the spatial expression [7]. The method proceeds from the basic risk equation (Equation 1), which defines the risk as a value of the simultaneous occurrence of threat and vulnerability of assets in the given area. The basic principle of the method is described in Fig. 1.

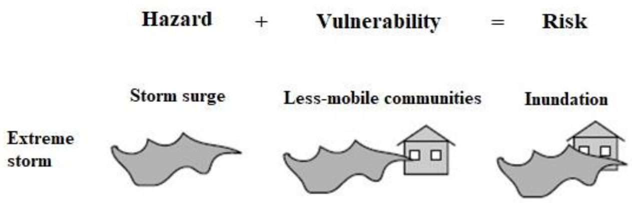

Figure 1: The princip of risk mapping [8].

$$Risk = R(H(Eh), V(Ev)) \quad (1)$$

The method is adjusted for the purposes of mapping the most hazardous area of the municipality (for the cumulative risk) and it is based on the assumption of clearly defined assets, i.e. population, environment and infrastructure in the territory of the municipality. These assets are common for the entire territory of the town. The method is then modified already at the level of the threat by means of the cumulation.

In the event of occurrence of two or more threats/risks at one place, we talk about the so-called cumulative threat/risk [9]. On the basis of the previously mentioned assumption only the cumulative threat is further processed. The cumulation of threats makes the results of risk mapping more accurate, and allows assigning the value of resulting cumulative risk level to the space. Based on the cumulation of threats in a limited fragment of space, this fragment can be assigned a T_f value corresponding to the sum of values/number of threats T_i (see Equation 2).

$$T_f = \sum Ti \quad (2)$$

The values of threat can be expressed in binary form (yes/no). In the case of threats of different intensity, it is possible to select a multi-level threat scale (e.g. 0–5) where individual fragments are assigned the value corresponding to the sum of the threat values in the given fragment. In general, setting the values of threat extent may be arbitrary but it is necessary to respect this setting further on. In the event of a large number of coinciding threats it is also possible to increase the threat value by a constant. A constant increase of the threat values is indicated by the coefficient K_f. The objective of applying the K_f coefficient is to increase the difference between the resulting threat values in individual polygons (fragments). Increasing the difference then leads to a higher degree of differentiation of the hazardous area.

The principle of fragmentation is described in more detail in Fig. 2 which depicts three types of threats (T1, T2, and T3). The individual threats are spatially defined by the given polygons. The intersection of individual polygons is created by fragments of threat which are assigned a threat value corresponding to the threats active in this fragment (e.g. F1 fragment represents threats T1, T2 and T3; F4 fragment represents threats T1, T2, etc.). Tab. 1 shows a list of newly-emerged fragments together with the assignment of threats active within these fragments.

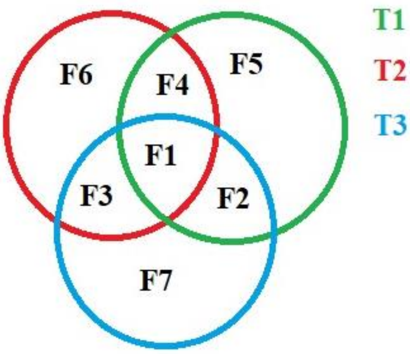

Figure 2: The principle of fragmentation [7].

Table 1: The list of newly-emerged fragments.

Fragment	Threat of Fragment
F1	T1,T2,T3
F2	T1,T3
F3	T2,T3
F4	T1,T2
F5	T1
F6	T2
F7	T3

Other methods used in the article are expert estimation, analysis, observation, and managed interview. All these methods were used to identify the main assets and threats in the

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town of UH. The data was obtained with the cooperation of employees from the local Department of Crisis Management.

PROBLEMEXPERIMENTS AND RESULTS

The actual maps of threats, vulnerability and risk were created with the use of spatial data found in OpenStreetMap (OSM) and SW application QGIS 2.6.1 which enabled processing this data. The Terex SW 3.1.1 was used to identify hazardous areas threatened by the leakage of dangerous chemical substances. The flood-land model of the Dibavod database was used for the 100-year, 50-year and 20-year floods.

A. Case study of risk mapping in Uherské Hradiště

UH is a town in the Czech Republic. This capital of the Uherské Hradiště district is located in the region of Zlín, with the population of 25,254 [10]. The cadastral area of the municipality is 21 km^2 and it is divided into 7 parts. Out of the total area of 21 km^2, the built-up area occupies 1.8 km^2, the agricultural land is 13.5 km^2, the forest land is 0.4 km^2, the body of water is 0.4 km^2 and other areas take up 4.8 km^2. The river Morava flows through the town. The town falls within a warm area characterized by long dry summers, warm springs and autumns, and short dry winters. The average annual temperature in the area ranges from 8.7 to 9.3 °C with the annual rainfall of 590 mm [10].

The main assets located in the UH territory are listed in Tab.2. In particular, they include population, environment, and infrastructure of the municipality. Crucial assets are distributed evenly throughout the municipality. Due to a large spatial extent of the registered threats and the even distribution of assets, danger to the vast majority of crucial assets was taken into consideration for any occurrence of the mapped threat. Because of this, the asset value does not need to be included in the risk map of the UH territory. The reasons are constant values for all areas endangered by the given threats. Therefore, the resulting risk map was in reality affected only by the amount and extent of potential threats in the given risk fragments.

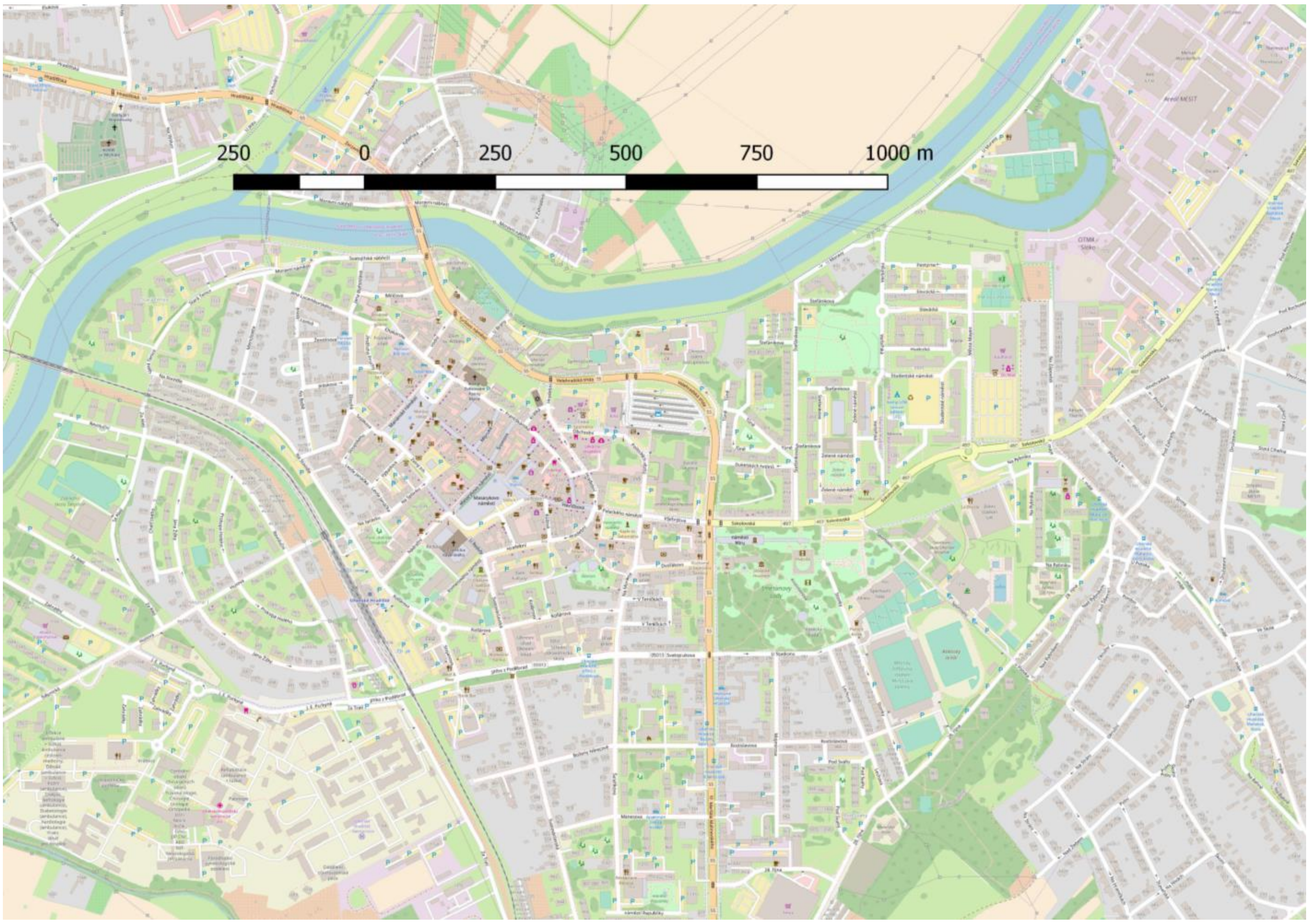

Figure 3: The map of vulnerability [10,11,13].

Risk map

The resulting risk map, comprising of spatial fragments of risk, was implemented using a vulnerability map and a threat map. The sub-maps of vulnerability and risk were processed based on assets and threats in the UH territory.

Vulnerability map

The vulnerability map is based on the spatial expression of assets n the UH territory. The assets are defined in Tab. 2.

Table 2: The main assets located in the UH territory [10].

Asset	Type of asset
Population	Population
MŠ Husova 838	Education
ZŠ Za Alejí 1072	Education
Speciální MŠ	Education
MŠ Komenského	Education
ZUŠ Uherské Hradiště	Education
Obchodní akademie	Education
SOU obchodu a služeb	Education
Gymnázium UNESCO Uherské Hradiště	Education
SPH a zdravotnická Uherské Hradiště	Education
SUP Uherské Hradiště	Education
ZŠ a MŠ Speciální	Education
ZŠ UNESCO	Education
ZŠ T. G. M. Mařatice	Education
Fakulta logistiky a krizového řízení	Education

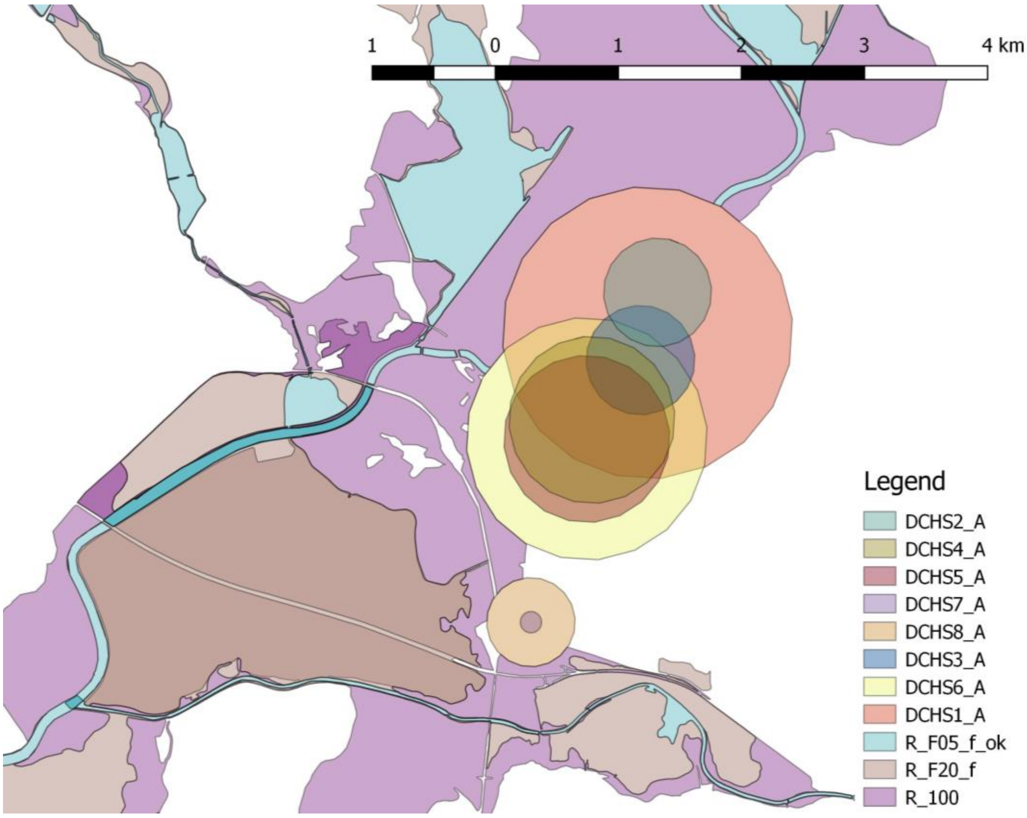

Figure 4: The map of threat [10,12,13,14].

Natural Environment	Environment
Power Lines	Lines
Route	Lines
Residential Building	Population
Fire Rescue Services	Safety
Police	Safety
Emergency Services	Safety
Football Arena	Sport
Winter Arena	Sport
Sport Arena	Sport
Shopping Centers	Facility
Restaurant	Facility
Cinema	Facility
Theater	Facility
City Park	Environment
City Hall	Facility

Fig. 3 depicts the assets and their location in the map of UH. In essence, it is the map of the municipality's infrastructure, including residential buildings. The population is included in the map in the form of attributes of residential buildings. The population is thus included on the basis of their permanent residence and their presence in companies, school facilities, hospitals, shopping malls, sports halls, etc. By their presence in these buildings the inhabitants of other towns and villages, who commute to work or school in UH, are also included into the assets. The quantity of these persons was based on the maximum capacities of the buildings and the numbers of persons registered in them. As previously mentioned, due to the extent of threats, all major groups of assets are endangered by individual threats and therefore, their impact on the resulting risk is constant.

Threat map

The threat map comprises of a spatial representation of major threats active in the territory of UH. In particular, the crucial threats include the leakage of dangerous chemical substances (DCS). Major threats in the form of the DCS leakage are outlined in Tab. 3. It describes sources of DCS leakage (operator and type of equipment), type of the DCS, its total stored quantity, and the size of the zones put at risk by possible leakage.

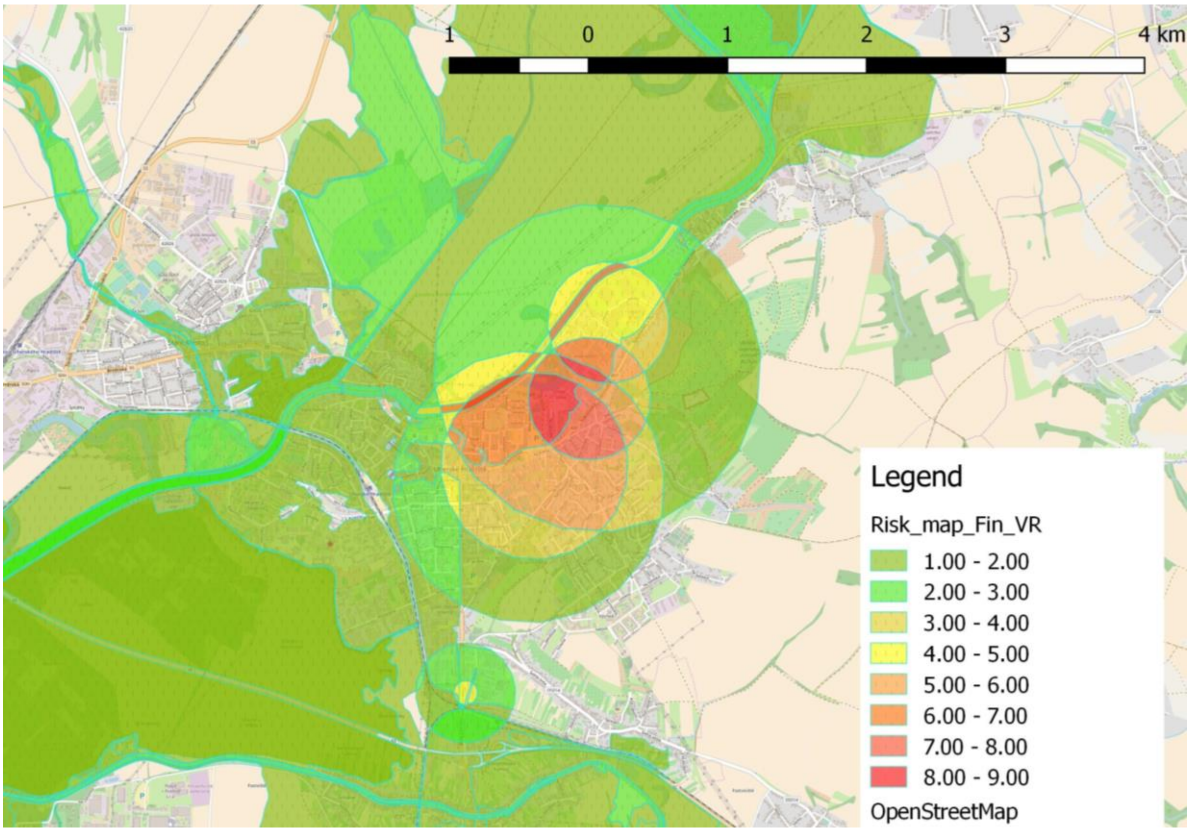

Figure 5: The map of risk [10,11,12,12,14].

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13718-13725

Table 3: The objects of DCS leakage [10].

Name	Dangerous chemical substances	Quantity
Winter stadium Uherské Hradiště	Ammonia	800 kg
Slovácké vodárny a kanalizace, a. s.	Technical petrol	517 kg
	Acetylene	228 kg
Mesit pcb, s. r. o.	Sulfuric acid	1500 kg
OTMA-SLOKO s. r. o	Sulfur dioxide	2500 kg
Aquapark Uherské Hradiště	Chlorine - gas	780 kg
	Sulfuric acid	960 kg

The zones of leakage for individual DCS types are marked in the threat map by circles with a radius corresponding to the reach of the DCS leakage.

Other major threats dealt with in the case study include floods, namely 100-year, 20-year and 5-year floods. Each type of flood is represented in the map by a continuous territory that corresponds to the area threatened by the given extent of flooding.

The resulting threat map is presented in Fig. 4. Individual types of threats are color-coded and described by a caption. Objects marked as DCHS 1–8 represent possible leakages of the DCS (see Tab. 3). Objects R_FXX stand for 5, 20 and 100-year floods.

On the basis of the vulnerability and threat maps, the resulting risk map was processed. When creating the risk map, a "threat value" attribute has been created for each threat fragment; this attribute indicates the value of the particular threat. In this case, all spatial objects were assigned a constant value, which was multiplied by a threat weighting coefficient (*Kw*), see Equation 3.

$$T_f = \sum(Ti*Kw) \qquad (3)$$

Here, a constant value which equals to 1 (based on the assumption 0/1, threat is absent/present) was assigned to the threat objects, and the value of the weighting coefficient was 2 for all threat objects. The objective of assigning a weighting coefficient was to increase the difference in values of cumulative threats in individual threat fragments.

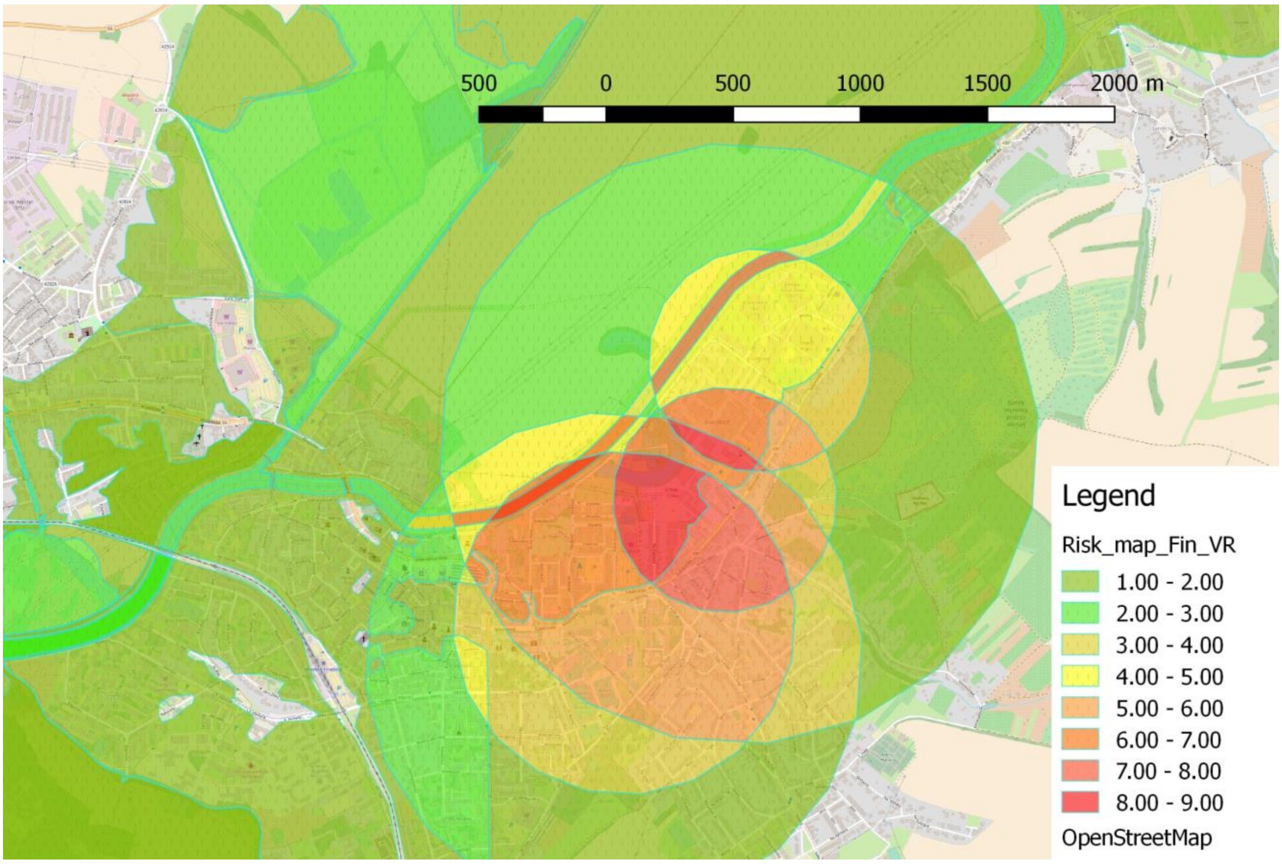

Figure 6: The detail of risk map [10,11,12,12,14].

Assigning the “threat value” attribute to each threat has made it possible to create the resulting risk map. The resulting risk map is presented in Fig. 5 and 6. The map divides the town of UH into individual risk fragments to which the value of the risk is assigned. Based on the risk value, a color corresponding to the given value is then assigned to each fragment. The value of the color indicates a degree of risk of the given fragment. The higher the color value, the higher the risk in the fragment. Fragments with the highest level of risk are red, while medium level is yellow and low level is green. Areas of zero risk (with respect to the included threats) are not color-coded. Their representation is provided only by displaying the assets.

CONCLUSION

Using the GIS tools for risk mapping seems to be fairly promising. The main advantage of using the GIS is a high degree of visualization and a clear presentation of the results. In addition, this method is beneficial with respect to the spatial identification of risk areas. The presented case study describes risk mapping using fragmentation of space. Fragmentation of space allows localization of the most hazardous areas in the territory of a given municipality within the case study in UH, the mapped risks were connected to the crucial threats in the municipal territory (DCS leakage and floods). The most critical part of the case study was its main focus on risks connected to crucial threats. The case study does not address risks/threats with lesser consequences or lesser likelihood of occurrence. Nevertheless, this fact can stimulate further research in this area and support inclusion of additional risks in the resulting risk map. Despite this shortcoming, the case study performed in UH confirms the hypothesis of the suitability of the risk analysis method and at the same time it brings valuable results in the field for the determination of the most hazardous parts of the municipality. The case study highlighted the suitability of adding the threat/risk weighting coefficient, which makes it possible to increase the difference in the value of each threat/risk fragment. This increase in difference allows for the output, which is the resulting risk map, to be more understandable, and it also helps to identify the hazardous areas clearly.

ACKNOWLEDGMENT

This paper is supported by the Internal Grant Agency at Tomas Bata University in Zlín, projects No. IGA/FLKR/2017/003 and No. IGA/FLKR/2017/004.

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