Mapping the Risks by Means of Geographic Information Systems

Jakub Rak, Lucie Jurikova, and David Sevcik

Abstract— *This contribution introduces possibilities in the application of geographic information systems (GIS) for mapping and analysis of risks. The introduction of the article is focused on basic concepts and assumptions that the research proceeds from. The next part is devoted to a demonstration of a specific application, which is in this case the transport of dangerous substances between two cities. In addition, this part also examines the method of risk mapping and the choice of the most suitable route for the dangerous chemical substance using the GIS. The article also deals with the determination of risk zones in the event of accidents. Moreover, it specifies possibilities of employing the GIS in crisis and security applications.*

Keywords—*Information systems, population protection, sheltering, information technologies, Geographic information systems.*

INTRODUCTION

In the Czech Republic the protection of the population by sheltering undergoes extensive modifications. In accordance with a document "Concept of protection of population by the year 2013 until the year 2020" the permanent shelters are being cancelled while improvised shelters are to be relied on in the future. Due to cost savings and a reduced urgency of the issue, less attention is being paid to sheltering. The situation differs slightly in individual territories (regions and municipalities); generally, it is not being dealt with effectively. "The concept of protection of population" assumes the recognition of the increasing hazard (risk) of an extensive military conflict within a sufficient time scale. In a period of approximately 2 to 3 years the eventual construction and rebuilding of premises into improvised, and to a limited extent, into permanent shelters are planned. This basic idea appears to be correct and its objective is in the first place to save substantial financial expenses. However, its execution is complex. This procedure is not interconnected with any methodology, systematic instructions or methods stating how and to what extent sheltering should be provided. To what extent the issue will be handled is the responsibility of the municipalities. Nevertheless, the municipalities do not deal with the problems in order to save on financial resources. For this reason, the situation in individual regions of the Czech Republic differs considerably. Issuing of an obligatory methodology or instructions on the matter of sheltering would be a comprehensive solution. No matter what form the methodology takes, the evaluation of risks, hazards and vulnerability (in the field of sheltering and emergency quarters), and their mapping in the territory of the given region, municipality or other subject, should be a part of it. Specifically in this field the use of geographic information systems (GIS) appears to be quite appropriate. And thus, this article is focused on the possibility of employing the GIS for mapping risks for the needs of population sheltering [7].

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PROBLEM FORMULATION

As indicated in the introduction, the absence of a common methodology or other regulations for sheltering represents a major issue. One potential solution is to create a standard tool for designing and planning of sheltering in the municipality. In order to make such a tool operational and to a high quality, the mapping and the analysis of the risks supplemented with their evaluation should be a part of it. There exists a whole range of ways and methods for the analysis and evaluation of risks. A quite promising solution appears the employment of spatial analyses implemented by means of the GIS. Above all, the problem related to using the GIS in risks analysis for population sheltering lies within the process of the execution of spatial analysis. Another issue is data selection and its acquisition and the method of evaluation of the attributes.

A. Risk, hazard and vulnerability - definitions of terms

For the need of risk mapping it is important to define the basic concepts and their mutual relationships. In the mapping of risk one encounters the basic concept of risk as such and with it closely connected concepts of hazard and vulnerability. Their mutual relation is expressed by the equation no. 1. As is apparent from the equation, risk (R) is a function of hazard (H) and vulnerability (V) [2].

$$Risk = R(H(E_h), V(E_v)) \quad (1)$$

Where, hazard is a function H of the hazard elements Eh, vulnerability is a function V of the vulnerability elements Ev, and risk is a function R of the results of the hazard and vulnerability functions.

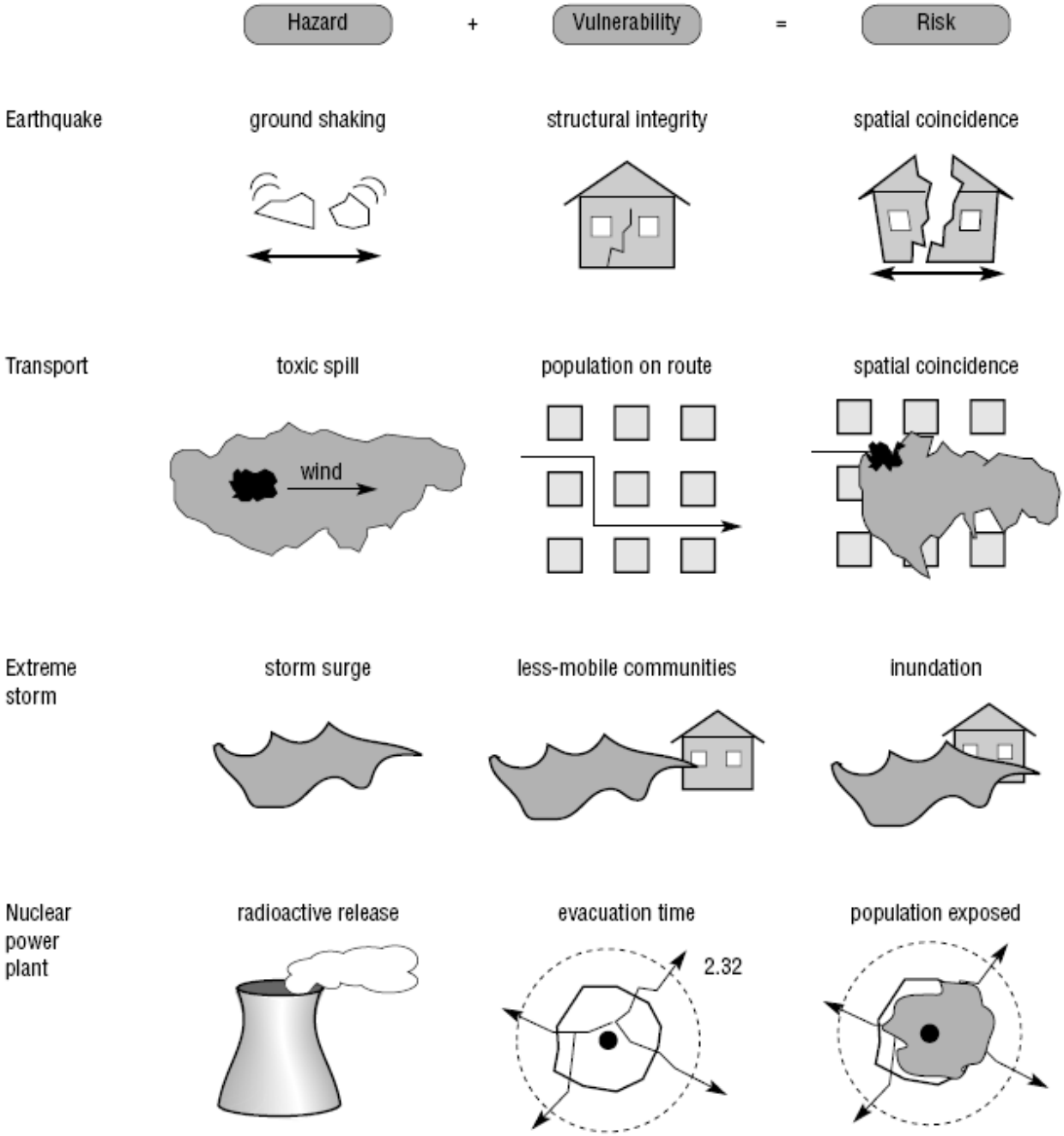

Fig.1. The relationship between risk, vulnerability and hazard. [2]

The relation among these functions can be seen in Fig. 1. As Fig. 1 indicates, hazard is the given danger that poses a threat for the protected values. In this case these are earthquake, the spread of dangerous substances, extreme windstorms and an accident in a nuclear power plant [3].

Based on the equation and the mutual expression of the relation of hazard and vulnerability the key areas to be handled become apparent. In order to create a map of risks it is necessary to create a map of hazards and vulnerability first.

Areas of the GIS application to mapping hazard, vulnerability and risks

Nowadays, there exist many analytical methods that allow relatively comprehensive and detailed mapping and evaluation of risk. However, they have one crucial disadvantage and that is that with increasing comprehensiveness and extensiveness of the analysis the amount of the processed and presented data also increases. Consequently, this leads to a more complicated evaluation of such an analysis. It is necessary for the evaluation to be processed by an experienced person who devotes the required time to it. In most cases, the field of sheltering is managed by the staff of the municipalities and such requirements are unrealistic. To a considerable extent it is possible to increase transparency and to reduce the time needed for the evaluation of the analysis by using graphs and charts. However, there exists another problem with "carrying" spatial information, which is solved by a legend with an address (or eventually coordinates).

From the perspective of municipalities it is necessary to be able to easily analyse the risks within a relatively short time or where applicable use data distributed by superior authorities. Therefore, the fundamental problem is the presentation of results (data) of the analysis in such a form that enables quick and easy evaluation. This can be achieved by means of maps, namely by data presentation in map form. Thus, the use of maps for showing various types of risks and their extent seems to be an appropriate solution. In a single map it is possible to enter information on the extent (magnitude of risk, hazard and vulnerability) and also spatial data (location, extent of territory, etc.).

PROBLEM SOLUTION

The GIS enables data to be presented in spatial form – by means of the maps with spatial information and their attributes (coordinates, altitude, etc.).

Spatial analyses are sets of techniques for analysis and modelling of localized objects where results depend on the arrangement of these objects and their properties. Spatial analyses represent sets of analytical methods that require the attribute data of the studied objects, as well as their locations to be obtained.

Spatial data analyses are associated with the study of the spatial data arrangement. Specifically, they deal with a search for new relations between arrangement and objects' attributes or features within the studied area and with the modelling of these relationships in order to achieve a better understanding and predicting of progression in the area [6].

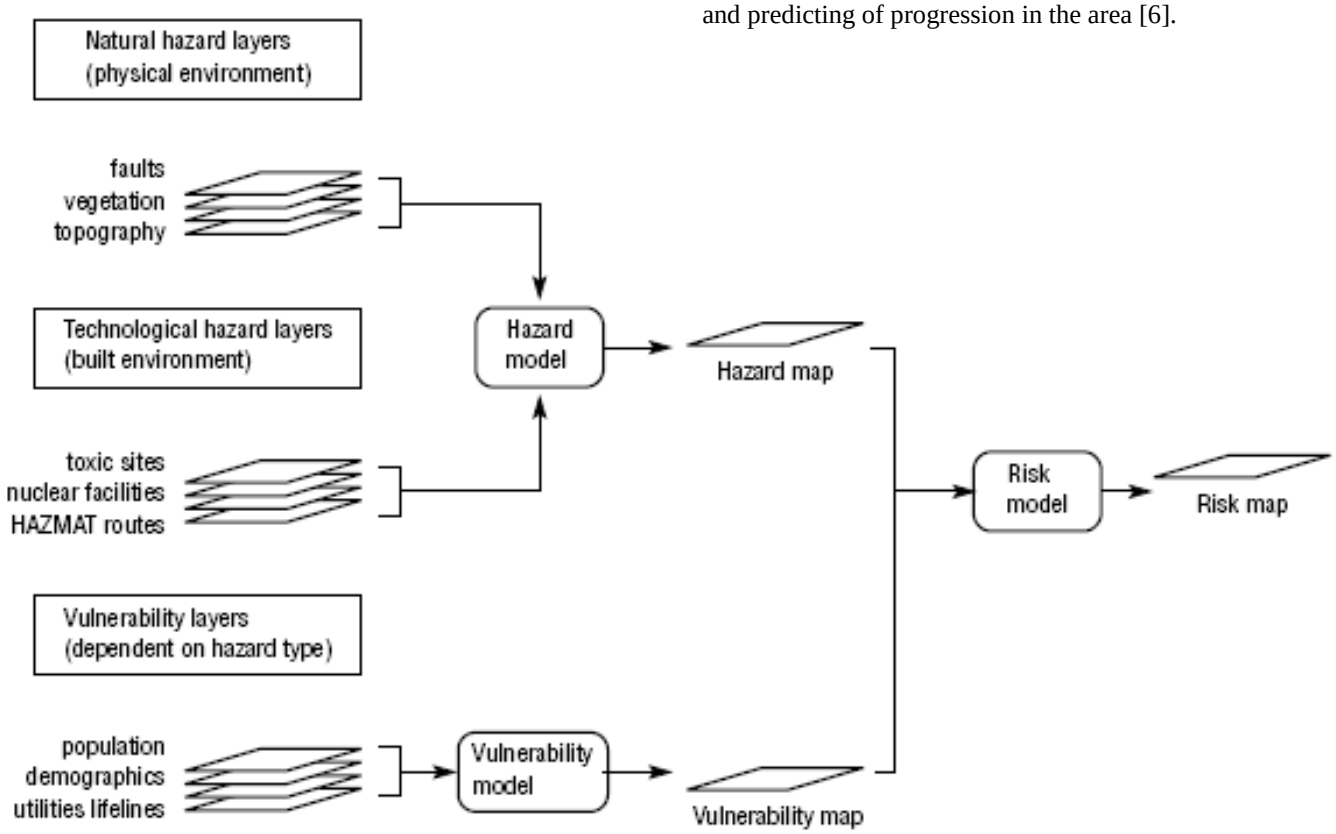

Fig.2. The risk mapping. [2]

The analyses of the spatial data can be divided into several categories. Primarily, these are [6]:

a) Used procedures of applied techniques

- Spatial statistics;
- Map analysis – in the sense of map algebra;
- Overlay operations;
- Methods of mathematical modelling;
- Interpolation methods;
- Location and allocation methods;
- Network analyses;
- Other analyses of the area and their connections.

b) Method of data processing

- Visualization methods: they focus on visualization of spatial data without modification of graphical elements of data;
- Research methods: do not show the original data but use spatially modified data;
- Methods of modelling: their objective is to create an appropriate model and to verify its appropriateness for the intended purpose.

Data in such form is easy to evaluate and results can be presented. There is no need to compare values in the tables or accomplish other similar error-prone and time demanding processes. Such maps are called maps of risk, hazard and vulnerability [2].

The process of creating the map is depicted in Fig. 2. The key issues are data and mathematical models. Mathematical models represent a relatively complex area. These are mathematical calculations which include classical analyses.

From the perspective of the GIS and its usage in the process of population sheltering data plays a more significant role. The problem does not reside in defining the form or processing of data but mainly in obtaining it. Widely available spatial data bears a lot of useful information; however, data essential for planning population sheltering is usually unavailable or does not exist in the required format. For these reasons, it is in most cases necessary to modify the required data or convert it to the desired format prior to the initiation of creating maps of risks. On the modification and processing of data in the spatial format, together with the addition of necessary attributes, it is possible to continue in creating the map of risk.

As can be seen in Fig. 2 creating of the risk map consists of several basic steps. These steps are:

- Acquiring – data creation and preparation;
- Processing of data into individual maps (of hazard and vulnerability);
- Interconnection of maps of hazard and vulnerability – creation of the map of risks.

B. The example of creating the risk map from the perspective of population sheltering

The following section contains an example of creating hazard and vulnerability maps and their mutual interconnection in the risk map by means of the GIS. Compared to previous manual methods of risk mapping software processing is significantly more effective and puts less demand on the time and effort of the staff of the responsible authorities. Nevertheless, the inability to use the GIS and insufficient digital literacy of individual members of the staff cause problems. However, these problems disappear over time, depending on the increasing skills of the staff.

The process of creating the risk map consists of the following:

a) Problem definition and initial assumptions

The example shows the transport of dangerous substances from city A to city B. The transport is performed by road traffic in tankers (see Fig. 3 and 4). Any accident can lead to contamination by dangerous substance of a radius of 5 km with severe effects on the lives and health of the population, 10 km with moderate and slight effects and up to 20 km with effects on the environment. Within the framework of preparation for such a situation it is necessary to provide evacuation, emergency quarters and handling of potential hazard to the environment in the risk area. Tasks being dealt with by means of the GIS are:

- Finding the best route (based on the vulnerability map);
- Delimitation of hazard zones (based on the hazard map);
- Delimitation of vulnerability zones (based on the vulnerability map).

b) Selection of the optimal route

- Fig. 3 and 4 depicts two possible routes in which dangerous substance can be transported. Based on the comparison of the population number in the vicinity of the routes, the first route appears to be more suitable (see the figure above).

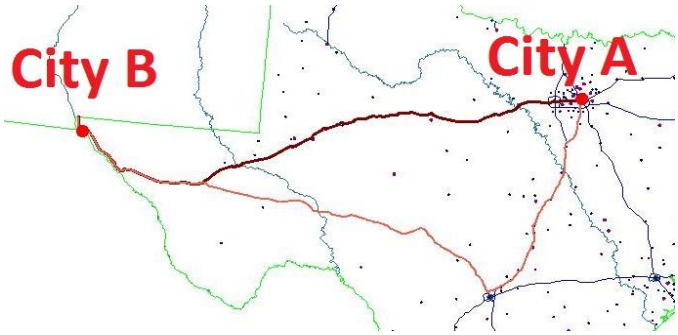

Fig.3. Cities A and B and two possible routes

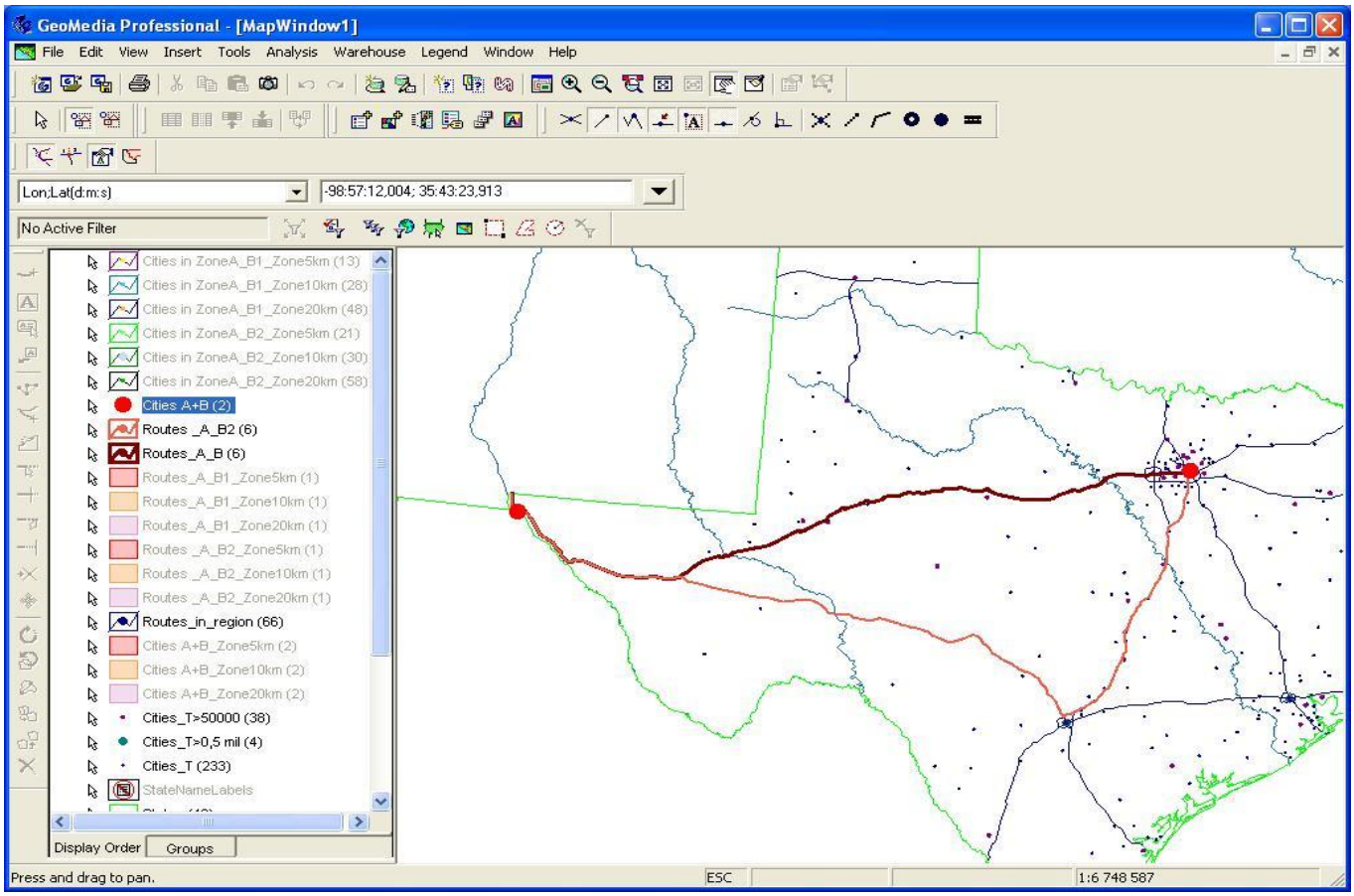

Fig.4. Cities A and B and two possible routes

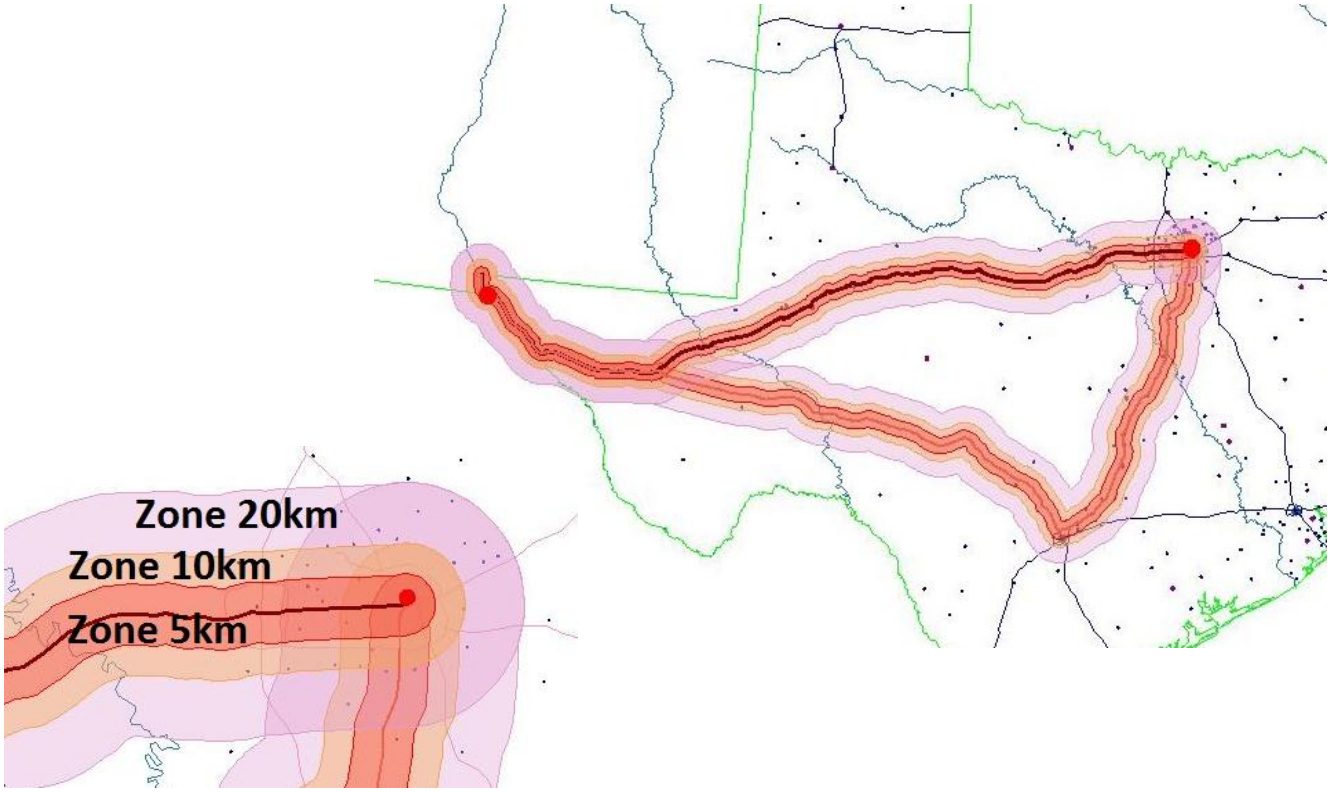

Fig.5. Hazard map

c) Creating of the hazard map

The map of hazard depicts a territory which can be affected in case of the accident. Hazards are divided into several zones (categories) in dependence on the amount of potential damages and losses in the territory, the lives and health of population. Hazard maps and their details are evident in the Fig. 5.

d) Creating of the vulnerability map

The vulnerability map represents protected values located in the territory directly affected by hazard. These values are, above all, the lives and health of population, their property and environment. In this case these are towns and rivers put at risk by dangerous substance transportation. Depending on the distance from the transport route and possible effect they are colour-coded and divided into 3 groups according to the size. The division into groups corresponds to 3 zones used in the hazard map. The vulnerability map is shown in the Fig. 6.

e) Interconnection of maps of hazard and vulnerability – creating of the map of risk

After the creation of maps of hazard and vulnerability, the risk map was created by comparing (interconnecting) those two maps. This map provides information on the geographic location and level of risk. The risk level is represented by a different colour range, which enables quick and easy orientation in the map as well as its interpretation. If needed, the map can be modified in the GIS or only certain layers can be displayed. Owing to this variability the risk map can have a wide range of applications. The final risk map is in Fig. 7.

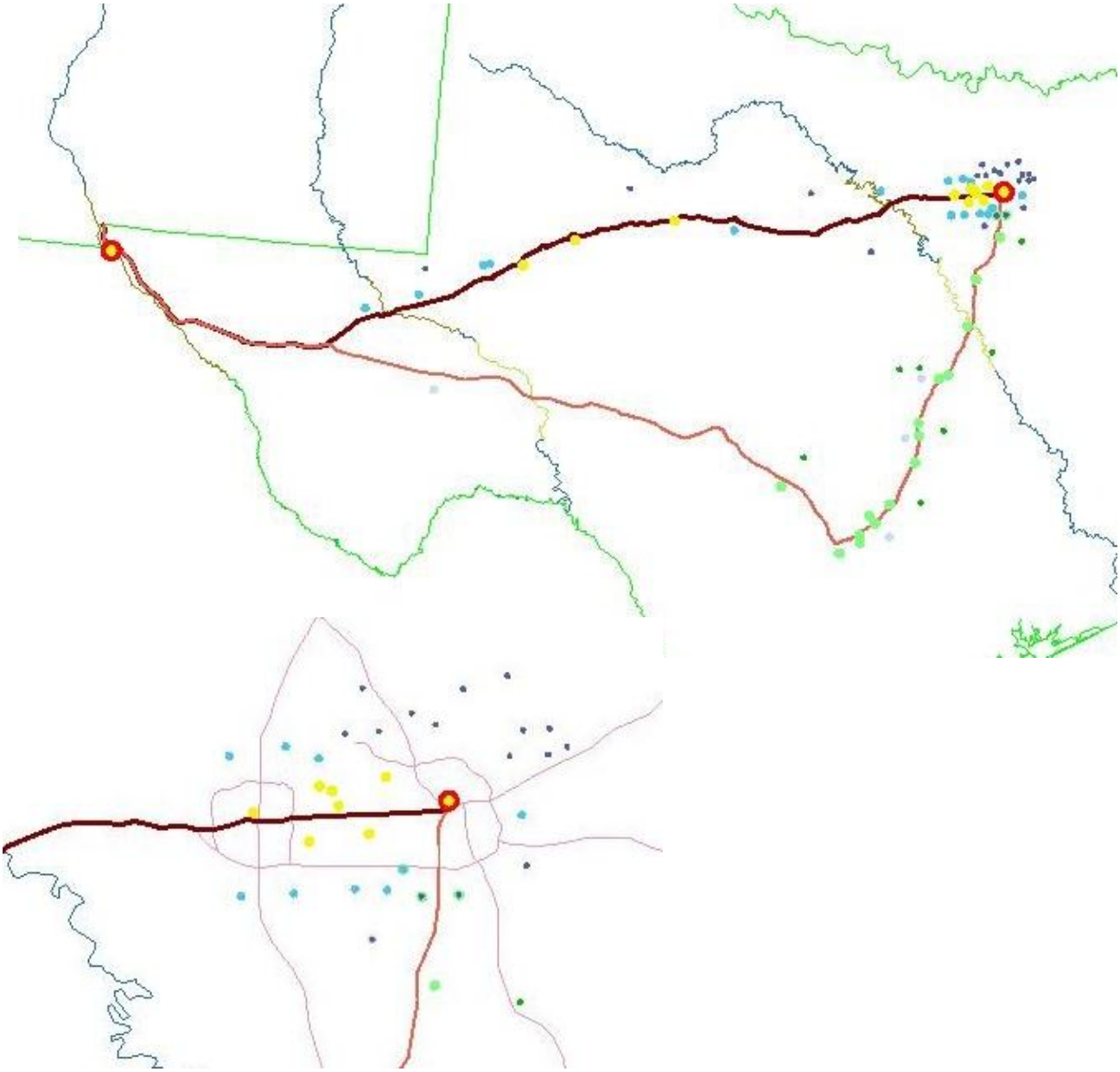

Fig.6. Vulnerability map

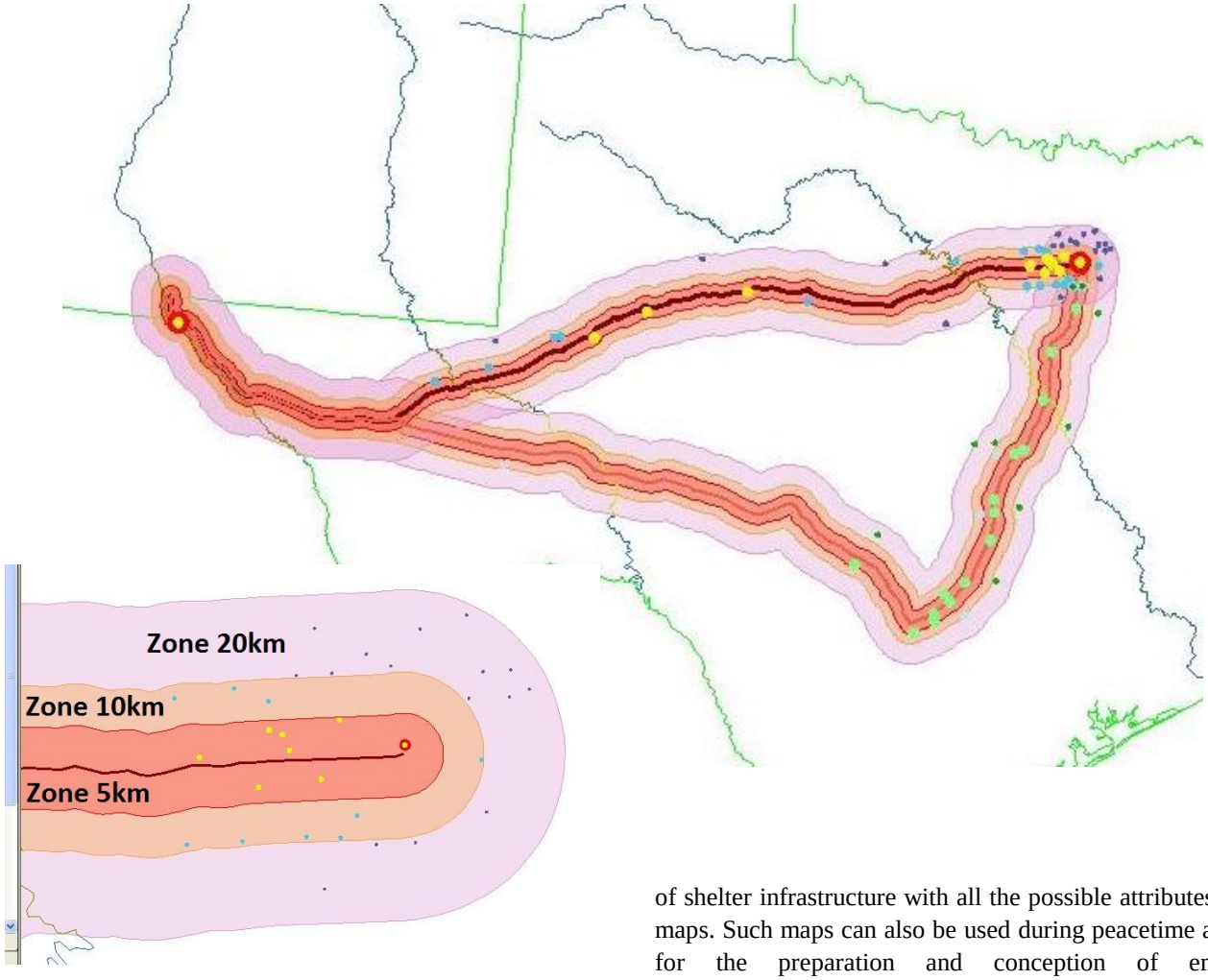

Fig.7. Risk map

Risk maps should be presented in sufficient size, colour format and with a legend in such a way as to show fine details.

Pursuant to the skills and experience of the staff with the GIS software it is subsequently possible to work with the generated maps. This is, above all, an interconnection with other data and the creation of further analyses. Not only is this his activity dependent on users' capabilities but it also relies on the quality and quantity of data available (map bases and other attributed data – numbers of population, house numbers, or owners of buildings). It should be emphasized that this data forms the basis of every GIS and based on its quality and extensiveness the corresponding outputs can be generated.

C. Possibilities of using maps of hazard, vulnerability and risk in the process of population sheltering

The maps of hazard, risk and vulnerability are beneficial in the field of preparation of population sheltering; more precisely, in the process of selecting suitable shelters or areas for shelters. They seem to be appropriate particularly during the preparatory actions when it is possible to enter the location of shelter infrastructure with all the possible attributes into the maps. Such maps can also be used during peacetime and serve for the preparation and conception of emergency accommodation. Naturally, they are used for their primary purpose, which is putting shelters into operation, evacuation and managing the process of sheltering during the state of war or other state of crisis.

The generated analyses (data) can, consequently, also be used for other types of extraordinary or emergency events. For systematization of work it is then possible to create a comprehensive database for the majority of extraordinary events and states of crisis which are likely to emerge within the territory of municipality, region or state. The creation of such a database would bring considerable savings in time as well as systematization in the field of crisis management, population protection and similar activities. In addition, this could also increase the need to understand the GIS and information technologies in general. However, the development of IT also brings indisputable risks. One of the most serious risks is the loss of credibility of data and its possible misuse, which could lead to security hazards. It should be taken into account that some data and predominantly the results of analyses may be subject to certain degrees of confidentiality (in the Czech Republic regulated by Acts No. 412/2005 and No. 240/2000). The basic requirements for the information (data) in the field of population protection and crisis management in general are similar to other information systems. These are as follows:

- Accessibility
- Confidentiality
- Integrity
- Authenticity

The features listed are the basic security requirements for information (data). Their detailed description, including all connections, is beyond the scope of this article. The features are mentioned specifically to give a comprehensive understanding of the issue.

CONCLUSION

Mapping of hazard, vulnerability and from them resulting risks is an essential element in the process of population sheltering. Particularly nowadays, when there is a reduction of funds spent on population sheltering, it is necessary to be concerned with a less costly solution for the preparation of sheltering. As stated in the "Concept of protection of population" the current solution of population sheltering is primarily based on the preparation, while the actual construction and building modifications are to be accomplished on increasing hazard. The use of the GIS in creating the maps of hazard, risk and vulnerability simplifies the process of hazard mapping and thus reduces the costs. Risk maps in the form of spatial data can also be used in the stages of sheltering following the mapping of risks. Owing to this and thanks to easy data transferability the GIS is an ideal tool.

Therefore, the creation of maps of risk, vulnerability and hazard is only the first step in a process of sheltering planning. It is evident from the example above that the GIS can be used specifically in the planning of evacuation routes, zones and areas of sheltering. However, for the full use of the GIS the data in a certain format is needed, which is a major problem that prevents the wider use of the GIS within the field of sheltering. With increasing use of software the increasing amount of spatial and other electronic data can be expected; this data could be then used for work with the GIS.

ACKNOWLEDGEMENTS

This paper is supported by the Internal Grant Agency at TBU in Zlin, project No. IGA/FAI/2012/028, IGA/FAI/2012/054 and by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089.

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