Development of an application for estimating the benefits of constructional and non-constructional measures for flood risk reduction

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DEVELOPMENT OF AN APPLICATION FOR ESTIMATING THE BENEFITS OF STRUCTURAL AND NON - STRUCTURAL MEASURES FOR FLOOD RISK REDUCTION

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ABSTRACT: Floods are the most frequent natural disasters and cannot be prevented. However, we can mitigate their consequences by implementing flood protection measures, which have to be economically sound. Therefore, when planning such measures, we have to know how to reduce the damage caused by floods and increase the actual benefits of the implemented measures. In the presented project, we upgraded the existing unified method for Slovenia. This method covers flood damage in different sectors (people and health, cultural heritage, natural environment, residential, agricultural and business sectors). For each of the sectors, a simple equation is used to calculate the damage cost, taking into account the strength, duration and dimension of the expected flood event with different return periods as well as exposure, vulnerability and values of the exposed elements in the targeted area. To estimate these values, both data from the census and market values were used. Using the proposed methodology, an application was developed based on the geographic information system. According to their type, the input data are based on three main forms: point, (poly)line, and (multi)polygon. Separate databases were established for each type of data. The developed application was tested in three flood areas in Slovenia. According to the results, it was adjusted for use by various groups of users.

KEYWORDS: floods, flood damage, application, methodology, benefits, costs

IZRADA APLIKACIJE ZA PROCJENU KORISTI GRAĐEVINSKIH I NEGRAĐEVINSKIH MJERA ZA SMANJENJE RIZIKA OD POPLAVA

SAŽETAK: Poplave su najčešće prirodne nepogode i ne mogu se spriječiti. Međutim, njihove posljedice možemo ublažiti primjenom mjera zaštite od poplava, koje moraju biti ekonomski izvodljive. Stoga pri planiranju takvih mjera moramo znati kako smanjiti štetu prouzročenu poplavama, a povećati stvarne koristi od provođenje mjera. U prikazanom projektu smo unaprijedili postojeću jedinstvenu metodu za Sloveniju. Ova metoda obuhvaća štete od poplava u različitim sektorima (ljudi i zdravlje, kulturno nasljeđe, prirodni okoliš, stambeni, poljoprivredni i poslovni sektor). Za svaki od tih sektora primjenjuje se jednostavna jednadžba za izračunavanje troškova štete, uzimajući pri tom u obzir snagu, trajanje i dimenziju očekivanog poplavnog događaja s različitim povratnim razdobljima i izloženošću, ranjivošću i vrijednostima izloženih elemenata na ciljanom području. U svrhu procjene tih vrijednosti koristili smo podatke iz popisa stanovništva i tržišne vrijednosti. Primjenom predložene metodologije izradili smo aplikaciju zasnovanu na geografskom informacijskom sustavu. Prema tipu, ulazni podaci imaju tri glavna oblika: točkasti, (poli)linijski i (multi)poligonski. Za svaki tip podataka uspostavljene su posebne baze podataka. Izrađena aplikacija je testirana na tri poplavna područja u Sloveniji. Prema rezultatima je prilagođena za upotrebu raznih skupina korisnika.

KLJUČNE RIJEČI: poplave, štete od poplava, aplikacija, metodologija, koristi, troškovi

1. INTRODUCTION

The main purpose of the Directive 2007/60/EC on the assessment and management of flood risks (hereinafter Flood Directive) is to reduce the risks of adverse consequences associated with floods, especially for human health, the environment, cultural heritage, and economic activity in all Member States of the European Union. In recent years, the efforts to reduce flood risk have focused on flood damage assessment, since in this way decision and policy makers can receive important information for effective flood risk management (Merz et al., 2010).

Therefore, in Europe and worldwide many different methodologies have been developed for flood damage assessment, which are fundamentally different depending on whether we are assessing the damage based on the data from past flood events (empirical data) or whether we are assessing the potential damage in the future (synthetic data) (Meyer et al., 2013). For assessing the expected or potential damage in the future, many models are in use, since their structure, input, and output data depend not only on the data availability but also on the model purpose (Jongman et al., 2012). For example, the Multi-Coloured Manual (Penning-Roswell et al., 2005) is regarded as one of the most advanced methods for flood damage assessment, as absolute flood damage curves are taken into account in the calculation. In Germany FLEMOps and FLEMOcs (Thieken et al., 2008; Kreibich et al., 2010) models were developed for direct monetary estimation of damage in the private and commercial sector, respectively. In Croatia NACER model was developed (Vidmar et al., 2015; Zabret et al., 2018) where damage assessment is possible for seven different sectors. For each of the sectors, economic or market values, the number of exposed elements, and the depth-damage curves were determined. In the framework of the EU's Joint Research Centre, a pan-European model was developed for estimating flood damage at the macro level of all 27 EU Member States (Huizinga, 2007).

Notwithstanding the abundance of existing models, studies have shown that is not recommended to directly transfer a model developed for a specific area in a different area, as errors in damage assessment can be large (e.g. Kreibich and Neuhold, 2012).

In 2014, a methodology for assessing the benefits of structural and non-structural measures to reduce flood risk (IzVRS, 2014) was developed in Slovenia. The expected flood damage before and after implementing flood protection measures (benefits) can be calculated for 4 sectors: human health, the environment, cultural heritage, and economic activity. However, in 2017, the Ministry of the Environment and Spatial Planning recognized the need to review and upgrade the methodology. Improvements of the methodology were needed to take into account the latest data on flood damage, especially that to cultural heritage, public infrastructure, watercourses, and water infrastructure.

In this paper, we present the upgraded methodology and the KRPAN application that was developed based on this methodology. In Slovenian KRPAN stands for Kumulativni Računi Poplavnih škod in ANalize (*Cumulative Calculation of Flood Damage and Analyses)*. The input data that are used to calculate the expected flood damage are presented and the results of the calculation example are explained. Last but not least, challenges for future improvements of the methodology, and consequently of KRPAN, are given.

2. METHODOLOGY

2.1 Basis for methodology development

The development of the methodology was based on seven major starting points:

Expected flood damage calculations are shown by sectors and the method is applicable for the entire territory of the Republic of Slovenia. Calculation parameters are set in a way that does not favour individual entities depending on the location.

The method and the application are based on the relevant data that are freely available and/or that were obtained from the competent ministries, including those belonging to the category of personal data. Due to the General Data Protection Regulation (GDPR) some of the data need to be masked or generalized so they are not visible in the results display.

The values of sector components are determined on the basis of known price lists (e.g., price list for inventory damage in case of natural disasters in the Republic of Slovenia – AJDA application).

The assessment of the expected flood damage is objective. However, in analysing individual cases, there are still open options that may be included additionally by the auditor for explaining the importance of the suggested protection measure for development or protection of the area.

In the economic cost-benefit analysis of measures to reduce flood risk, there is no human health sector, as was the case with the original method (IzVRS, 2014).

KRPAN is a support tool for experts deciding about the suitability of project solutions in the process of economic and financial report preparation as required by the Decree on the Uniform Methodology for the Preparation and Treatment of Investment Documentation in the Field of Public Finance.

All data are used in accordance with the regulations and requirements of the database administrators and those who provided the data for the needs of developing this methodology and KRPAN.

2.2 General equation for assessing the expected flood damage

For each of the sectors (environment, cultural heritage, economic activity) a simple equation (1) is used for assessing the expected damage (*ED*) due to a flood event with return period T in a given area:

$$ED = S \times D \times E \times Vu \times Va, \tag{1}$$

where *S* represents the strength of the event (water depth and/or velocity), *D* is dimension (number or size of the exposed element in a given area), *E* is exposure (probability that an individual sector element will be present in a given area in a given time), *Vu* is vulnerability (structural damage of the individual element), and *Va* is the economic value of the individual element in a given area.

The method for the environment domain takes into account the parameters and values for determining the aesthetic value of the environment and biodiversity-dependent services. The values also cover intangible damages (i.e. environmental goods and services that have no market prices) using the Contingent Valuation Method from the literature (IzVRS, 2014, Markantonis et al., 2013). Damages to cultural heritage cover tangible damages based on average damages recorded in the AJDA application and intangible damages based on the magnitude of tangible damages and an additional factor for intangible damage (Dassanayake et al., 2012), for which *Vu* of the individual elements of cultural assets were proposed already in 2011 (Adamič et al., 2011). Tangible damage to structures, equipment and other fixtures of residential buildings is based on depth-damage curves (FEMA, 2014). Additionally, intangible damages due to replacement housing are determined for residential buildings. The method also covers tangible damages to vehicles and the cost of cleaning urban and other external surfaces next to the buildings. Tangible damages to business entities, i.e. structural damages based on depth-damage curves are determined (FEMA, 2014). Damages to equipment, machinery, and stocks and damages due to loss in revenue are determined in four company size classes according to average recorded damages during past events. Based on the recorded damages in the AJDA application we determined the average expected damage to watercourses, for various flood event magnitudes (Q_{10}, Q_{100}, Q_{500}). The tangible damage to public infrastructure is determined as the average of recorded damages in AJDA. For critical sections where public infrastructure collapse is possible a higher vulnerability factor is set. Damages to agricultural land and crops are based on the parameters used in the original method (Glavan et al., 2012; IzVRS, 2014). Based on the proposed method it is possible to determine the benefits of non-structural measures, and benefits of the measures of flood forecasting and the issuing of alerts, awareness-raising, sealing, and adjustments of buildings. This application may also provide a useful tool for assessing the benefit of non-structural measures in spatial planning.

3. APPLICATION

3.1 Input data

The development of the methodology, and consequently of KRPAN, was based primarily on the data availability. In particular, the optimization of large-scale databases was a key process, as this enables the application to be used on personal computers (on 64-bit operating systems). The established relational database allows periodic updating of input data. All built-in GIS tools that are necessary for the operation of KRPAN are freely available (e.g. SAGA (Conrad et al., 2015), GDAL). Display of output results is possible with the widely used Google Earth application, as well as with other GIS or CAD open-source tools. In order to establish KRPAN in the GIS tools, in the first step it was necessary to divide input data into three types, namely polygons, lines, and points:

- **Polygon layers** cover spatial data such as the Buildings Cadastre, land use, and other data that are not geolocated (cars, tourists, etc.) or cannot be included in the software environment due to the legal restrictions on database usage (number of residents per building, etc.). For this purpose, the polygon layer of a "spatial district" is used as a basic statistical unit, facilitating links with other databases. The basic spatial layer thus takes into account over 1.3 million of complex polygons. Damage to cultural heritage is provided as a separate polygon layer in the application. For the damage calculations, the application only takes into account those data whose attribute values relate to the spatial districts considered. Such data preparation allows for optimisation of calculation capacities, which permits the running of calculations on regular computers.
- **Line layers** are based on the data from the Cadastre of Public Infrastructure Works, such us public roads, utility network, and energy network, and provide the basis to determine damage to separate entities. Similarly, to the polygon layer, the spatial layer is set up by capturing line data, totalling at over 100,000 records in this data layer. For the calculations, the application takes into account only those attribute data that relate to the selected calculation area – spatial district – considered. As a separate line layer the application includes the calculation of damage to rivers, which is shown separately from other calculations.
- **The point data** included in the application cover industrial facilities, passenger cars, and compensations for lacking a habitable residence. The availability of the databases in restricted as regards the usage of personal data (population records, employment), for which there are legal provisions on personal data protection in place. Therefore, personal data (population, passenger cars) are included as a generalisation, calculated from the total number of entities present in a spatial district. In the application, legal entities are considered in terms of the size of the enterprises and the associated spatial district. The point data layer includes around 500,000 entries.

3.2 Annual damage curve

KRPAN enables calculation of flood damage estimation for any area in Slovenia. If we have data of several flood events with the associated probability of occurrence and the associated extent of damage caused by the event, we can construct a curve of the expected damage as a function of the probability of occurrence of events. The expected damage is higher in events with low probability of occurrence, and *vice versa*. To construct a curve, we need at least 3 points (Figure 1). With more events data, the actual curve provides a better approximation. In Slovenia, flood hazard maps are prepared for discharges with return periods of 10, 100, and 500 years. Therefore, KRPAN was developed to allow for the calculation of expected annual damage based on these maps.

3.3 Calculation steps

We can divide the calculation procedure into 2 major steps:

- **Step 1 - Definition of the calculation area:** The application allows for the input of the calculation area in Google Earth environment or using any other GIS tool. National flood hazards maps can be used to define the area concerned, which are as a rule used to analyse flood damage prior to introducing flood mitigation measures, and detailed flood hazards maps used for analyses after the measures have been put in place. The desired area can be manually selected in Google Earth directly, if there are no flood maps available. The calculation area has to be saved in the *shapefile* format for further calculation steps.

- **Step 2 - Calculation in KRPAN:** Once the study area is saved in the appropriate format, the user can continue with the calculation process in the application. The flood damage calculation is always run for the cases, i.e. before and after the planned measure. The application allows for two methods of damage calculations: when water depth is provided, damage is calculated using damage curves for known water depths during flood events. When the water depth is not known, the application calculates damage using damage curves by adopting the default average depth of floods in Slovenia (0.62 m). KRPAN is designed as a console application, which means that it is used via a text-only computer interface (command-line interface, CLI). Because the calculation of the expected flood damage is a complex task due to the amount of data to be processed in the background, the use of this type of an application is more appropriate than using a program with a graphical user interface (GUI). The CLI program allows faster completion of the tasks and it takes a lot less computer system resources than GUI (e.g. Mauro, 2018).

3.4 Results

The result of the calculation can be displayed in the GIS (at the element level of detail) or in MS Excel. Figure 2 shows the graphical representation of the input data, which are then shown on the screen in the Google Earth environment as polygons, lines, or point. By clicking the selected element a table is generated showing the basic attribute data (basic information on the structure, zoned land use, damage class) and the amount of damage in a flood event for each element separately. If the user was calculating the expected annual damage, MS Excel summary table is generated automatically (Figure 3).

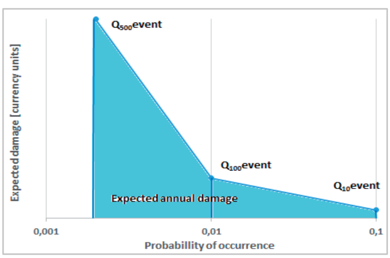

Figure 1. Example of expected annual damage curve based on three points

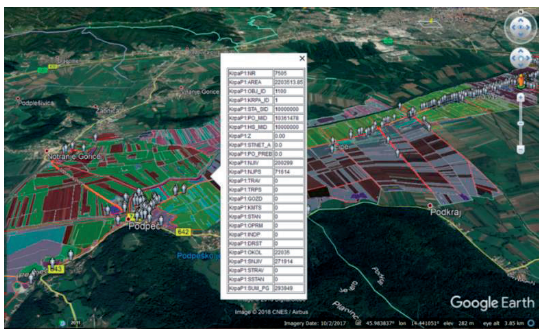

Figure 2. Display of the assessed flood damage in the Google Earth application at the element level of detail

The final table shows damage calculations bytaking into account the size of floods occurring with various probabilities (10-, 100-, and 500-year return periods) and the expected annual damage per individual element at risk and the expected total annual damage in the area concerned. The benefit of the planned measure for damage reduction during floods is evaluated as the difference between the expected damage prior to the measure and the expected damage after the measures have been put in place.

3.5 Results analysis

The largest percentage of the estimated flood damage represent damage to the building structure (~60 %), followed by economic damage (~30 %), while damages in other sectors do not exceed 10 % in total.

Računsko območje:	lokacija			
Ocenjeno število ogrožencev:	0	113	120	
OGROŽENO	Škoda_Q010(€)	Škoda_Q100(€)	Škoda_Q500(€)	**PLŠ(€)**
KULTURNA DEDIŠČINA - Profana stavbna dediščina	0	13.728	27.451	782
INFRASTRUKTURA - Državne ceste	2.906	74.020	97.697	4.149
INFRASTRUKTURA - Lokalne ceste	0	16.297	32.917	930
INFRASTRUKTURA - Gozdne ceste	636	65	249	33
INFRASTRUKTURA - Elektroenergetsko podzemno omrežje	2.751	20.528	21.466	1.216
INFRASTRUKTURA - Vodovodno omrežje	16.384	43.970	45.135	3.072
INFRASTRUKTURA - Kanalizacijsko omrežje	1.607	28.549	30.848	1.595
KMETIJSTVO - Njiva	12.313	16.235	16.536	1.416
KMETIJSTVO - Posevki_njiva	8.804	11.611	11.826	1.012
KMETIJSTVO - Travnik	2.398	4.465	4.675	345
KMETIJSTVO - Posevki_travnik	7.410	13.806	14.452	1.068
KMETIJSTVO - Gozd	139	267	335	21
GRAJENE POVRŠINE - Čiščenje in dekontaminacija	5.379	68.794	77.087	3.921
GRAJENE POVRŠINE - Osebna vozila	8.185	104.715	117.334	5.969
STAVBE - Konstrukcija, kmetijska oprema in mehanizacija	0	239.874	255.855	12.777
STAVBE - Konstrukcija stanovanjske stavbe	1.399	1.301.625	1.313.414	69.096
STAVBE - Oprema stanovanjske stavbe	823	765.915	772.852	40.658
STAVBE - Konstrukcija industrijske in poslovne	0	49.762	49.762	2.637
STAVBE - Konstrukcija druge stavbe, pomožne	1.814	96.132	95.644	5.175
OKOLJE - Estetska vrednost, biodiverziteta	29.175	47.280	49.394	3.827
PROMET - Osebna vozila	0	71.820	76.074	3.823
STANOVANJA - Prebivalci nadomestno začasno bivanje	0	67.808	71.827	3.610
IND. IN POSL. SUBJEKTI - Oprema, stroji in zaloge_mikro družba	0	5.600	5.600	297
IND. IN POSL. SUBJEKTI - Oprema, stroji in zaloge_majhna družba	0	16.000	16.000	848
IND. IN POSL. SUBJEKTI - Izpad prihodkov_mikro družba	0	1.400	1.400	74
IND. IN POSL. SUBJEKTI - Izpad prihodkov_majhna družba	0	11.200	11.200	594
VODE - Vodotoki	50.028	247.185	768.026	17.435
Skupno (€)	152.151	3.338.651	3.985.056	186.380
Nepredvidene škode 10% (€)	301.396	6.589.554	398.506	18.638
SKUPNA PRIČAKOVANA LETNA ŠKODA (zaokroženo na 000 €)	454.000	9.928.000	4.384.000	**205.000**

Figure 3. Summary of the assessed flood damage in an excel table. Results are given per sector and per events with 10-, 100-, and 500-year return periods. In the last column (PLŠ), the expected annual flood damage is calculated

Therefore, for calculating flood damage to the building structure, we checked the adequacy of the methodology and KRPAN in two ways: 1) by comparing the selected construction price with the NACER model, 2) by comparing the results with the AJDA data (URSZR, 2018).The selected construction price in KRPAN is 800 EUR/m^2 by taking into account the vulnerability factor, which is comparable with the price in the NACER model for the Republic of Croatia, where the value was 780 EUR/m^2 (5.700 kn) (Brilly et al., 2014). The estimated flood damage by considering the flood damage curve at the average depth of flood water in Slovenia (i.e. 0.62 m) on the construction of the building amounts to 170 EUR/m^2. The estimated damage is comparable with the data from AJDA reports on the flood damage from past events and with the costs reported in the restoration project after the flood event in Kostanjevica na Krki, Slovenia.

CONCLUSIONS

One of the main advantages of the proposed upgraded methodology is its transferability to the entire territory of the Republic of Slovenia. We would like to point out that despite the in-depth preparation and extensive work involved in the development of this methodology and KRPAN, the results must be evaluated from objective and professional points of view. As some data had to be generalised or they were not available, the result of the calculation is an estimate of the expected future damage if a flood event with a return period T occurs in a specific area rather than the actual amount of the expected damage. The use of the method and the application is primarily intended for decision and policy makers in managing the risks associated with flood damage, in order to determine the relevance of the proposed flood protection measures. Some flood protection measures may not be of benefit to a wider society, but are important for the local community, and *vice versa*.

There are still some challenges for the future improvement of the methodology, and thus of KRPAN, especially in terms of automated updating of data. The application is designed in a way that allows for its usage, without limitations, also outside Slovenian territory. As a pre-requisite, spatial data must be appropriately processed and adjusted according to the characteristics and availability of databases for the area concerned.

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