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APPLICATION OF GIS FOR A CLIMATE CHANGE PREPARED DISASTER MANAGEMENT IN CSONGRÁD COUNTY, HUNGARY

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Abstract

The work of disaster management can only properly be supported by data stored in certified databases, since correct decisions can be made on the base of such data. Nowadays these data can be found in databases managed by several organisations, or only a part of the necessary data is available through GIS services. The tasks of disaster management include prevention, i.e. the preparation for potential incidents and the elaboration of related scenarios and plans taking into consideration the altering risk landscape caused by climate change. The development of modelling processes and applications based on GIS databases and the integration of the results in work processes gain ground more and more in this work phase. Geoinformatics is able to provide support for decision-making in two ways: in strategic planning and in the operative task solution. The present study demonstrates a multi-hazard multi-scale GIS tool development in Csongrád County (Hungary) in accordance with the aims of the Sendai Framework. This geoinformatic tool is applicable to support the decision-making not only of the management board but the deployed rescue units in case of an evacuation through the optimized locations of the gathering places.

Keywords: database, modelling, evacuation, information acquisition, decision support, disaster management

INTRODUCTION

Natural hazards are causing significant lives and economic losses. The amount of losses expected to increase globally thanks to the climate change as it was concluded at the findings of the 5th IPCC assessment report and also showed by the results of NatCatSERVICE and Sigma/Swiss RE global natural catastrophe loss databases of the past four decades. Direct and indirect damages are rising mainly because of socio-demographic factors such as population growth, ongoing urbanization and increasing values (IPCC, 2014; Hoeppe, 2016; Newman et al., 2017; Zuccaro and Leone, 2018). New risks were generated, because the exposure of persons and assets has increased faster than vulnerability decreased, thus indicating the need to further strengthen disaster preparedness for response (UNISDR, 2015). The number of NatCatSERVICE registered natural catastrophes were growing predominantly due to the weather-related events like storms and floods, but no relevant increase in geophysical events (e.g. earthquakes, tsunamis, and volcanic eruptions) was evident. This provides some justification to assume that climate change in particular, plays a relevant role in the ascending tendency of losses (Hoeppe, 2016).

The Sendai Framework was endorsed by the United Nations General Assembly in 2015. The framework solidifies a paradigm shift from managing disasters to managing current and future risks. It also foster resilience with an enhanced and leveraged disaster preparedness. One of the guiding principles indicate clearly that member States have the primary responsibility to prevent new and reduce existing disaster risk. Furthermore it promotes collaboration across global and regional mechanisms (e.g. climate change adaptation and sustainable development) and institutions for the implementation and coherence of instruments and tools relevant to disaster risk reduction, Sustainable Development Goals, especially goal 13 to “take urgent action to combat climate change and its impacts” including its specific target „to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries” cannot be reached without taking into consideration the impacts of natural hazards in a changing climate (UN CCS, 2017). Clear connections were already established between the three global agendas including the Paris Agreement (Fig. 1). Synergies between climate change adaptation and disaster risk reduction are also emphasized in all the main strategies and agreements at EU and regional level e.g. EU Climate Change Adaptation Strategy, the EU Cohesion policy and within the four EU macro-regional strategies including EU Strategy for the Danube Region having a priority area (PA5 - environmental risks) dedicated to both topics. Beyond the EU Civil Protection Mechanism several examples of effective transboundary collaboration exist to increase preparedness, for example, along the Upper-Rhine River the firefighting services in Strasbourg and Kehl train together and regularly exchange experiences. Here countries are operating a joint River Risk Control Training Center to train specialists from both sides of the border.

Furthermore an illustrated French-German dictionary of emergency response vocabulary has been developed. Above all the common deployment and joint cross-border management team of the 'Europa 1' firefighting vessel demonstrate the advantages of the enhanced preparedness on transboundary level (Abad et al., 2018).

For the better understanding of disaster risk, priority 1 of the Sendai Framework promotes access to and support for innovation and technology, together with the long-term, multi-hazard and solution-driven research and development in the field of disaster risk management. In addition, priority 4 urges to periodically review preparedness and contingency plans and strengthen technical and logistical capacities to ensure better response in emergencies. The framework also highlights the need towards regular exercises, including evacuation drills, training and the establishment of area-based support systems, with a view to ensure rapid and effective response to disasters and related displacement, including access to safe shelter, essential relief supplies, as appropriate to local needs (UNISDR, 2015).The support services of prevention, preparation, planning, intervention and hazard defence – i.e. the most important activities related to disaster management – can be advanced considerably by means of a GIS system. This fact has been recognised at national and local levels as well (László et al., 2014; Sik et al., 2014; Szatmári et al., 2014). Providing relevant information to the public is an important part of prevention; during preparation, measures are to be taken to protect areas exposed to critical hazards; in the case of an incidental disaster, the organisation of rescue is the most important task; and plans are to be prepared for the period of temporary operation and for the restoration of the original state.

In the phases of prevention, preparation and planning, GIS solutions that can be used in practice should be provided for the persons who take part in the management of emergency situations. Based on these solutions, the decision-makers will be able to make decisions on the rescue of human life and the protection of property, as well as on other priorities in disaster situations (Mezey, 2007; Perge, 2015).

The tasks of disaster management can be executed in practice by the use of databases of adequate quality and the applications based on them. Recognising this necessity, the Csongrád County Directorate for Disaster Management (Csongrád CDDM) started to plan GIS tools, methods and applications, and to implement their practical use.

The modelling principles developed by the Csongrád CDDM help the prevention work as well as the operative management when required. The application of the modelling processes is typical for a restricted circle of professionals, but their results can be used by the whole organisation via a web-based GIS platform. The purpose of the development of this GIS application is to manage the situations that may evolve during potential disasters and emergency situations, and to support the coordination of rescue and restoration.

The new GIS system/application can be used for the management of floods, industrial accidents and wide-ranging natural disasters that require prolonged defence.

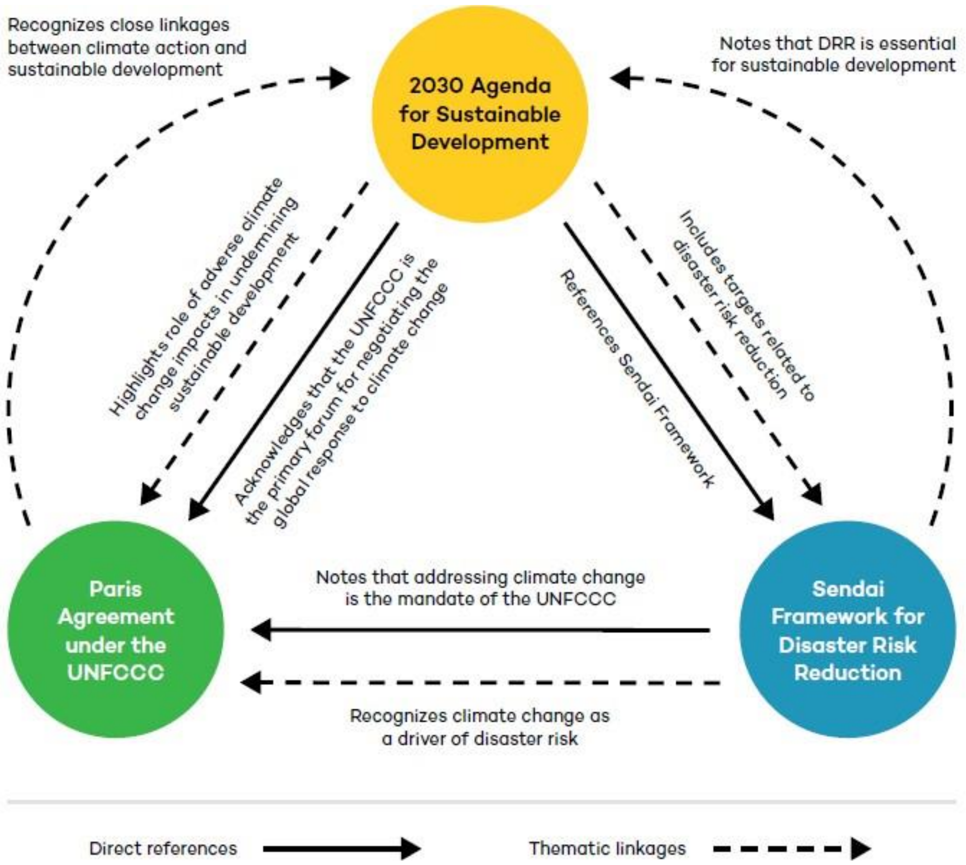

Fig. 1 Interlinkages among the global agendas (Dazé et al., 2018)

Several studies and papers have been published in connection with emergency evacuation assisting decision support systems and modelling of vulnerability (Cova and Church, 1997; Newman et al., 2017). In Northern Hungary, flash floods cause serious difficulties, and therefore the Floodlog model was developed for this environment (Ladányi and Reko, 2014).

The purpose of Csongrád CDDM was to develop and implement a GIS system in which it would be possible to make projections and to retrieve data promptly in the case of sudden incidents (first of all information about the elements – population, objects etc. – exposed to hazards).

STUDY AREA

The models and functions used in the presented GIS system were developed specifically for Csongrád County (flood areas, hydrography), in particular for the city of Szeged. Csongrád County is located in the southern border region of Hungary, and Szeged is the seat of the county. Tisza, the second largest river of Hungary, flows through the city, and has already put Szeged to great hazard several times (1879, 1967 and 2006.). According to most recent official data, the population of Szeged is around 161,000, and the administrative area of the city is 281 km^2. Due to its size, it is an ideal choice for the modelling of evacuation. It is a place with wide experience in floods, where the result of the modelling can play an important role in practice as well. Any time soon, this evacuation model can be used for other similar places that may be exposed to the hazard of floods.

DATA AND METHODOLOGY

The lack of data and information available to actors is the another challenge associated with pursuing integrated approaches to adaptation, sustainable development and disaster risk reduction (UN CCS, 2017). In the course of developing the GIS database that serves as a basis for the presented GIS system, it had to be taken into consideration that some of the data was maintained by other organisations and other data was based on own data collection.. One of the most important data sets consists of the results – derived data, for example: results of special analysis or query or select by location – of modelling and GIS operations.

Csongrád CDDM can use the databases of partner organisations either through an internet connection (public internet connection or Virtual Personal Network – through a protected network connection) or with regular updating. Most of these data consists of the data maintained by the General Directorate of Water Management, and we have been able to use these data (e.g. information about flood areas in Web Map Service).

In the case of evacuation, the most important thing is to know how many people – and in how much time – can reach the designated assembly points from a given area after they have been properly alerted. Investigations should also take into consideration the capacity and geometry of the transportation network, the current weather conditions and time of day (Cova and Church, 1997). The disaster related decision-making of individuals and societies is influenced furthermore by their attitudes during evacuation procedures. This was well illustrated in case of the Xangsane typhoon event of Vietnam where although the local population was well aware of the risks, the elderly did not want to leave their homes as it was unacceptable to die in another place (Spiekermann et al., 2015). According to the experiences, this image can be modified considerably by the fact that some of the inhabitants will always move from the endangered area on their own. The ratio of these people can be different in the various city districts, depending on the social groups that live in the given location (the basic requirement of "self-evacuation" is having a motor vehicle). According to practical experiences the ratio of "self-evacuating" people is around 70%. Evacuation compliance rates in hazardous material accidents, however, will likely be high, probably as high as 98% (Sorensen and Mileti, 1988).

During the evacuation process, special attention must be paid to older people, people with impaired mobility and other people needing attendance, which can significantly influence the evacuation time (Sorensen et al., 2002). Making accurate plans are made difficult by the fact that the storage of such data may affect personal rights, though the knowledge of them is indispensable for accurate planning, since these people must be brought along separately – so their addresses and numbers are basic input data for route planning. Now the disaster management authority is in possession of the residential addresses of people older than 70, and manages these data as a special output dataset indicated on the map as well. This result is presented in the web based GIS platform (in a browser, recommended Firefox, Chrome). The geoprocessing results are presented automatically and could be download also in excel format.

In the modelling phase, the worst case scenario should be applied, i.e. when all evacuees start to move on foot to the designated assembly point. So we have specially considered pedestrian traffic with a speed of 3 km/h (due to the movement of packages, children and family groups).

Several GIS analyses were run for planning the evacuation at the level of the city. The concept was based on the assembly points defined in legal regulations. Than three methods were used for GIS analyses (1) generation of Thiessen polygons (ESRI Thiessen), (2) allocation (use the allocation analyst of the assembly points ESRI Allocation) and (3) access time polygons (Service Area tool – ESRI Service Area) on the assumption of pedestrian traffic. In the Thiessen polygon method, the result was not that much applicable, because the border of the result polygon can't paste to system of the settlements. The allocation analyst showed better results but the result was not polygon, only it showed, that the addresses are which assembly point belong to.

The final model was made in ArcGIS model builder for the planning of the scenarios (Fig. 2). The reason for assuming pedestrian traffic was that in a crisis situation most people leave the danger zone without observing the traffic rules, and during the evacuation, usually the people who do not possess any motor vehicle to leave their home appear at the assembly points.

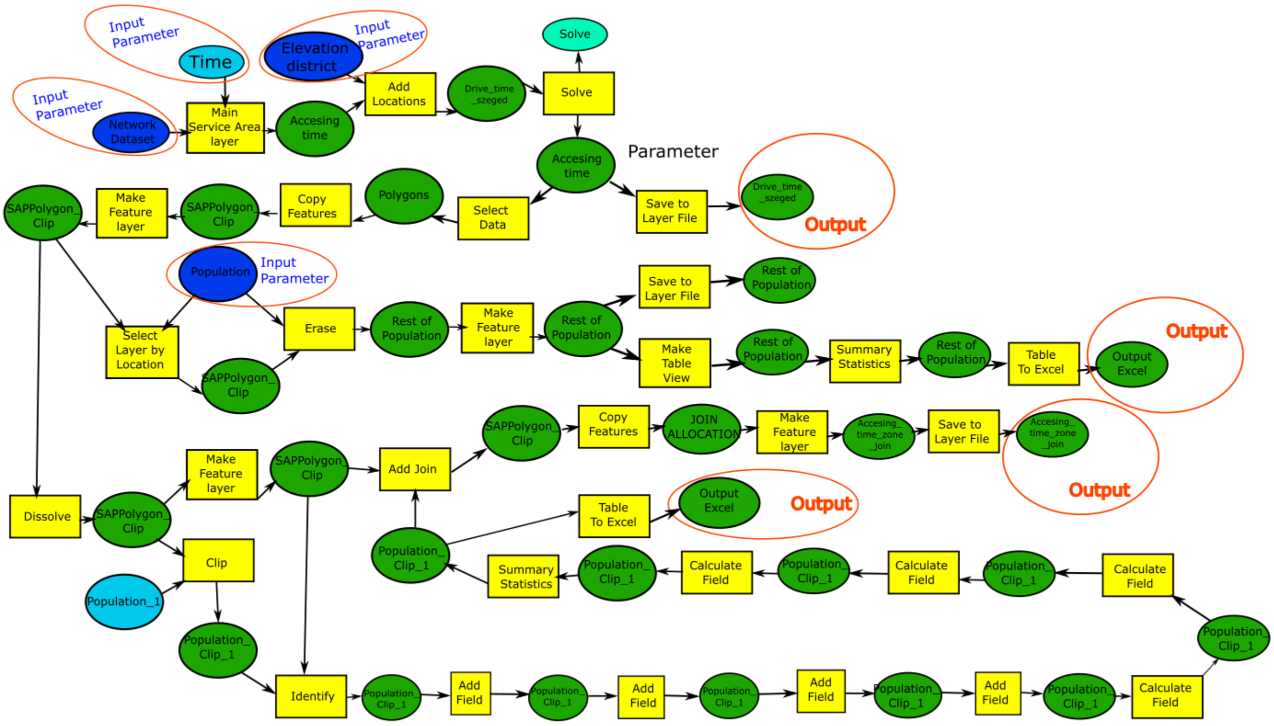

Fig. 2 Schematic diagram of the evacuation model

The best result, i.e. the tightest (there is no empty area between the coverage) coverage of the area, was achieved by mapping of the access time polygons.

The results of the evacuation model are used in the framework of stationary services in the GIS system. the format of the data publication is Web Map Service or Web Feature Service. These two types could use on client (Desktop GIS software on a PC) or in a web GIS application (in Javascript environment or older version in Flash). A special query function was developed (publicated in a geoprocess service on ArcGIS server) to give the accurate number of the people as required by the planning phase, and it makes it possible to collect the population data in an exact manner during the elaboration of the municipal emergency response plans. This facility will be integrated in the web-based system in the future (Fig. 3.).

In the case of evacuation an area based query was applied, since the affected area is maximum 0.25 – 1 km²

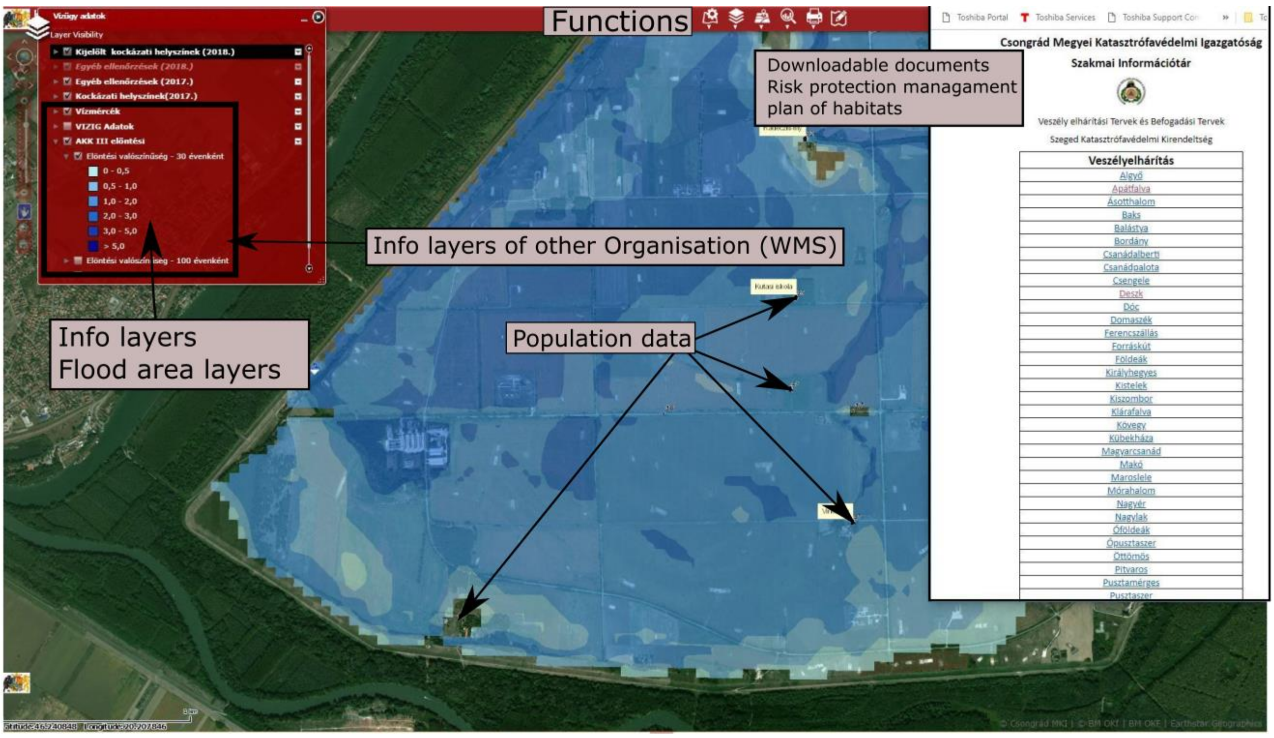

Fig. 3 The final GIS application in use: flood area with population data of residential areas (farms). All municipal emergency response plans can be download.

in this case (500 m distance from the source of danger), and this query is a complex operation, since the query is carried out on several separate databases at the same time. Numerous zones can be set for the query of the information about the incident locations, depending of the type of the required data. With this tool, the head of the operation is able to designate the affected area and get immediate information about the population and other objects that can be found in the given area (Fig. 4.).

RESULTS

The process of the use of the civil protection GIS system can be divided into two phases. The phase of planning is performed mainly in desktop environment, with server support. Some of the databases work in the desktop section as well, but special attention must be paid to their updating because the contact between the PC-s and the server is not constant. If somebody works without internet connect with an older version, the analysis could provide an inaccurate result, because the IT department upgraded the database meanwhile. Of course there is no problem in the web application.

A server-based GIS solution working in a protected internal network has been used for the support of operative work and other data retrieval processes. The application can be used at any location where the protected network can be accessed and does not require any special GIS knowledge from the users. The division of labour within the system is as follows: close technical cooperation with the GIS section in the planning and development phase (desktop and server administration); support of operative work from the web application exclusively for professional users.

The system has been developed on the ESRI platform, in which ArcMap 10.5 (desktop), ArcGIS for Server 10.5. The databases types are geodatabases (special ArcGIS type) and MSSQL databases (MSSQL

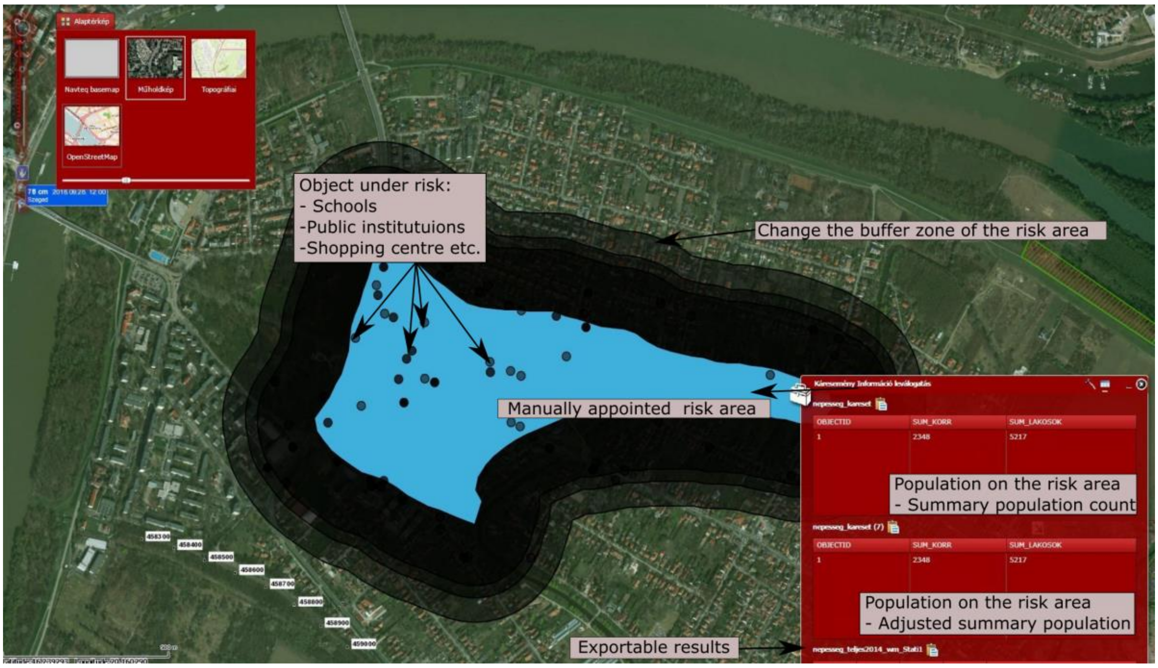

Fig 4 The final GIS application in use: manually appointed risk area with queried data, for example – population, population between 8 and 16 o' clock.

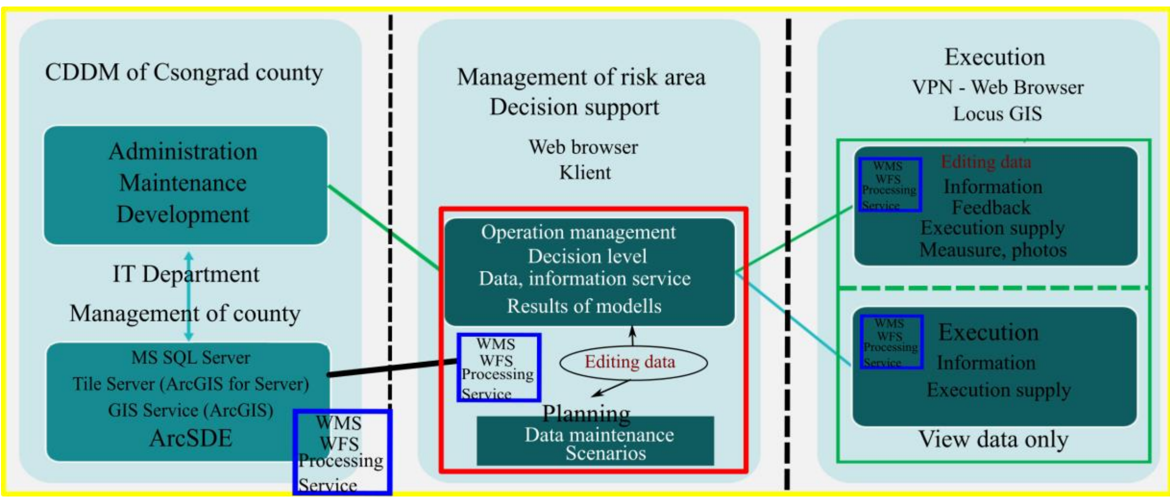

Fig 5 The structure of final GIS system with levels of operation, decision and maintenance

server). We also use the databases in combination for the services. The data is stored in separated servers. The ArcSDE facility is used for data that can be edited in web environment (Fig.5.) or in desktop environment.

At the present, official evacuation districts are assigned based on the election districts defined by law (Fig 6.). The applied model of the present study specifies new, GIS based evacuation districts. The data of the evacuation modelling, the engineering structures of flood control (defence lines, floodgates etc.) and objects exposed to hazard can be accessed simultaneously in the geoinformatics system anywhere.

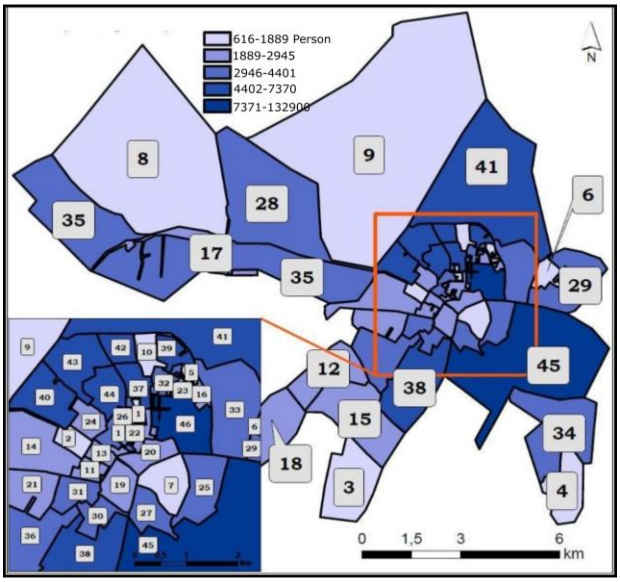

Fig. 6 The evacuation district of the city of Szeged at the present defined by law (Győri, 2015)

The available functions integrated into the systems include data retrieval and other GIS operations (query according to region or attribute, buffer zones, test of upper limit, distance measurement, coordinate query, export of GIS data etc.)

With the recently developed evacuation model, planning is not only possible with fixed input data (evacuation zones, assembly points) following the legal regulations rigidly, but a dynamic planning process can be developed as well. By changing the input parameters, it is possible to adapt to the changing circumstances, and it is not absolutely necessary to the data fixed in the municipal emergency response plans. If the situation requires the evacuation district may be changed by the spatial restructuring of the assembly points, which would be impossible in the case of a fixed plan. The model can be used to determine the areas that can be reached in intervals of 0-5, 5-15, 15-25 and 25-35 minutes. At the level of the locality, this series of intervals has ensured appropriate coverage for the existing assembly points.

The districts generated as a result of modelling are not districts adjusted to streets. In the case of Szeged, it can be seen that there is a "blind spot" even in the case of access time of 35 minutes. As for the blind spots, depending on the situation, the operative staff of disaster management may decide on the designation of new temporary assembly centres because of the 35-minute access time on foot (Fig. 7.).

In the case of evacuation zones established by modelling, the assembly points are loaded more or less uniformly. In the case of preventive planning, this spatial scheme is basically determined by the location of the objects that are essentially suitable for the role of an assembly centre. It has been one of the purposes of our modelling to analyse how the borders of the evacuation zones will change in comparison to those defined in the original legal regulations if we use the GIS approach. However, if we compare the evacuation districts established by the two methods (i.e. the election districts and the GIS analysis), considerable

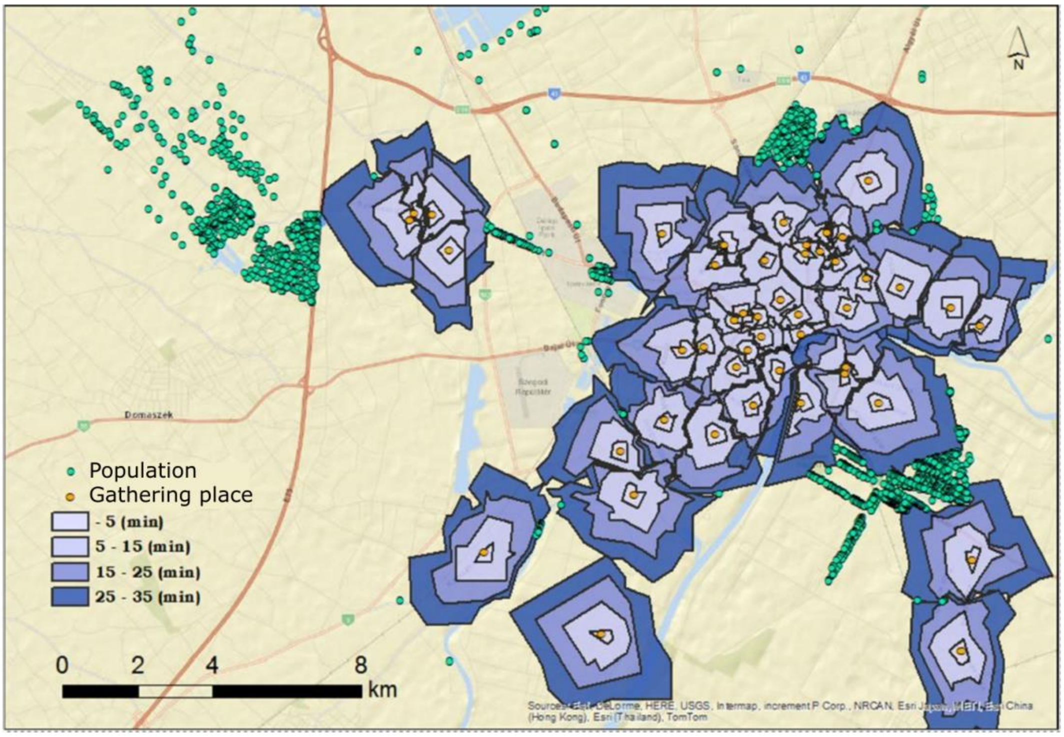

Fig. 7 Results of evacuation Model with incident locations (Győri, 2015)

differences can be found in their spatial extent and location. Due to strict legal requirements, the factors taken into account in the case of election districts are not the same as in the case of GIS analysis. Here only the population and other already existing geographical databases are needed for the modelling.

Several scenarios can been run for the final model. The variable parameter is the ratio of "self-evacuating" population. This parameter has been integrated into the model, thus the load of the individual assembly points can be calculated and the necessary further actions can be planned. The planning of the further measures related to the scenarios is continuous and depends on the actual situation. Using this system, information layers that may help the management of incidents can be displayed anywhere in a web environment (Fig. 8.).

The results of queries and modelling can be exported to .kmz and .kml or .shp files, and these files can be used on-site with a suitable application on smart phones. The Csongrád CDDM favours the LOCUS GIS (www.locusmap.eu) application that has been able to operate offline on several field practices, since it is suitable for displaying the data, managing the GPS and field data recording according to pre-defined templates (in .shp format). If required, the rescue unit which is exposed to a hazard can be followed on a public website by using the Live tracking mode. The data can also be used without internet connection; furthermore, the application is suitable for recording data (e.g. the locations of drain water), which at a later moment, after recovery of the internet connection can be send to the server.

CONCLUSION

In the field of disaster management, geoinformatics started to gain ground as a decision-supporting tool/system in the last 8-10 years. However, its areas of use are restricted to operative activity (support of immediate interventions). The presented approach intends to support the field of preparation and prevention as well in line with the requirements of the Sendai Framework. The modelling work was performed for a city of the size of a typical county seat in Hungary. Henceforth the Csongrád CDDM intends to use this model for every locality exposed to flood risk in the county and to store the available data in a database. The main problem was that the evacuation plans of residential areas were defined without GIS planning. A new GIS based approach was developed for the evacuation plans. The base of the GIS application is the result of the model and the geoprocessing of the model. With this GIS application the professionals can make established decisions between the variable circumstances. At the present the analysis was tested in Szeged, but in the close future it will be applied to other settlements in Csongrád county.

The former practices and application experiences indicate clearly that this direction should be followed and may be used simultaneously with the evacuation districts defined by law. Further planned steps include the adjustment of the modelling results to the geometry of the street network, but this requires further modelling work.

Geoinformatics as a strong tool of decision-preparation and decision-support serves the preparation

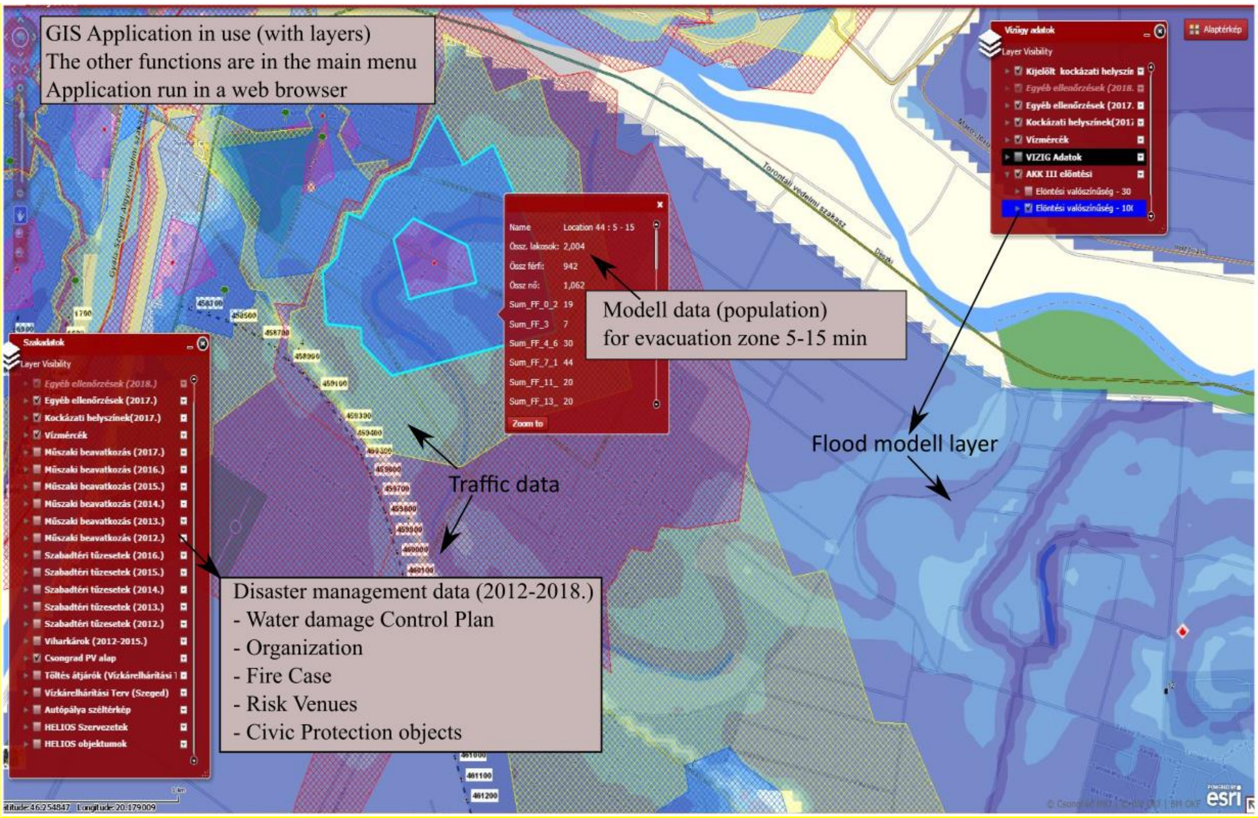

Fig. 8 The geographical extent of the evacuation districts in the GIS application in web browser. It can see the other relevant information layers which visible in the platform

for solving problems arising within the field of duties of civil protection. In the near future, the Csongrád CDDM is intent to continuously foster the usage of geoinformatic solutions.

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