

Dynamical Flash Flood Risk Forecast

Petr Rapant and Jaromír Kolejka

Abstract Flash floods represent very dynamical natural phenomenon. Mostly, they are the result of torrential rains which can rise suddenly in any part of a country and are tough to predict. Of course, there are many weather forecasting systems, but their spatial and temporal resolution is usually insufficient for these purposes. There are also monitoring systems which can either register precipitation over the ground (a network of rain gauge stations) or runoff in riverbeds (a network of hydrometric stations). Again, spatial (and possibly temporal) resolution is not sufficient, and in the case of runoff monitoring, there is a substantial delay between actual rainfall and registration of runoff in riverbeds. And, of course, when the hydrometric station registers higher runoff than the flash floods is running or even over. From the point of early warning, all these systems reveal disadvantages. Aside from these systems, there is one which provides us with timely information about the spatial and temporal distribution of precipitation intensity over the ground. That is weather radar. We will demonstrate possible usage of these data for dynamic prediction of flash flood risk distribution in space and time over the monitored area. Proper processing of these data in combination with soil saturation indicator established using Flash flood guidance methodology developed by the US Hydrologic Research Center can generate timely information usable for early warning with a substantially reduced level of false warnings.

Keywords Flash flood · Risk prediction · Weather radar

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I. Ivan et al. (eds.), *Dynamics in GIScience*, Lecture Notes in Geoinformation and Cartography, DOI 10.1007/978-3-319-61297-3_27

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Introduction

Flash floods are a natural highly dynamical phenomenon which is hard to predict. Their random occurrence and rapid development limit the possibility to develop a reliable and efficient early warning system. However, due to changing climate conditions, the occurrence of the flash floods has become increasingly frequent. That is why the interest in flash floods is growing.

The primary cause of devastating flash floods is torrential rainfall. There are many other factors, such as the soil saturation, the terrain slope, the catchment area, geology, soil type, and the urbanisation of the territory, which also influence these floods (Březková 2011; Drbal 2009; Šercl 2015). That is why torrential rain does not necessarily cause a flash flood every time—other factors can eliminate this threat.

Because of the complexity of the process generating flash floods and the complex nature of parameters governing this process, that are moreover spatially distributed, it is hard to develop the reliable and efficient early warning system. National hydro-meteorological institutes can collect data describing rainfall and runoff distribution through precipitation gauge stations and hydrometric gauge stations, put received data to the hydrological models and obtain a probable distribution of flood in the territory, but this process is quite time-consuming. The other problem is that spatial and, in some cases, even temporal resolution of data gathered and models developed is insufficient. That is why we still do not have such the early warning system in full operation.

On the other hand, there is a method for gathering data describing a distribution of precipitation over land with sufficient spatial and temporal resolution. It is a weather radar. National hydro-meteorological institutes usually operate a system of these radars covering the whole territory of the country. In the case of the Czech Hydro-Meteorological Institute, data are provided in raster format with spatial resolution 1×1 km and temporal resolution 5 min. Such data are very suitable for the development of the flash flood early warning system (CZRAD 2011).

As it was mentioned above, many other factors influence the rise of the flash flood. The most important one is the soil saturation by preceding precipitation. This factor is very well described by the soil saturation indicator. The Czech Hydro-Meteorological Institute produces the soil saturation indicator established using Flash flood guidance methodology developed by the US Hydrologic Research Centre and adopted to the Czech conditions (HPPS ČHMÚ 2016). Including of this indicator to the process of a flash flood risk assessment can help to correct to some extent the assessed flash flood risk and decrease the rate of false warnings issuing.

Developed Methodology

In the last years, we have focused on the development of scenarios of geoinformation technologies applications to crisis management. One scenario was focused on a quick flash flood prediction. The first things we took into account when developing this scenario were:

- there is only a very short time interval between falling of precipitation and rise of a flash flood,
- that is why we should derive only qualitative information describing areas potentially hit by the flash flood, which can be obtained quickly,
- so we do not need a quantitative estimation of precipitation nor exact numerical rainfall-runoff modelling,
- also, data from hydrological gauge stations situated on rivers are obsolete for this purpose—they register an already existing flood.

Next, it is good to remember that:

- the greatest damage and loss of life are caused by concentrated runoff of torrential rainfall in influent watercourses, and
- residents of communities in which it does not rain, but that lay downstream and shall be thus also affected by the runoff water may be at risk too.

Based on these considerations, we have decided that (adopted from Rapant et al. 2015b):

- proposed methodology should be based on weather radar data, which provide the greatest detail both in the space and in the time dimension,
- the radar data will be processed in a raw state, without any adjustment to eliminate most of any time delay caused by the pre-processing of radar data,
- data, therefore, can be processed only qualitatively—which fits well with our entry requirements,
- qualitative assessment will be performed on individual sections of watercourses
- to minimise the number of parameters affecting the evaluation of the risk of flash floods:
 - by assuming that the runoff spreads along the watercourses at a constant speed of 10 km per hour
 - by counting the total contribution of rainfall to the runoff in sections of watercourses in last two hours
 - by supposing that the soils are fully saturated (so called the worst case scenario),
- the flash flood risk level at the watercourse sections is visualised using a five-level scale.

The proposed methodology was implemented in Python as a toolbox for ArcGIS. This toolbox continuously processes incoming weather radar data and

generate an up-to-date map of the flash flood risk distribution along the individual sections of the watercourses. Weather radar data are totalized across watersheds, sums are directly transferred to respective river sections and relayed downstream up to the distance of 20 km. All such contributions are totalized along every watercourse sections, and resulting sums are classified using five level scale (no risk–low risk–high risk–very high risk–extremely high risk).

Later, after gaining some practical experience, we included the soil saturation indicator provided by Czech Hydro-Meteorological Institute (HPPS ČHMÚ 2016) to the proposed methodology. We use it for evaluation of propensity of soils to infiltration of precipitation. With growing propensity to infiltration, the level of flash flood risk decreases. This step helped to reduce substantially false warnings.

Results

The proposed methodology was tested in many local case studies in Czechia (Rapant et al. 2015a, b, 2016). Gained results demonstrate that the proposed method is effective and also efficient in evaluating the flash flood risk and generating information suitable for early warning purposes. Two examples are shown for the events from 24.6.2009 (middle Moravia) and 7.8.2010 (north-west Bohemia).

Figure 1 demonstrates that predicted rise of the flash flood risk precedes real development in order of hours by comparing the course of the predicted risk with actual measurements done at gauge station Kozlovice on the river Ondřejnice.

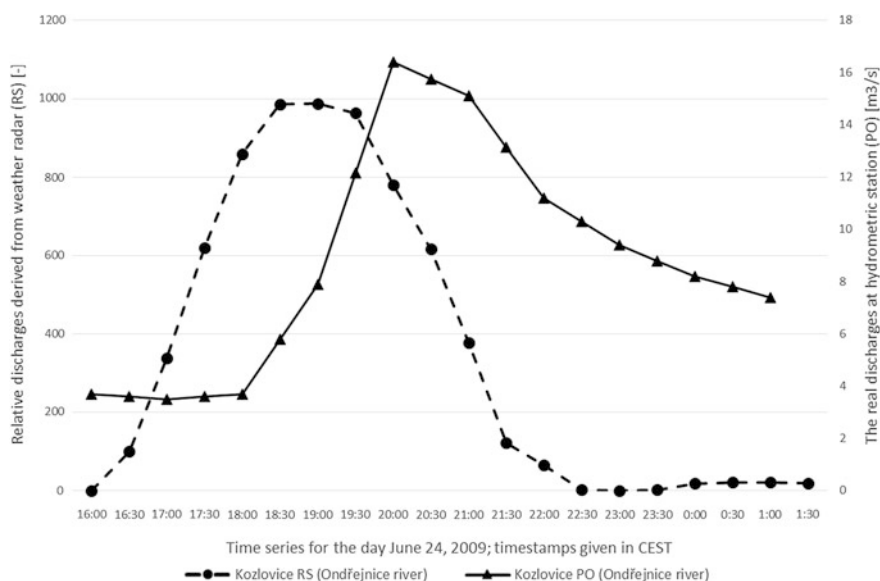


Fig. 1 Comparison of the curve of relative discharge derived from weather radar data (RS) with the curve of actual discharge (PO; data courtesy of Odra River Basin Management Company, a state enterprise) measured by a hydrometric station located in Kozlovice on the river Ondřejnice, 24.6.2009

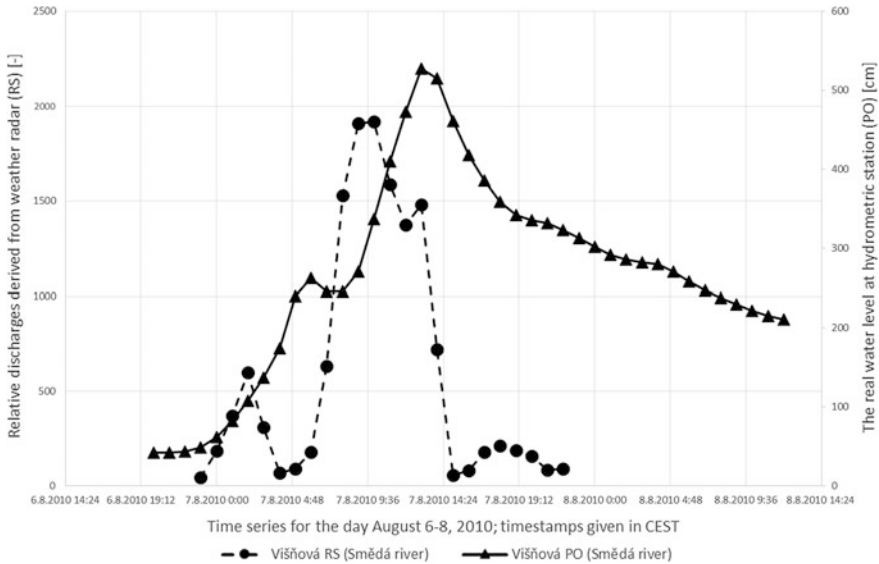


Fig. 2 Comparison of the curve of relative discharge derived from weather radar data (RS) with the curve of actual discharge (PO; data courtesy of Czech Hydro-Meteorological Institute) measured by a hydrometric station located in Višňová on the river Smědá, 7.8.2010

The similar situation is displayed in Fig. 2 for the gauge station Višňová on the river Smědá. It is necessary to mention that in both cases, the soils were highly saturated at the beginning of the respective events.

In the next step, we focused on inclusion of the soil saturation indicator to the proposed methodology. Case studies were designed to cover the whole territory of Czechia. The predicted flash flood risk was compared with real events related to flooding and registered in the database of statistical monitoring of events managed by the Fire Rescue Service (FRS) of Czechia.

The Soil Saturation Indicator

The soil saturation indicator is provided as a raster with pixel size 1×1 km. Values are expressed using ordered qualitative scale: extremely unsaturated–unsaturated–saturated to retention capacity–saturated–highly saturated–extremely saturated. Colour scale starts at dark red and finishes at dark green (HPPS ČHMÚ 2016).

The Fire Rescue Service Database

This database contains information about all interventions of firefighters. All records include GPS coordinates of the place of intervention, so they are well

localised. Every record contains tens of items, but we received only a subset of them, providing data necessary for identifying the event, spatially localise it and select relevant events.

Original and Improved Predictions

The soil saturation indicator is interpreted qualitatively: first three levels represent soils which can absorb at least part of the rainfall, last three levels represent regions with limited or no ability to absorb any precipitation. Simply put: Red areas are taken as they are not susceptible to flooding, the susceptibility of green areas rises with the darkness of the green colour.

Figure 3 demonstrates the maximum value of flash flood risk predicted for river sections during whole the day 25.6.2016. We can see that the entire territory of Bohemia (the western part of Czechia) should be subject to the early warning sometimes during the day. But if we compare this prediction with real events relating to flooding as they were registered in FRS database, we can also see that most of these warnings would be false. In Fig. 4 we see situation after including the soil saturation indicator: the correspondence between prediction and reality is much better. Similar results were also obtained for other days (e.g. Fig. 5).

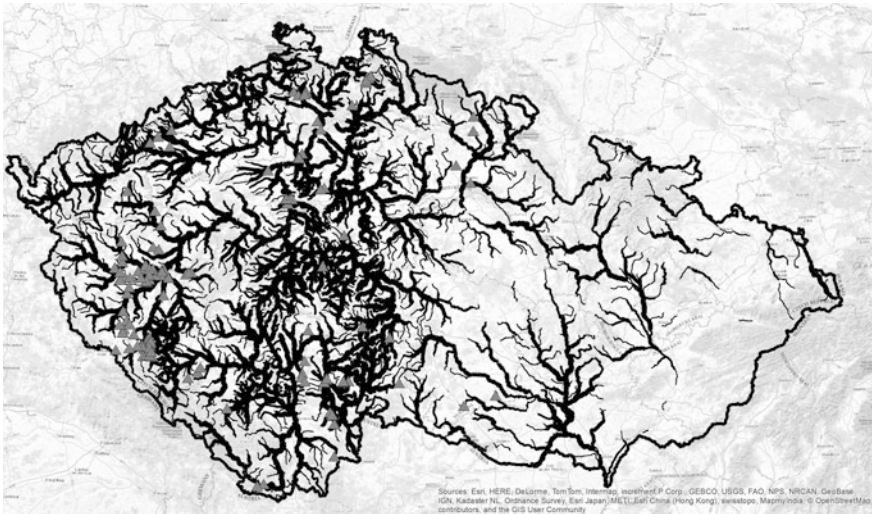


Fig. 3 Comparison of the maximum value of flash flood risk predicted for river sections during whole the day 25.6.2016 with real events relating to flooding as they were registered in FRS database (data courtesy of Fire Rescue Service, Czechia). *Grey triangle* represent events from FRS database; *black lines* represent level of flash flood risk using five level scale (no risk–low risk–high risk–very high risk–extremely high risk; coded by line thickness)

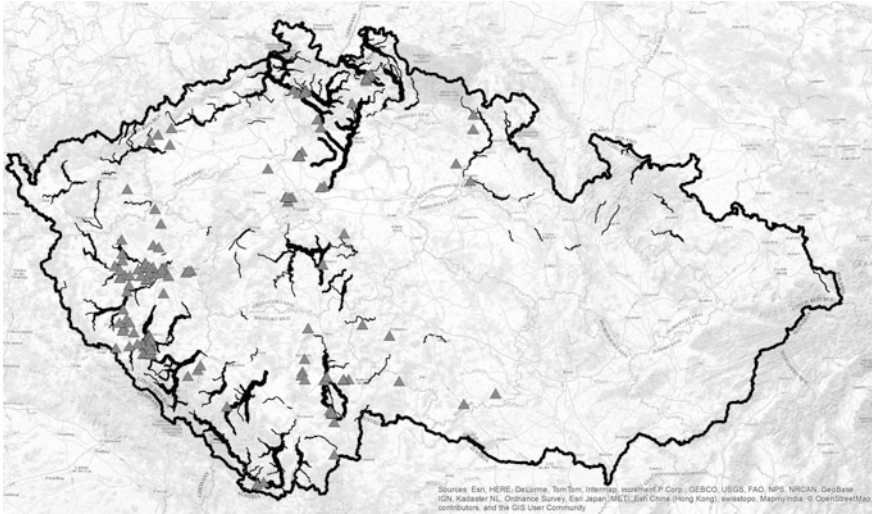


Fig. 4 Comparison of the maximum value of flash flood risk predicted for river sections during whole the day 25.6.2016, reduced by inclusion of soil saturation index to the proposed methodology, with real events relating to flooding as they were registered in FRS database (data courtesy of Fire Rescue Service, Czechia)

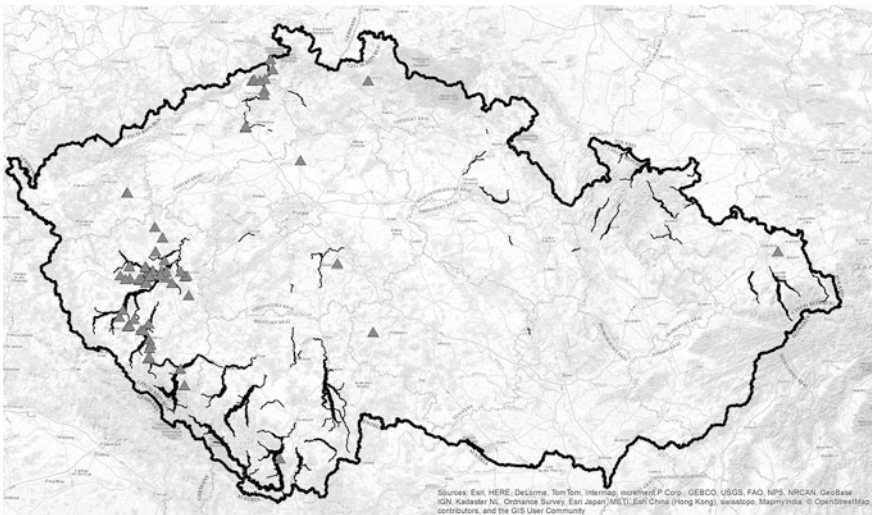


Fig. 5 Comparison of the maximum value of flash flood risk predicted for river sections during whole the day 26.6.2016, reduced by inclusion of soil saturation index to the proposed methodology, with real events relating to flooding as they were registered in FRS database (data courtesy of Fire Rescue Service, Czechia)

Discussion

Today's warning systems are typically based on mathematical models (NOAA_NWS 2010; Sene 2013; Volos 2007). Their aim is to quantify the impacts of torrential rainfall in the area. Very often they focus more on regional flooding (Alfieri et al. 2011), whose progress is not as fast. However, they are also known systems, focusing primarily on flash floods (Cosmo 2015; Dorman 2013). These are often also trying to predict the onset of heavy rains. Thus conceived systems are demanding for detailed data about areas that are not routinely available. The consequence is a paradoxical situation: predictions are the result of mathematical models (what can give us an illusion of accuracy), but they are burdened with high uncertainty (what is not always clear).

Our approach is different. It does not use the rainfall-runoff models, does not quantify the impact of torrential rains in the country and it is based on the rainfall already registered by radar measurements. With this, the time between precipitation falling and issuing a warning is very short. Residents can thus get the warning in advance before the potential development of the flash flood. FFG inclusion into the methodology significantly reduced the number of false warnings.

On the other hand, the examples also show some limitations of the proposed methodology. It does not work well for small streams (surface runoff is a predominant phenomenon here) and does not cover large regional watercourses with sufficient capacity of their riverbed. In other cases, the methodology appears to be both effective and efficient.

Acknowledgements This work was supported by the project called "Disaster management support scenarios using geoinformation technologies" No VG20132015106, program Safety Research promoted by Ministry of Interior, Czechia and by Faculty of Mining and Geology, VSB-Technical University of Ostrava, Czechia.

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