The Use of Geomatics Tools in Critical Infrastructure Management

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Abstract

The purpose of the article is to characterize crisis management, including the main stages of the activities of anti-crisis headquarters. The paper presents extensive examples of critical infrastructure and develops sample maps in QGIS software, which can be important tools in conducting the activities of crisis management services. It presents A Free and OpenSource Geographic Information System QGIS software for identifying selected critical infrastructure objects based on available GIS Open data from the Malaysian region and Poland. The analysis presents selected geoprocessing tools for generating areas with a set distance from identified critical infrastructure objects called buffers. Buffer layers are areas, visible on the generated maps, that can be used as a tool to visualize potential actions for emergency management services. Identifying these buffer zones makes it possible to build strategies for implementing adequate prevention or rescue actions during an emergency. Risk classification in specific buffer zones is presented, which can be used to optimize the actions taken by crisis management services. A wide range of functionality of geographic spatial information systems is demonstrated, which increases the efficiency of operations and optimization of decision-making in crisis management. The publication can provide a valuable example of the use of available information systems in crisis management.

Keywords: *geomatics, crisis management, critical infrastructure*

1. INTRODUCTION

The dynamic development of civilization brings with it many changes and megatrends, which at the same time have a positive impact on the quality of life of society, but on the other hand, bring dynamic changes for ecology on a global scale[1,2].

Progressive digitization and dynamic development of new technologies is associated with a new era in the so-called Industry 4.0 and 5.0., however, it is still employees in the organization that are the main foundations for further development [3–6].

Every human activity is associated with risk, therefore there is a great need to reduce and prevent this risk, so as to effectively limit potential material and moral losses. Therefore, the subject of crisis management and the role of IT systems in the effectiveness of these activities has been addressed in this article.

The dynamic development of information systems is widely used in the practice of emergency management. Geographic information systems are tools that allow the collection, management and analysis of data on the spatial location of objects and phenomena, which involves working with layers containing the data under study and allowing their visualization through maps and 3D scenes.

In emergency management, GIS can, among other things, provide secure access to up-to-date information necessary for accurate decision-making[7, 8]. GIS are used in practice to create, among other things, various types of hazard maps, which depict the geographic area covered by a hazard, taking into account various event scenarios; risk maps, also known as a risk matrix or risk model, which provide a description of the effects of a hazard on people, the environment, property and infrastructure.

Tasks of GIS in emergency management GIS provides considerable opportunities in managing, predicting and evaluating facts in emergency situations; they are useful for decision-making in all management functions (planning, organizing, leading, controlling). The application of GIS in emergency management can consist of the following tasks:

- managing information about actual and/or potential threats, identifying and assessing sources of threats, quick access to collected data, combining information layers,
- inventorying objects and events, integrating data obtained from various sources,
- performing in-depth spatial analyses, modeling and simulations, creating thematic maps,
- hazard maps, e.g. forecasting the impact zone of clouds of released toxic substances, flood hazard maps,
- analysis of land use, assessment of its exposure to potential hazards, and resources of services, inspections and guards that can take action,
- emergency risk analysis, modeling of emergency development, identification of disaster-prone areas,
- planning of rescue operations, determination of points of intersection of roads with the danger zone to determine the location of law enforcement patrols isolating

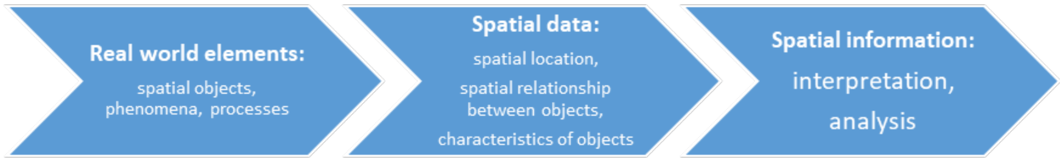

Fig. 1. The process of generating spatial information. Source: own elaboration

Rys. 1. Proces generowania informacji przestrzennej. Źródło: opracowanie własne

Fig. 2. Stages of GIS project. Source: own elaboration

Rys. 2. Etapy projektu GIS. Źródło: opracowanie własne

the danger zone, coordination of the activities of various services during rescue operations,

- identification of address points for which evacuation should be carried out, designation of places for evacuation of the population in case of emergency,
- estimating the number of people in the threatened area,
- studying the distribution of fires and other incidents,
- -analysis of floodplains during floods (flood risk maps),
- monitoring changes and determining the amount of damage,
- publishing maps and information on the Internet, and others. These tasks form the basis of the activities carried out by the services responsible for ensuring security. [9].

In this article, we will refer to the term critical infrastructure defined as real and cyber systems including: facilities, equipment or installations that are necessary for the minimum functioning of the economy and the state. Examples of critical infrastructure on a national and regional scale may include such systems as energy, water, food, energy resources and fuels supply, communications systems, ICT networks, financial systems, rescue and health systems, transportation systems, etc. Critical infrastructure plays a key role in the functioning of any state and is therefore subject to special oversight. As a result of events caused by, among other things, forces of nature or as a consequence of human actions, critical infrastructure may be destroyed, damaged, and its operation may be disrupted, so that the lives and property of citizens may be endangered. The cause of damage to critical infrastructure can be a disaster of various kinds, which is also interchangeably referred to as a crisis that causes destabilization and a sense of insecurity and can affect a community. Hence, the protection of critical infrastructure is one of the priorities facing government institutions of countries. The essence of the tasks related to critical infrastructure boils down not only to ensuring its protection from threats, but also to ensuring that any damage and disruptions to its functioning can be dealt with in the optimal time and do not cause additional losses to citizens and the economy. Hence, crisis management services are established in countries, ready to respond in case of emergency in areas affected by disaster or other random events. Emergency management services carry out activities in four main phases. In the first phase, the services always carry out activities aimed primarily at preventing undesirable events, and these activities are primarily related to actions to eliminate, reduce or limit the effects of possible hazards. The second phase concerns preparatory activities related to advance planning of undertakings in the event of a threat or disaster, and securing resources of forces and means to carry out rescue operations. The third phase of activities is response, the purpose of which is to halt the development of the emergency situation, provide direct assistance to the injured and limit losses and damage. The fourth stage of emergency management services is reconstruction, which is the type of action in the event of a disaster, which concerns material and moral undertakings aimed at restoring the previous state of affairs, before the emergency.

The purpose of the article is to characterize crisis management, including the main stages of the activities of anti-crisis headquarters. The paper presents extensive examples of critical infrastructure and develops sample maps in QGIS software, which can be important tools in conducting the activities of crisis management services. This paper presents A Free and Open Source Geographic Information System QGIS software for identifying selected critical infrastructure objects based on available GIS Open data from the Malaysian region and Poland. The analysis presents selected geoprocessing tools for generating areas with a set distance from identified critical infrastructure objects called buffers. Buffer layers are areas, visible on the generated maps, that can be used as a tool to visualize potential actions for emergency management services. Identifying these buffer zones makes it possible to build strategies for implementing adequate prevention or rescue actions during an emergency. The publication can provide a valuable example of the use of available information systems in crisis management.

2. THE FUNCTIONALITY OF QGIS SOFTWARE

A significant part of objects, phenomena and processes occurring in reality are spatial in nature, as they are defined by a specific place and time. All data on spatial objects, including phenomena and processes, located or occurring in space are called spatial data. This data, properly analyzed and interpreted, is a source of spatial information. Figure 1 shows the process of extracting from the complex real world selected elements, for example, selected critical infrastructure objects, with specific characteristics, which

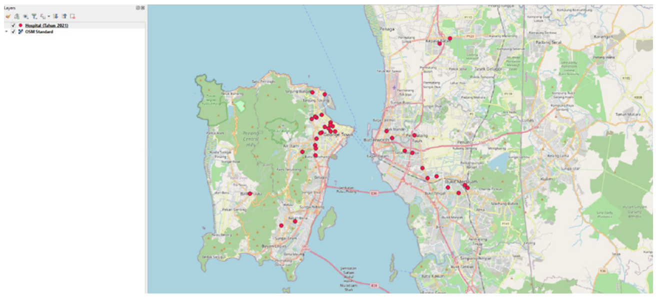

Fig. 3. Identification of critical infrastructure facilities in QGIS region Malaysia
Rys. 3. Identyfikacja obiektów infrastruktury krytycznej w regionie QGIS Malezja

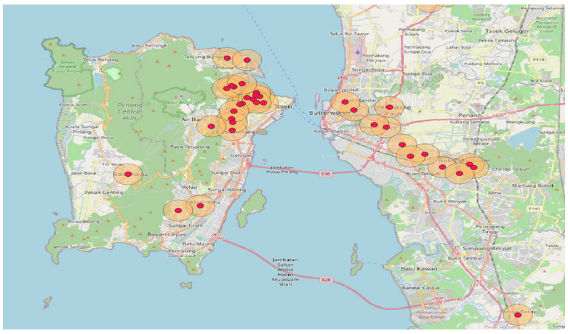

Fig. 4. Determination of buffer zones for surveyed critical infrastructure objects in QGIS Malaysia region
Rys. 4. Wyznaczenie stref buforowych dla badanych obiektów infrastruktury krytycznej w regionie QGIS Malaysia

after appropriate interpretation and analysis provide specific spatial information, otherwise known as geo-information.

GIS is an acronym for Geographic Information System and is usually defined as an organized set of computer hardware, software, spatially (or geographically) referenced data, and people (contractors and users), created to efficiently: storing/collecting, sharing, processing, analyzing, and visualizing spatial (geographic) data.

The development of GIS began less than fifty years ago, when Roger Tomlinson developed a model for collecting spatial data and created the world's first GIS system – the Geographic Information System of Canada. Its creation initiated the rapid development of GIS tools and analytical methods and techniques. In the early days of GIS implementation, they were mainly applied to professional projects for administration, management and planning, and scientific research.

This is because geographic data is understood to be that which is referenced to geographic coordinates, that is, it preserves spatial relationships corresponding to a specific cartographic mapping. Spatial data, on the other hand, can be mapped in any datum that uses rectangular coordinates (x, y), so also geographic reference, hence spatial data is considered to encompass a broader set, including geographic data. GIS data represent the results of measurements or otherwise acquired features that characterize the location, type and characteristics of an object, its size, composition, physical, chemical properties, legal status, etc. Data are represented by numbers, letters, symbols or in any other form suitable for entering into a computer and for further processing and visualization. They can appear in the form of so-called discrete or continuous data, which correspond to the two main types of layers, namely vector and raster data. Spatial information is supplemented by descriptive data, which as such is non-spatial data, but contains characteristics of the previous two types of data and is related to them.

3. METHODOLOGY AND DATA

This article presents the final GIS maps in which buffer zones were applied to vector layers representing critical infrastructure objects. The analysis was based on the four stages of GIS design presented in Figure 2, which are Identifying targets, collecting data, performing analysis, and generating maps with results.

The first stage of the research defined the purpose of the analysis, i.e. Identification of buffer zones for selected critical infrastructure facilities. In the second stage of the research, data for analysis was selected. Currently, there is a rapid development of open access databases for various types of GIS data. In this paper, open access data from the Malaysian territory GEO HUB was used. A set of files necessary for loading into QGIS was downloaded from the database, which contained information on hospital facilities located on Penang Malaysia island. Hospitals are critical infrastructure facilities, as they provide life and health protection for the population from the selected territory. The third stage of the study was analysis. The study uses selected analytical tools available in GIS systems. Typical GIS software systems have built-in analytical modules that are capable of performing all data processing functionalities. They are organized in the form of so-called toolboxes (literally translated as "toolbox") or grouped in the form of sets of so-called plugins or extensions. When a tool is selected, a dialog box appears, where the user defines the parameters necessary to perform the operation. Often a help window is also available, providing an explanation of how the tool works.

The third stage of the research identified zones called buffers, which is among the popular geoprocessing tools. We define buffering as the operation of delimiting zones from selected objects known as buffers. As a result of this operation, a polygon layer is created with areas that are no farther than a given criterion from the indicated objects. Many such polygons can be created, and each polygon can correspond to a different distance, for example.

Tab. 1. Risk matrix. Source: based on [9]

Tab. 1. Macierz ryzyka. Źródło: na podstawie [9]

PROBABILITY	1	HIGH			
	2	MEDIUM			
	3	LOW			
RISK VALUE			A	B	C
			LOW	MEDIUM	HIGH
			CONSEQUENCES		

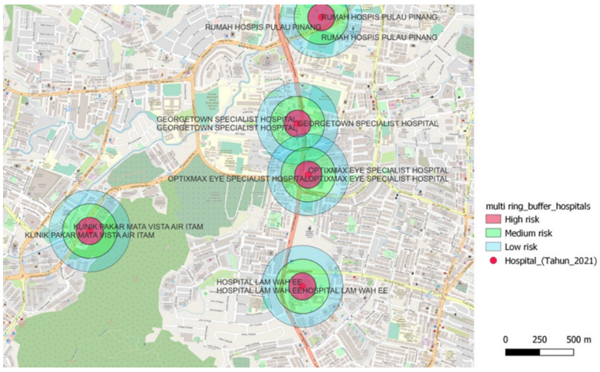

Fig. 5. Risk classification for buffer zones for the studied critical infrastructure facilities in QGIS area Malaysia. Source: own elaboration

Rys. 5. Klasyfikacja ryzyka dla stref buforowych dla badanych obiektów infrastruktury krytycznej w obszarze QGIS Malezja. Źródło: opracowanie własne

What's more, this distance can depend on the value indicated in the given object's attribute. The fourth stage of the research is the generation of the corresponding maps, which are a visualization of the effects of the analyses made.

4. RESULTS

4.1 Case study 1 Malaysia

The first step in analyzing the data in the software is to import the data and display it on a workspace. In the example studied, open-access data in the data geohub portal from Malaysia was used, with data on the location of hospitals on Penang Island, among others, as an example of critical infrastructure. The data was loaded as a vector layer as presented in Figure 3.

The second stage of the analysis was to use a standard geoprocessing tool to determine buffers for identified critical infrastructure facilities. Buffer areas in practice are an excellent tool for visualizing protection zones for selected objects located in the selected area as shown in Figure 4.

In the third stage of the analysis, risk classification was carried out for a selected number of buffer zones of the analyzed critical infrastructure objects. For this purpose, the multiring buffer tool was used in the software, which is presented in Figure 5.

The activities of emergency management services can be defined for the designated areas with a given buffer, and can also be differentiated for individual groups of risk, i.e. for several buffers categorized for the corresponding risk scale.

Risk, according to the Polish standard ISO 31000:2012, means the influence of internal and external factors on the uncertainty of achieving the set goals. In relation to emergencies, risk can be defined as an identified undesirable event that may occur with a certain probability. To quantify risk (the probability of a specific effect occurring at a specific time or in a specific situation) in crisis management, the formula is used [9]:

$$R = P \times S \qquad (1)$$

where:

R – risk,

P – probability of occurrence of a crisis situation,

S – value of potential losses, estimated destruction after the occurrence of a crisis situation.

When assessing probability and impact, the Risk matrices, presented in Table 1, are applicable.

When using 3-point scales to assess the probability and impact of risks, the matrix allows you to identify three types of risk values (Table 1):

- small (blue color),
- medium (green color),
- large (red color).

If risk components are extracted, the values of these components (partial risks, depending on the type of emergency) should be defined, calculated and summed.

Categorization by distance makes it possible to create multiple security zones according to the identified threat level. In the figure, processing tools were used to determine three zones: high risk, medium risk and moderate risk for the analysed critical infrastructure in the Penang Malaysia island area.

As presented in the selected example, GIS software can be widely used to support and organize the work of emergency management services. Its rich tools and functionalities allow efficient visualization of various types of strategic plans and possible actions for selected areas of analysis.

4.2 Case study 2 Poland

As presented in the selected example, GIS software can be commonly used to support and organize the work of crisis management services. Its rich tools and functionalities enable efficient visualization of various types of strategic plans and possible actions for selected areas of analysis. The spatial geoinformation system is commonly used in crisis management. The article presents the area of Poland, the city of Cieszyn, where GIS was used to map flood hazards and landslide hazards, which was presen-

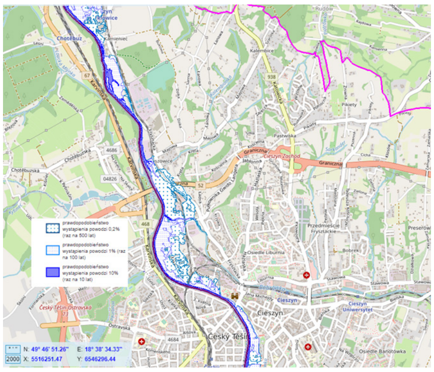

Fig. 6. Flood map according to GIS system. Source: own elaboration based on open data: geoportal of the city of Cieszyn
Rys. 6. Mapa powodziowa wg systemu GIS. Źródło: opracowanie własne na podstawie danych otwartych: geoportal miasta Cieszyna

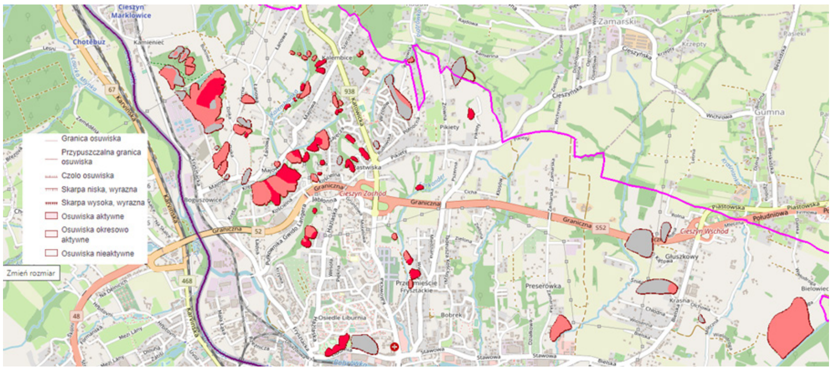

Fig. 7. Landslide map according to GIS system
Rys. 7. Mapa osuwisk wg systemu GIS

ted in the fig 6 and 7. Areas of particular flood risk have been classified into four categories: a) areas where the probability of flooding is average and amounts to once in 100 years, b) areas where the probability of flooding is high and amounts to once in 10 years, c) areas between the shoreline and the levee or natural high bank, in which the route of the flood embankment, as well as islands and sludge areas, were built, d) technical belt.

Areas of particular flood risk are identified through a series of analytical and research works leading to the creation of flood hazard maps and flood risk maps. On their basis, a flood risk management plan is created.

Among the many geological hazards in the city of Cieszyn, landslides occur in a significant number. In total, 82 landslides are registered in the Landslide Protection System of the Polish Geological Institute in the Cieszyn commune. Areas of active landslides cannot be developed. On the map, active landslides or periodically active landslides are marked in red, inactive landslides are marked in grey.

5. CONCLUSION

The purpose of the paper is to present the functionality of QGIS software for identifying critical infrastructure on a map and the use of selected geoprocessing tools for determining buffers, i.e. protective areas for selected critical infrastructure objects.

As demonstrated in the given study, QGIS software enables universal access to spatial information. Dynamic development means that we should expect rapid development of mobile-GIS, i.e. increasing access to GIS databases from mobile devices, using these devices for acquisition, management and automatic updating of spatial databases in near real time. The variety of technical and organizational solutions of GIS indicates the need to implement universally applicable, universal standards and norms in this area. This article demonstrates the application of GIS in security engineering, for example, for the purposes of decision support in public administration, or in authorities responsible for public security or emergency management. Properly selected GIS software on the basis of prepared data can help solve many security engineering problems by supporting the decision-making process. The study identifies potential critical infrastructure objects, locates them on a map, and generates so-called security buffers for these objects to which risk classification has been made. The tools presented can find application in decision-making for specific actions in case of crisis events such as pandemic and many others. Each zone with an appropriately assigned risk type can be associated with a specific range of anti-crisis actions and define specific actions of emergency management services such as access controls or disinfection. QGIS maps provide access to the operational picture and allow for a more efficient process of optimal decision-making.

6. ACKNOWLEDGEMENTS

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Wykorzystanie narzędzi geomatycznych w zarządzaniu infrastrukturą krytyczną

Celem artykułu jest scharakteryzowanie zarządzania kryzysowego, w tym głównych etapów działania sztabów antykryzysowych. W artykule przedstawiono obszerne przykłady infrastruktury krytycznej oraz opracowano przykładowe mapy w oprogramowaniu QGIS, które mogą być ważnymi narzędziami w prowadzeniu działań służb zarządzania kryzysowego. Przedstawiono oprogramowanie QGIS Free i OpenSource Geographic Information System do identyfikacji wybranych obiektów infrastruktury krytycznej na podstawie dostępnych danych GIS Open z regionu Malezji i Polski. W analizie przedstawiono wybrane narzędzia geoprzetwarzania służące do generowania obszarów o ustalonej odległości od zidentyfikowanych obiektów infrastruktury krytycznej zwanych buforami. Warstwy buforowe to obszary widoczne na generowanych mapach, które mogą posłużyć jako narzędzie do wizualizacji potencjalnych działań dla służb zarządzania kryzysowego. Zidentyfikowanie tych stref buforowych umożliwia budowanie strategii wdrażania adekwatnych działań zapobiegawczych lub ratowniczych w sytuacji zagrożenia. Przedstawiono klasyfikację ryzyka w poszczególnych strefach buforowych, która może posłużyć do optymalizacji działań podejmowanych przez służby zarządzania kryzysowego. Zademonstrowano szeroki zakres funkcjonalności systemów informacji przestrzennej geograficznej, który zwiększa efektywność działań i optymalizację podejmowania decyzji w zarządzaniu kryzysowym. Publikacja może stanowić cenny przykład wykorzystania dostępnych systemów informatycznych w zarządzaniu kryzysowym.

Słowa kluczowe: *geomatyka, zarządzanie kryzysowe, infrastruktura krytyczna*