Andrea Majlingová
Štefan Galla
Martin Zachar
Ján Buzalka
Péter Pántya

Evaluation of Dynamic Modelling Applications to Support the Disaster Risk Management at Local Level

The paper is dealing with the evaluation of selected dynamic modelling tools to support disaster risk management at a chosen place. We also introduce the approach and results of modelling the forest fire and flood behaviour. For fire modelling the FARSITE environment was applied. For flood behaviour modelling we applied the HEC-RAS and HEC-GeoRAS environments. The experimental area for forest fire behaviour modelling is a locality situated in Stare Hory cadastral unit, Slovakia, which was affected by a forest fire in 2011. For flood modelling a part of the Krupinica watercourse catchment area was chosen, which threatens the town of Krupina. Based on the flood and fire modelling results acquired during and after the fire and flood, we strongly recommend the implementation of the above mentioned modelling tools for crisis and disaster management.

Keywords: disaster risk management, FARSITE, HEC-RAS, modelling

Introduction

As a result of climate change, the frequency of extreme weather situations and the number of emergencies increases every year. It is fundamental to know the probability of their occurrence, their hazards and impacts on the social, natural and economic environment to plan the coping capacities and mitigate the impact. All these issues are part of risk management (Kóródi, 2014).

Risk management is a logical and systematic method for determining the context of any operation or process, identifying risks, analysing, evaluating and on-going monitoring, which allows minimizing losses and maximizing opportunities (Simak, 2006).

The risk is always perceived as the probability of a certain negative effect's occurrence. Even when asking questions with "when" or "how" we talk about risk. It is possible to record and observe the relationship between the damage caused by a negative (adverse) event and the frequency of its occurrence or to find out the period of return of a specific emergency situation. There are a number of ways to determine the risk, depending on the components that have to be considered. The risk is understood as a function of its individual components: hazard, vulnerability, exposure and resilience of a system.

The risk component assessed in the context of this paper is vulnerability. Vulnerability is a characteristic which is directly linked to the impact of an emergency: the damages incurred and the cost of rehabilitation. Generally it is assessed from the following three aspacts: social, environmental and economic.

In order to optimize the entire process of risk assessment and management we focus on geographical information systems (GIS) and systems for modelling and simulation of the behaviour of selected types of emergencies. The advantage of the presented program environments is their availability, because they are freely downloadable, without the need to purchase any license for their use.

Forest fire behaviour modelling

The origins of modelling and simulation of forest and natural fires date back to the late 1980s. It was brought about by increasingly large fires that threatened human lives and caused losses. Currently there are two approaches to model fires in the natural environment. Modelling large areas with a semi-empirical model and modelling smaller areas using the so-called physical models. Mathematical models are used, inter alia, in the legislation on fire protection, in the implementation of the prescribed fire prevention measures and in predicting the behaviour of the fire.

- **Empirical models** – the spread of fire is described by functions obtained by approximating the experimental data, while they do not take into account any physical mechanism. Results can only be used in similar conditions in which they were acquired.
- **Semi-empirical models** – they combine knowledge of physical principles, particularly energy conservation and experimental detection of unknown parameters of the model. They do not distinguish between the different modes of heat transfer. The most important and most common practice among these models is the Rothermel`s model for the spread of fire (Rothermel 1983). It expresses the speed of fire propagation as a function of the density of the fuel, burning intensity and heat required to ignite another fuel.
- **Physical models** – they distinguish modes of heat transfer, namely: direct contact with the flame, thermal conductivity, heat radiation and contact with the burning debris drifted by the wind. They address the conservation laws of energy, momentum, mass and ingredients, while fuel is modelled as porous environment (Weisenpacher 2007).

In fire simulation empirical and semi-empirical models are applied, in addition to a specific modelling and simulation technique, which is used to represent the environment and the fire. The most common simulation techniques are:

- **Cellular automata** – the landscape surface and vegetation are represented as a grid composed of cells characterized by topographical and fuel parameters. The rules can be set to determine the fire's probability to spread from a specific cell to another on the basis of its performance and condition of adjacent cells. The Portuguese Fire Station system is based on the principle of cellular automata.
- **Elliptical propagation** – enveloping models. The landscape is represented as a two-dimensional continuous media covered by fuel, while the spread of fire is modelled by the Huygens principle. Each point of the current line of fire becomes a source of propagation of small secondary fires with elliptical shape. Dimensions, shape and orientation of the ellipses are specified by slope, direction and speed of the wind and the type of fuel at that point. The envelope enclosing all the secondary ellipses indicates the line of fire for the next time slot. The FARSITE system is based on the principle of the elliptical propagation (Weisenpacher 2007).

Generally the FARSITE environment is recommended to model forest and natural fires, which combines the mathematical model of fire propagation with the GIS environment. This environment has been tested in Slovakia since 2002, however, Aggtelek National Park, Hungary has also been testing it since 2005 (Restas, 2006a; 2006b).

FARSITE (Fire Area Simulator) is a model for spatially and temporally simulating the spread and behaviour of fires under conditions of heterogeneous terrain, fuels, and weather. The modelling approach uses an implementation of Huygen's principle of wave propagation for simulating the growth of a fire front (Papadopoulos, 2011). The process is in fact very close to the widely used methods employed manually for the same purpose (Rothermel 1983). The difference being that the process is automated, faster, and more detailed than practical by hand. Furthermore, the projected fire perimeters and behaviour are portable numerically and graphically to other PC applications and to GIS applications. These advantages, however, come with the requirements for more, and more organized, information on the topography, fuels, and weather (Finney 1998). There were also some efforts at Aggtelek National Park, Hungary to compile GIS with different Remote Sensing applications (Restas, 2006c; 2006d).

Flood behaviour modelling

Numerical modelling of hydrological processes is increasingly becoming a tool for hydrological analysis. Using Geographic Information Systems and Remote Sensing (RS) is a logical step, because GIS and remote sensing as well as the software environments for modelling work with spatial data. Based on this concept, the data required for hydrological modelling can be divided into the following groups (Vondrák 2007):

- **Static** – the data on catchments and river reaches,
- **Dynamic** – the time series of hydrometeorological data.

Hydrological models can be divided in practical terms to the rainfall-runoff and hydrodynamic models. The first group addresses the rainfall-runoff phenomena most frequently in the individual emergencies, when they produce a hydrograph for the selected profiles from the causal rainfall. Hydrodynamic models solve the hydraulic water transformation in the watercourse channel, in the flood-water management systems and objects (Vondrák 2007). Hydrological models has been classified by a number of authors. One of the most important works is the work of Maidment (Maidment 1993).

For flood impact modelling we selected the HEC-RAS and HEC-GeoRAS environments. There is another software environment that uses the same inputs and provides very similar outputs to the HEC-RAS environment. The advantage of the HEC-RAS environment is the fact that it does not require a licence, it can be downloaded from the web page (www.hec.usace.army.mil/software/hec-ras/downloads.aspx) for free.

HEC-GeoRAS is a set of processes, tools and devices for processing geospatial data in ArcGIS. Linking it with ArcGIS enables the import of geometric data in the calculations of the hydrodynamic model embedded in the environment of HEC-RAS. After processing the spatial data in the hydrodynamic modelling of the HEC-RAS environment, the modelling results are exported from HEC-RAS, then imported to HEC-GeoRAS to visualize them in GeoSpace. For modelling flood impacts in HEC-RAS/HEC-GeoRAS, it is required to have a digital terrain model (DTM), a geographical vector layer of river system, that is recommended because of the vectorisation of aerial images in the HEC-GeoRAS environment (Lubinszká, 2010).

In general, HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The HEC-RAS system contains four one-dimensional river analysis components for: steady flow water surface profile computations; unsteady flow simulation; movable boundary sediment transport computations; and water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed (www.hec.usage.army.mil).

Experiment description

To perform the forest fire modelling and simulation we chose a forest fire that occurred in Stare Hory Mts., Central Slovakia, in 2011. The territory, which was affected by forest fire in 2011, is located in Starohorska valley. It is a mostly mountainous and a fairly rugged terrain. Starohorská valley is the boundary of two mountain systems (and two national parks): Great Fatra Mts. and Low Tatras Mts. Based on the forest management information on the fire affected area the following information is worth mentioning:

- Forest area affected by fire: 43.88 ha
- Stand age: 15 – 175 years old
- Tree species composition: coniferous 35% (spruce, fir), broadleaves 65% (beech, maple, rowan)
- Extent of the damage in the particular stands: 20% - 100%
- Number of days with fire: 3 days

On 10/4/2011 at 14.25 an emergency call came in to the operational centre of the Regional Directorate of Fire and Rescue Corps in Banska Bystrica about a forest fire occurring in the Stare Hory Mts. locality. The fire was successfully suppressed on 12/04/2011 at 16.30. In this case, there was surface fire and underground fire as well. The following stands were affected by the fire: 402, 403, 404, 405, 408, 409 and 410. Totally, 43.88 hectares were damaged by fire. The total damage amounted to 222,974 EUR. A total of 20 fire engines and about 70 other appliances were deployed to get the fire under control. Air Tankers made 166 water drops in total, dropping 301,500 litres.

The FARSITE environment was used to model impacts and the development of forest fire, which had been tested in Slovakia for a long time. The input data for modelling included topographical data provided by the Topographical Institute in Banska Bystrica, data on meteorological situation provided by the Slovak Hydrometeorological Institute in Bratislava and data on forest fuel that were acquired during field survey and from laboratory testing. The main task of field surveys was the quantification of surface forest fuels near the village Horny Jelenec, situated in Great Fatra Mts., near where the modelled fire occurred. The intention was to obtain information on the amount and spatial distribution of surface fuel in the forest, including humus, leaf litter, litter, moss, herbs, grasses, seeds and fruits, branches that present a potential danger for the formation or spread of fire. The fire technical parameters of fuel specimens taken during the field survey were tested in laboratory conditions (Monosi et al. 2015).

The HEC-RAS and HEC-GeoRAS environments were applied to model the flood behaviour and its impacts. As modelling scenarios we assessed the impacts of the 100-years and 500-years floods on Krupinica watercourse on Krupina town citizens and their property. The input data for modelling included the digital terrain model, aerial photos (images) of the experimental area and technical data on the Krupinica watercourse. Those were mainly the following parameters: flow rate for $Q_{100} = 73\ m^3.s^{-1}$, flow rate for $Q_{500} = 170\ m^3.s^{-1}$. The data were provided by the Zvolen branch of the Slovak Water Management Enterprise, S.E..

For the purposes of hydrological modelling it was also necessary to determine an index of land use for each cross section. In this case, the index for the urban areas was set for 0.05. For permanent grasslands and meadows the index was taken as 0.055. It was also necessary to enter the riverbed index of 0.035.

Results and discussion

First, we introduce the fire behaviour modelling results. The modelled fire was announced to the operation centre in Banska Bystrica at 14.25, 10/4/2011. According to the reports on the intervention the fire was contained only at 16.30, 12/4/2014 after 50 hours of fire duration. The fire area was determined at 43.88 hectares at that time. The fire perimeter was determined as 3.63 km (see Fig. 1).

Based on modelling results of the fire, calculated in FARSITE, at 16.30, 12/4/2014 the fire area reached 44.6 hectares (calculated in the horizontal direction), or 51.3 hectares (in the calculation the topographic features are considered) and its perimeter 3.9 km or 4.2 km (influence of topography considered). According to these data the fire area calculation results were 98.2% accurate. It was specified based on the comparison of areas calculated in the horizontal direction, since these are in the Fire Report derived from the 2D data representations. The precision of modelling is relatively high considering the comparison of the real fire area to the modelled one. However, for accurate modelling it is required to verify the fire shape, i.e. visual assessment is necessary.

Figure 1. provides a view of stands affected by fire and the fire area perimeter gained from FARSITE modelling. It should be noted that data on the extent of the actual fire area needed for visual assessment for the accuracy of modelling was not available, because none of the surveyed data providers (Regional Directory of Fire and Rescue Corps in Banska Bystrica, Forests of SR, S.E. in Banska Bystrica) have such layer. We only managed to get a map of the forest stands affected by fire, but since the stands were not affected completely during fire, the data are only approximate. However, as the only source of data on fire damage they were applied in the verification of the fire modelling results.

In Figure 1 the data on ground and aerial attacks of fire brigades were implemented in the form of so-called barriers, through which the fire did not break out in the modelling process. The fire affected all the mentioned stands, but did not completely destroy all of them. Based on the fire modelling results it is possible to identify persons and biotopes of national or European significance in danger.

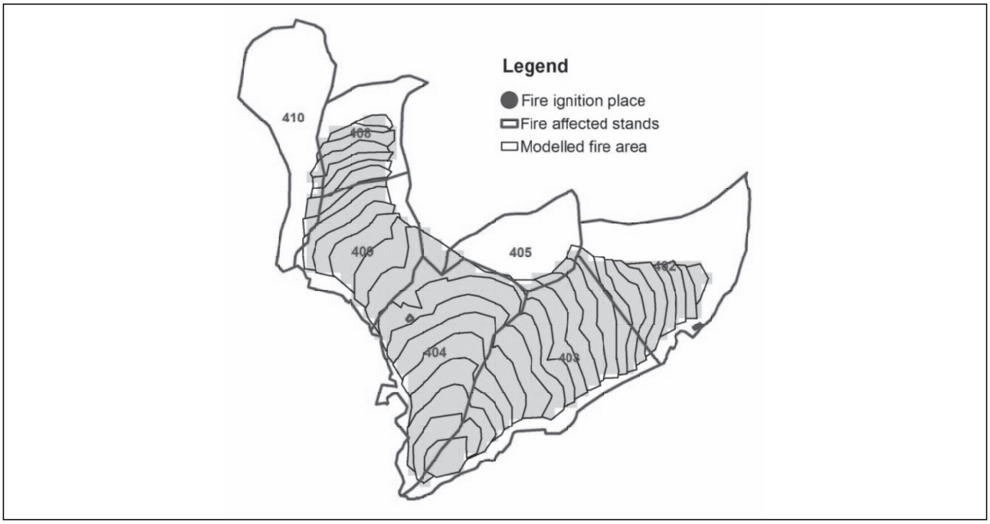

Figure 1. Resulting area of the fire gained from modelling in FARSITE in comparison with the fire affected stands area (Source: Majlingová 2014)

In the followings, we introduce the results of flood behaviour modelling. The following figures (Figure 2, 3) show the results of modelling Q_{100} and Q_{500} flood in the program HEC – RAS. The results are visualised in HEC-GeoRAS, ArcGIS environment respectively.

Figure 2. Results of Q_{100} flood modelling (Source: Authors)

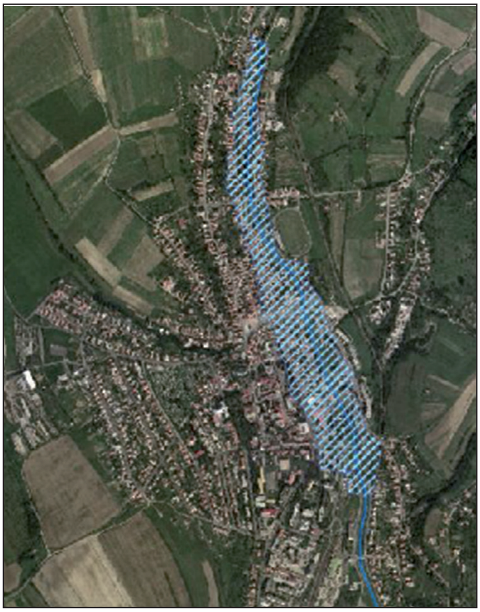

Figure 3. Results of Q500 flood modelling (Source: Authors)

In terms of threats to the population, in the case of the 100- year flood (Q_{100}) in the Krupinica watercourse about 70 citizens are in danger. Endangered persons would include mostly residents whose home is located in close distance to the river bed of the Krupinica watercourse. During this flood scenario the property of citizens and the Krupina town itself would be damaged. Damage to property would not be high. For sure, it could be avoided that any person would lose more than 50% of their property value.

Therefore, the vulnerability of the Krupina town area to the 100-year flood may be referred to as minor. This means that the impact of the flood would not significantly endanger the functioning system of the entire town. The only threat is to the regional dispatch centre of the Krupina Emergency Medical Service.

The threat to persons and damage to property caused by the 500-year flood (Q_{500}) would certainly be higher than Q_{100}. The inundation area would be more than double of the 100-year flood. The number of persons at risk would also increase to approximately 250 people. The increased number of persons exposed would mainly be due to the extension of the inundation area to the centre of Krupina town, where there are stores. Property damage would also be significantly higher, especially near the riverbed, where the life of the population would also be in danger.

At present, the level of flood protection in terms of assessing the impact of the 100-year flood can be considered as satisfactory. However, problems could be caused by the tributaries that flow into Krupinica watercourse in Krupina. These streams flow through channels under the ground. Culvert blockage could lead to inundation during torrential rains. Culverts and riverbeds are regularly inspected for waste or vegetation that could block the culvert. The regular inspection of these tributaries started after the 1999 flood, when the flood damage was partially caused by the mentioned tributaries of the Krupinica watercourse.

Figure 4. An useable tool during flood, a fire ship (Source: Authors)

The level of flood protection for a 100–year flood is considered satisfactory, however, we must note that the town is not ready or prepared to handle a 500-year flood in any way.

Conclusions

In crisis management, in particular in identifying potential risk areas, it would be useful to focus more attention on modelling the behaviour and development of crisis phenomena in freely available software environments that are already used for this purpose especially abroad. There are some obstacles to implement them in disaster management in Slovakia. These obstacles include: missing technical data on river bed parameters and digital terrain models with high spatial resolution, which are strongly required to achieve accurate modelling results.

One of the mentioned environments, the FARSITE, has been tested on regressive simulations of larger fires in Slovakia since 2002. The accuracy of these regressive fire simulations in this environment (Halada, Weisenpacher 2005, Majlingová et al. 2006, Majlingová, Vida 2008) was more than 90%. FARSITE allows modelling surface fires and crown fires. In addition, ground and aerial firefighting can be modelled influencing the further development of fire. The only obstacle to its immediate deployment in operational practice of fire brigades in Slovakia is the lack of data on quantitative and qualitative parameters of forest fuel, which requires field and laboratory research (Restás 2014).

The HEC-RAS and HEC-GeoRAS environments are very useful tools to model flood scenarios for any area with a stream or any other type of water course. Its application depends on the existence of data on the analysed watercourse and also on the user`s experience. Thanks to the modelling results it is possible to identify the population, property and critical infrastructure in danger thus helping the planning of prevention measures.

Both environments presented above can have and important role in supporting crises or risk managers in the process of disaster management.

Acknowledgement

This paper is the result of the implementation of the project: Centre of Excellence "Decision support in forest and landscape", ITMS: 26220120069, supported by the Research & Development Operational Programme funded by the ERDF and project VEGA 1/0953/13 – Geographical information on forest and forest landscape: Particularities of production and application.

References

Finney, M. A.: *FARSITE: Fire Area Simulator – Model Development and Evaluation.* Rocky Mountain Research Station, Forest Service, United States Department of Agriculture, 1998. Downloaded: 10.05.2015. http://fire.org/downloads/farsite/WebHelp/usersguide/ug1_introduction.htm

Koóroódi Gy.: *The role of the Institute of Disaster Management of National University of Public Service in the system of the Hungarian voluntary rescue organizations: searching, rescue and first aid,.* 22nd NISPAcee Conference. Budapest, Hungary, 2014.05.22–24. (available at: http://www.nispa.org/conf_paper_detail.php?cid=22&p=3184&pid=7198f).

Lubinszká, Z.: *Operačné postupy pririešenie krízových situácii na vodných tokoch* [Operational steps in managing the crisis situations on the watercourses]. PhD thesis. Zvolen: TU- DF, 2010.

Maidment, D avid. R. (ed.).: *Handbook of Hydrology,.* McGraw-Hill Education, New York,1993.

Majlingová, A.: *Informačné systémy efektívne honasadenia hasičský chjednotiek prilesných požiarochnavy branomúzemí SR* [Information systems of effective deployment of fire brigades in forest fires in selected area of the SRä]. PhD thesis. FŠI ŽU v Žiline, Žilina, 2014.

Monoši, M. – Majlingová, A. – Kapusiak, J.: *Lesné požiare* [Forest fires],. Žilinská Univerzita, Žilina, 2015. Downloaded: 13.05.2015.; http://www.forestportal.sk/lesne-hospodarstvo/ochrana-lesa/poziare/Stranky/default.aspx

Papadopulos, G. D.: *A Comparative Review on Wildfire Simulators;.* IEEE Systems Journal, Vol. 5, No. 2, June 2011, pp. 233-–243.

Restás, Á.: *Special Decision Making Method of Internal Security Managers at Tactical Level,.* 22nd NISPAcee Conference. Budapest, Hungary, 22–24. 04. 2014. (available at: http://www.nispa.org/conf_paper_detail.php?cid=22&p=3176&pid=7190)

Restás, Á.: *Integrated Vegetation Fire Management Program from Hungary,.* International Symposium on Environment, Identities and Mediterranean Area 2006, Corte, France, 2006. 07. 09.–12. Corte: IEEE, 2006. pp. 78–83. (a)

Restás, Á.: *Integrated Vegetation Fire Management at Aggtelek National Park,.* Forest Ecoglogy and Management 234, Elsewire Science (ScienceDirect), 2006. (b)

Restás, Á.: *Wildfire Management Supported by UAV Based Air Reconnaissance,.* SIMFOR 2006 First International Workshop on Fire Management, Havanna, Cuba, 19–22. 04. 2006, 1–10. (c)

Restás, Á. : *The Regulation Unmanned Aerial Vehicle of the Szendro Fire Department Supporting Fighting Against Forest Fires 1st of the World,.* Forest Ecology and Management, 234:(15) Elsevier Science (ScienceDirect), 2006. (d)

Rothermel, R. C.: *How to predict the spread and intensity of forest and range fires,.* General Technical Report INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 1983.

Vondrák, I.: *Informačnítechnologie pro modelování krízových situací* [Information technologies for modeling the crisis situations],. Sborník příspěv kuprvní horočníku workshopu, TU Ostrava, 106 s., 2007.

Weisenpacher, P.: *Možnostisystému WFDS prisimulácii lesných požiarov* [Possibilities of WFDS system in simulation of forest fires],. Zborník z medzinárodnej vedeckej konferencie, Ochrana území postihnutých ničí prírodnými pohromami, ‚Technická univerzitavo Zvolene&Žilinská univerzita v Žiline, 2007, 227–237.

Katasztrófavédelmi kockázatkezelést támogató dinamikus modellek értékelése helyi szinten

ANDREA MAJLINGOVÁ – ŠTEFAN GALLA – MARTIN ZACHAR – JÁN BUZALKA – PÉTER PÁNTYA

Jelen cikk a kiválasztott dinamikus modellezési eszközök katasztrófavédelmi alkalmazásának értékelésével foglalkozik a kiválasztott területeken. Bemutatjuk az erdőtüzek és árvizek modellezésének megközelítését, valamint eredményeit. A tüzek modellezésére a FARSITE programot használtuk, míg az árvizek esetében a HEC-RAS és a HEC-GeoRAS programokat alkalmaztuk. Az erdőtűz modellezésének kísérleti helyszíne Szlovákia Stare Hory járása, ahol 2011-ben erdőtűz pusztított. Az árvizek modellezésére a Krupina városát veszélyeztető Krupinica vízgyűjtő területére esett a választás. Az árvíz, illetve tűz közben és után gyűjtött adatok és a modell eredményeinek összevetése alapján határozottan javasoljuk a modellezési eszközök katasztrófavédelmi célú alkalmazását.

Kulcsszavak: katasztrófavédelem, FARSITE, HEC-RAS, modellezés