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THE ASSESSMENT OF LEVEL OF FLASH FLOODS THREAT OF URBANISED AREAS

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Abstract

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Flash floods (or torrential rain flooding) is another type of flood hazard which has caused casualties and significant property damages. A methodology for identification of urban areas, which can potentially be burdened by that type of flood hazard, was proposed. This method, also called Method of Critical Points (CP), is a repeatable process able to identify areas, which are significant in terms of formation of surface run-off and erosion. As addition to the preliminary flood risk assessment according to EU Directive 2007/60/ES on the Assessment and Management of Flood Risks, the presented methodology was applied for the entire area of the Czech Republic and the results are being used for the updating of non-technical measures, e.g. urban planning.
In the article, the principles of methodology of CP are described and results of the first application in the Czech Republic are presented, as well as possible interpretations of them.

Keywords: water erosion, critical point, flood risk, catchment area, porosity, concentrated surface runoff

INTRODUCTION

The contemporary landscape has a considerably diminished potential for water retention, which is primarily the result of inappropriate use, especially on hilly terrain, where there is more rapid surface runoff. Intensive precipitation can lead to flooding, while in dry periods the landscape suffers from drought. The way to improve this situation is to change the way the land is managed through the use of appropriate measures in the catchment area. Roughly half the agricultural land in the Czech Republic is threatened by water erosion. The solution to this problem will be a demanding process in terms of time and money. To ensure successful and optimal implementation, it is essential to define a schedule for the solution in time and space.

Identification of the most-threatened areas is possible, e.g. via land categorization in terms of potential occurrence of torrential rain flooding, with a negative effect on built-up areas. The approach described in this article combines an increase in the water-retention capability of the landscape with flood prevention and soil conservation measures. Based on the same principle, the study proposes the identification, in catchment area plans, of areas with a high risk of storm flooding with potential impact on urban areas.

This approach is based on methodology for localisation of land threatened by torrential rain flooding, which was drawn up within the preliminary assessment of flood risk in 2009 (Drbal *et al.*, 2009a). This methodical approach was drawn up in response to the fact that storm flooding caused by intensive localised downpours occurs relatively often in summertime in CZ, and such storms can occur practically anywhere. The combined difficulty of time and space localisation of the causal effect of storm flooding, and the high level of uncertainty in expressing the probability of occurrence (period of repetition) for a certain locality, were the reasons for the development of the so-called Critical Point method (Drbal, Dumbrovský *et al.*, 2009).

In principal, the method uses a repeatable procedure of identification of decisive areas in terms of the creation of concentrated surface runoff, with the aim of defining so-called critical points (CP) within built-up areas as an auxiliary indicator of the threat of concentrated surface runoff and transport of solid matter by torrential rains. For each contributory area, a value is worked out as a so-called indicator of critical conditions for the occurrence of negative effects of torrential rain flooding. The need to find a fitting approach is also based on the requirements of Directive 2007/60/ES. This requires all EU member states, in a phase known as preliminary identification of significant flooding risk, to examine all relevant types of flooding threat. The proposed procedure was actually tested in conditions and on data from pilot projects/studies in the Luha and Jičínka water catchment areas.

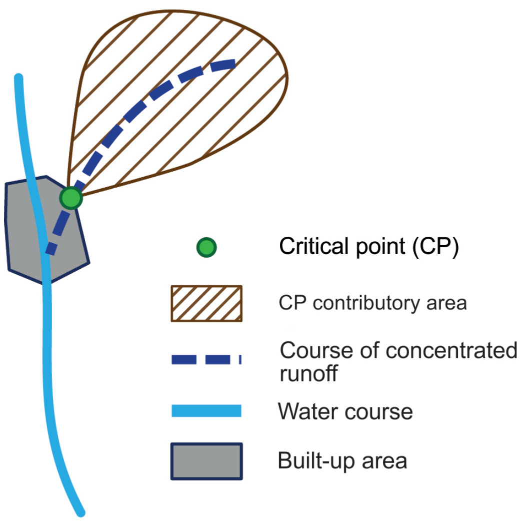
The identification of CP presents a repeatable approach to identifying decisive areas in terms of the creation of concentrated surface runoff, with the aim of determining areas of land within built up areas threatened by concentrated surface runoff and transport of solid matter by storm rainfall. The results of this approach should primarily serve the needs of local councils of potentially affected areas as a basis for the formation of flood-prevention and land-use plans, and for the proposal of measures within land consolidation.

The results of the critical point method identify contributory areas of land, which are only inter-related to a certain extent. In some regions, however, especially in relation to the level of urbanisation, their occurrence has increased distinctly. Therefore, for further use, an aggregation was carried out based on the weighted arithmetic mean of so-called indicator of critical conditions of contributory areas in relation to the size of grade 4 catchment areas. The result is the categorisation of the hydrological units/ into three levels of threat of storm flooding to urban areas. These categories should help in the proposal and implementation of appropriate measures to reduce the possible negative impact of flooding due to storm rainfall. The preferential implementation of measures in grade 4 water catchment areas, with a high level of risk of storm flooding, will contribute to significant changes in the rate of runoff and mitigation of erosion effect and all negative impacts, not only on productive agricultural land, personal assets and real estate in urban areas and transport infrastructure, but also on the water management infrastructure.

MATERIALS AND METHODS

Determining critical points and their contributory areas

Events of the past decade (2009, 2010 and 2013) clearly show that built up areas can even be affected by flooding in places where no water runs through. Within research work (including field studies) carried out after incidents of flooding, over 100 locations were identified in the Luha and Jičínka catchment areas where surface runoff infiltrates the built-up area of effected villages (Drbal, 2009b, Dumbrovský *et al*., 2009). A problematic aspect was identified in concluding profiles – outflows of catchment area of over 5 ha, where transported matter was a particular problem, causing partial damage to property. Considerable damage to property (distinct damage to buildings) however, occurred in stretches below concluding outflows with contributory areas of more than 0.3 km^2. For the identified concluding outflows in the Luha and Jičínka catchment basin, as with numerous other outflows affected by storm flooding in the past, an evaluation was made of all causal factors decisive in terms of the creation of concentrated surface runoff and transported matter. On the basis of criteria analysis, parameters of so-called critical



1: *Identifying critical points (CP) and their contributory areas* points (CP) were set. These were places where the course of the concentrated surface runoff enters built-up areas. A critical point is thus defined as a point where the boundary of a built-up area is broken by the course of concentrated runoff with a contributory area of ≥0.3 km² (Fig. 1).

Regarding the extent of the causal effect of torrential rainfall and the primarily local impact of consequent flooding, consideration is henceforth given to the critical points whose contributory areas do not exceed 10 km².

Further selection of critical points made use of the basic physical-geographical characteristics of their contributory areas: physical area, average slope, type of soil/use and proportion of arable land. For the contributory area of each CP a calculation was made of the value of the so-called critical conditions indicator for the occurrence of negative effects of torrential rain flooding (*F*).

For any specific CP contributory area, this indicator presents the combination of physical-geographical conditions, the form of land use, regional variations in landscape cover, and potential occurrence of extreme torrential rains (in relation to synoptic conditions):

$$F = P_{p,r} \cdot H_{m,r} \cdot (a1 \cdot I_p + a_2 \cdot ORP + a_3 \cdot CNII) \quad (1)$$

where

F..........the critical conditions indicator [-],

a ....the weight vector [1.48876; 3.09204; 0.467171],

$P_{p,r}$ ....the relative value of the size of the contributory area (considering a max. 10 km²) [-],

I_p..........the value of average slope of contributory area [%],

ORP....the proportion of arable land in the area [%],

CNII...represents characteristic of surface in consideration of run-off [-],

$H_{m,r}$......the relative value of total one day torrential rains with a repetition period of 100 years for territory within the Czech Republic [-]

Data for determination of *CNII* and *Hm,r* in ESRI GRID format for CZ territory is provided by the Czech Hydrometeorological Institute.

The subsequent selection of critical points was carried out according to the following parameters:

C1 – size of contributory area	0.3 – 10.0 km²,
C2 – average slope of contributory area	I_p ≥ 3.5 %,
C3 – proportion of arable land in basin	*ORP* ≥ 40 %,
C4 – critical conditions indicator	*F* ≥ 1.85.

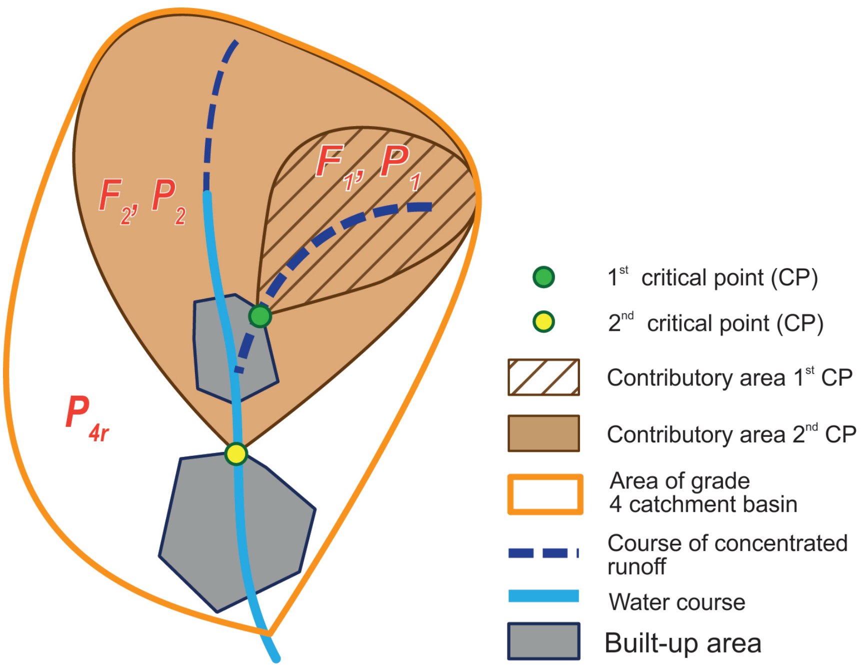
On the basis of investigation using model catchment basins, where damage occurred even from areas with a proportion of arable land lower than 40 %, or completely forested areas, the selection carried out according to the conditions of criteria C1 – C4 was extended to include critical points with contributory areas of 1 km² and above, with an average slope of 5 % or more:

C1A – size of contributory area	1.0–10.0 km²,
C2A – average slope of contributory area	≥5 %.

On the basis of these parameters of combined criteria, critical points and their contributory areas were determined for the whole of the Czech Republic.

The level of threat to urban areas from torrential rain flooding

The presented model for determining critical points identifies contributory areas which, to a certain extent, are inter-related, or even overlap. An



2: *Principle of overlapping critical point (CP) contributory areas* overlap of CP contributory areas occurs if a course of concentrated runoff (often with a standard water course running through it) incorporates several independent urban areas, and the land above the points at which these courses of concentrated runoff cross the boundary of the built-up area fulfils the C1 – C4 criteria (or C1A and C2A). In such a case, the contributory area of one critical point is a subset of the contributory area of another CP (Fig. 2). Multiple overlaps can occur.

Information on the localization of individual CP and their contributory areas is a useful basis for the proposal of complex land consolidation, or within landscape planning – i.e. on a "local level". From a regional perspective, including complete hydrological units, the information is still relatively fragmented. It was therefore preferable to extend the classification of torrential rain flood risk to cover a larger area. Aggregation was proposed based on a weighted arithmetic mean of critical conditions indicator (F_{w4r}), projected to the area of a hydrological unit, in this case grade 4 catchment basin.

Within the Czech Republic around 9000 grade 4 catchment basins are identified (as at 2014). CP contributory areas are predominantly subsets of individual grade 4 basins. In exceptional cases (grade 4 basin of relatively small area) the CP contributory area can overlap into several grade 4 basins. Each contributory area (or part of one) lying within a grade 4 basin is characterised by a value of critical conditions indicator (F_{w4r}). The weight for calculation of the weighted arithmetical mean is derived from the area that a given contributory area occupies in a grade 4 basin. If contributory areas overlap, then this overlap is included more than once in the calculation of the weighted average, always with the appropriate F value and the appertaining surface area (Fig. 2).

The resulting weighted critical condition indicator is then projected to the area of the grade 4 basin according to the formula:

$$F_{w4r} = \frac{\frac{\sum_{i=1}^{n} F_i P_i}{\sum_{i=1}^{n} P_i}}{P_{4r}}, \qquad (2)$$

where

F_{w4r} ... weighted mean of critical condition indicator projected to the area of the grade 4 basin [-]

F_i........ critical condition indicator of a given contributory area [-]

P_i ...... extent of given contributory area [km^2],

P_{4r} .... area of relevant grade 4 basin [km^2]

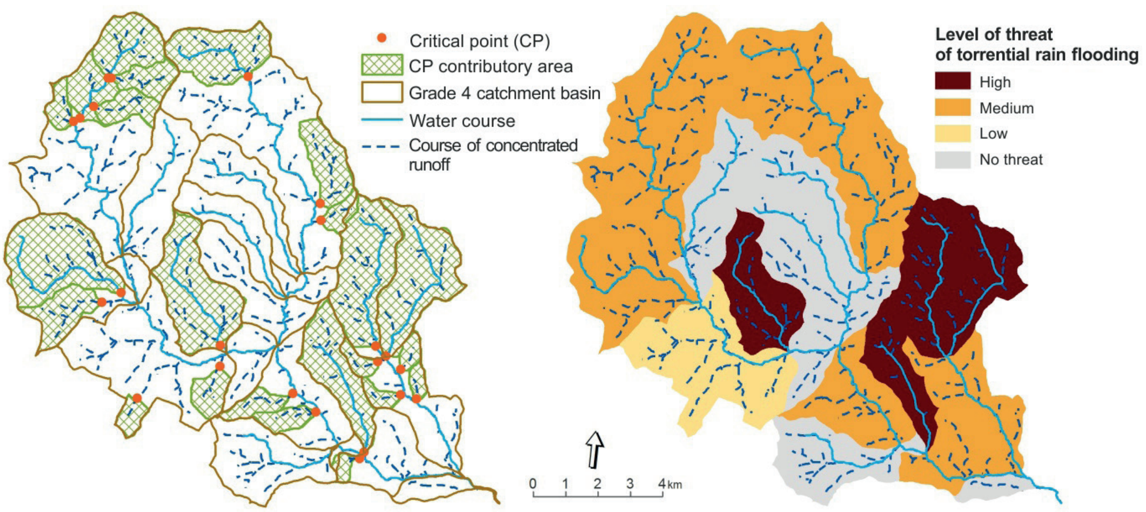
Weighted critical condition indicators projected to the area of a grade 4 basin (F_{w4r}) were calculated for the whole of the Czech Republic.

On the basis of results of research (including field studies) carried out in the Husí Potok, Luha and Jičínka basins, the level of threat to urban areas due to torrential rain flooding is separated into three categories (Tab. I)

I: *Level of threat to urban areas due to torrential rain flooding (CP – critical point)*

Level of threat	F_{w4r} value
high	3.01 and above
medium	1.01–3.00
low	0.01–1.00
no threat	0 (no CP)

The results were then verified on land in the pilot Husí Potok basin (Fig. 3), within the Luha and Jičínka basin.



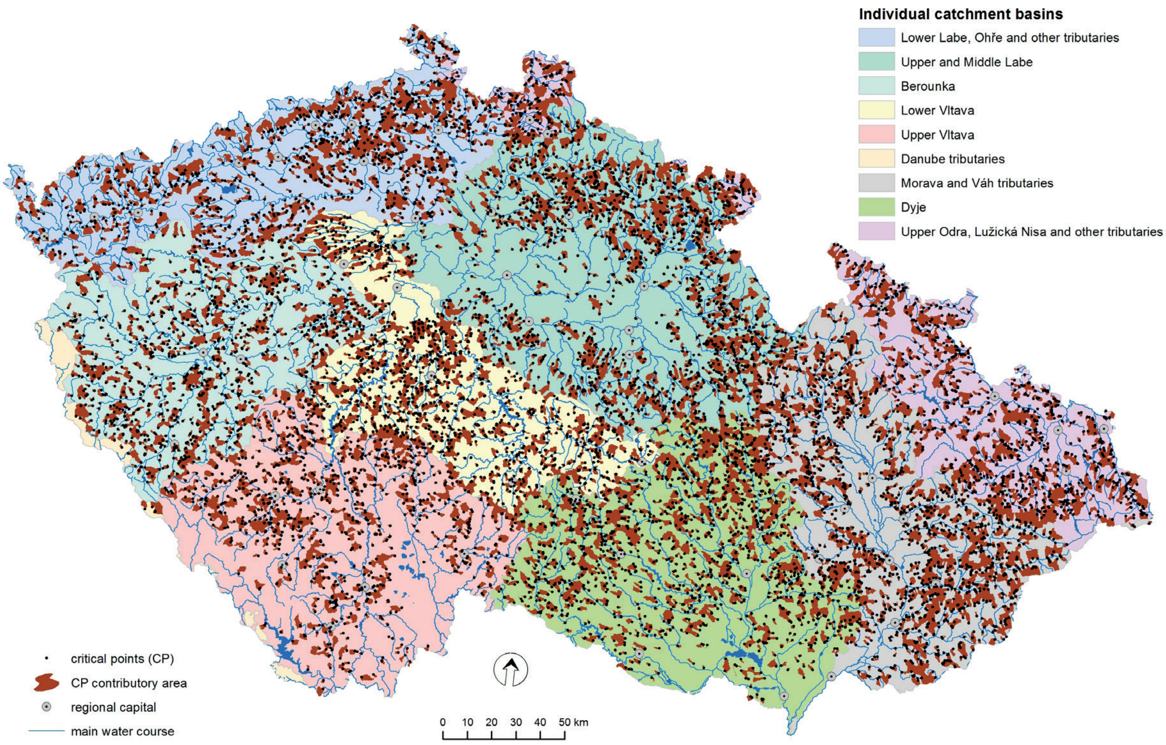
3: *Critical points (CP) and their contributory areas, and the level of threat of torrential rain flooding in the Husí Potok locality.*

RESULTS

On the basis of parameters of combined criteria C1 to C4, or C1A and C2A, a total of 9,261 critical points were chosen for the whole Czech Republic which have a greater (unknown) probability of occurrence of negative impact of torrential rain flooding (Fig. 4). The overall area of contributory areas of selected critical points in relation to built-up areas in CZ is 18,112.2 km^2, which represents 23 % of all land in the whole country. The results are available on the povis.cz portal.

For the districts in question this provides information on places where concentrated surface runoff can be expected to infiltrate built-up areas, and on what property may be at risk in the event of torrential rain. Local and national government have thus gained the basis for preparation of landscape planning and development. In the second round of planning (according to Directive 2007/60/EC), which ended in 2015, this basis was used in drawing up chapter V.2.3.3 Danger of torrential rain flooding in individual plans of partial catchment basins (MZe, 2015)

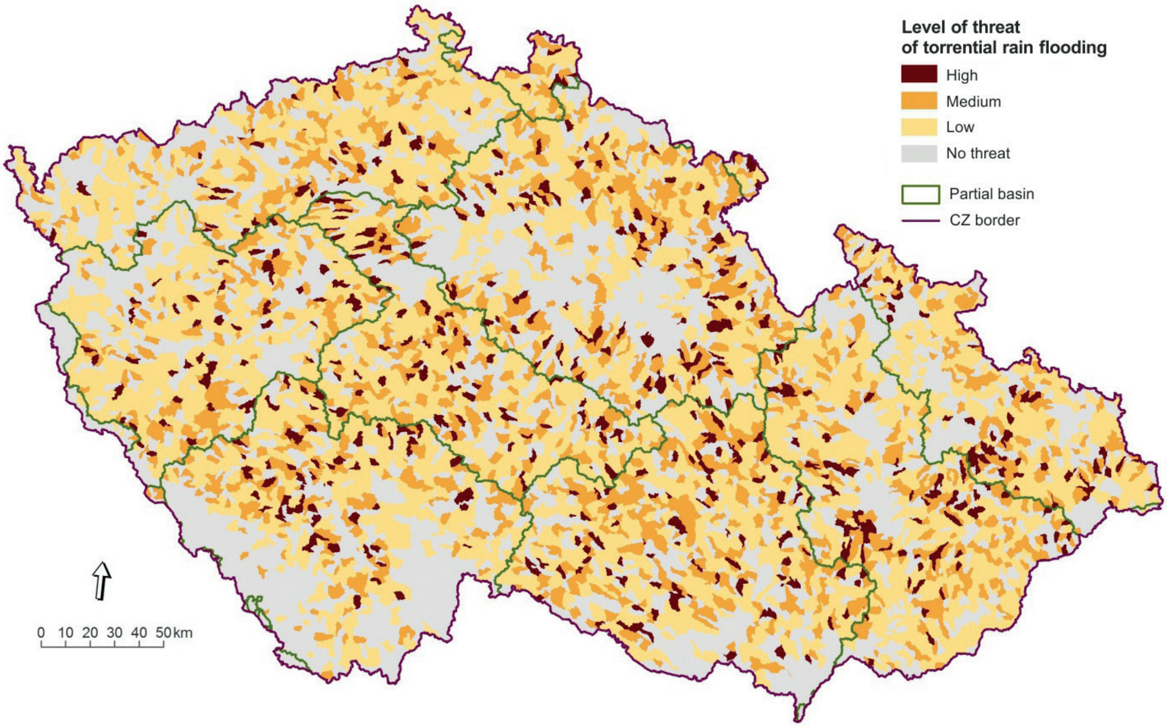
With the help of weighted indicators of critical points projected over the area of grade 4 basins, a regionalization of the level of threat to land from torrential rain was carried out, again for the entire CZ. Almost 35 % of land in CZ (ca. 27,500 km^2) lies outside any area threatened in this way. A further 40 % of land has only a low level of threat of torrential rain flooding (Tab. II). Just under 1/4 of the country falls into the medium and high level of threat (18.3 % and 5.7 % resp.).



4: *Identified critical points and their contributory areas within CZ*

II: *Extent of land with individual level of threat of torrential rain flooding*

Level of threat	Number of grade 4 basins	Average area of grade 4 basin	Total area(km^2)	Area (%)
High	616	7.34	4,524.3	5.7
Medium	1,448	9.97	14,441.7	18.3
Low	1,992	16.26	32,381.4	41.1
No threat	4,899	5.62	27,519.6	34.9



5: *Level of threat of torrential rain flooding within the entire CZ*

DISCUSSION

The majority of published studies on the theme of torrential rain flooding in CZ have dealt mainly with more precisely predicting this phenomenon, whether in space or time. The greatest effort in this direction has been made by the Czech Hydrometeorological Institute (Šercl, *et al.*, 2015, ČHMÚ, 2016a, 2016b). This theme has also been studied by experts in other centres (Rapant, *et al.*, 2016). All the stated studies belong to the category of measures regarded as preparedness. Expressing the level of flooding threat or risk is a question of prevention, because it serves primarily as a basis for planning land use in order to reduce such a risk and avoid any flood damage.

Procedures for visualising the level of potential impact of flood threat in general already have a certain tradition in the Czech Republic. The basic process is to express the flood risk by means of an appropriate parameter; determining vulnerability of land and activities carried out in areas threatened by potential flooding; expressing risk my means of qualitative, semi-quantitative and quantitative approaches (MŽP, 2011).

More problematic, and evidently more demanding in terms of uncertainty and demands on time and money, is the preparation of a basis suitable for expressing the danger of flooding, or rather its manifestation. Traditionally, information is provided in CZ to determine the occurrence of flood phenomena with a period of repetition of 5, 20, 100 and 500 years. On the basis of this information, maps are provided in areas with significant risk of flooding to show the depth and speed of water flow, and to show the threat and risk of flooding (MŽP, 2013). This information deals with only one of the forms of flood risk in CZ, that of flooded rivers.

Torrential rain flooding, however, is characteristic in its randomness, and therefore also its extreme nature in terms of expressing probability of occurrence. Other characteristics of this form of flooding are: possible occurrence at any point throughout the whole country, very limited or inaccurate spatio-temporal forecast of causal rainfall, local extent of impact worsened by inappropriate form of land use etc.

Identification of critical points (and their contributory areas) and categorization of land within CZ according to risk of torrential rain flooding give further basis for decision-making on preventive measures, especially on land in a catchment basin that is used to a greater extent as agricultural land.

The procedures used were chosen in order to make it possible to carry out calculations for the entire Czech Republic, and to allow repetition in the case of more detailed or more precise data (e.g. digital model of terrain). The critical point method, in particular, is still developing, further parameters are being sought which would enable at least a semi-quantitative expression of risk, or rather the extent of potential impact of torrential rain flooding.

CONCLUSION

The torrential rain flooding is a phenomenon with tragic consequences in the Czech Republic. Looking for a solution is highly demanding task. Visualizing the degree of potential consequences of this type of danger is one of them.

The main aim of the proposed methodology is to identify so-called critical points and their contributory areas. A critical point is defined as a spot where the boundary of a built-up area is intersected by the course of concentrated surface runoff. The size of the contributory area must range between 0.3 and 10.0 km^2. This methodology was used for whole territory of the Czech Republic. More than 9,000 of those critical points have been found. The sum of contributory areas of selected critical points in relation to built-up areas in CZ is more than 18,000 km^2, which represents 23 % of the whole country's area.

Information on the localization of individual critical points and their contributory areas is a useful basis for the proposal of complex land consolidation, or within landscape planning – i.e. on a "local level". From a regional perspective, including complete hydrological units, the information is still relatively fragmented. It was therefore preferable to extend the classification of torrential rain flood risk to cover a larger area. Aggregation was proposed based on a weighted arithmetic mean of critical conditions indicator, projected to the grade 4 catchment basin.

The hydrological units chosen by means of the set parameters represent the recommended prioritisation in the proposal and implementation of appropriate measures to reduce the potentially negative impact of torrential rain flooding. The selection of hydrological units also represents a proposal of areas where the implementation of measures based purely on CP contributory areas would contribute to a significant improvement in the drainage ratio and a reduction in erosion effect and all negative implications, not only on productive agricultural land, personal assets and real estate in urban areas and transport infrastructure, but also on the water management infrastructure.

Acknowledgements

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