Dwustopniowa aplikacja KRPAN do obliczania korzyści wynikających z zastosowania środków ochrony przeciwpowodziowej

The two-step KRPAN application for calculating the benefits of flood protection measures

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Summary

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 (cultural heritage, natural environment, residential, agricultural and business sector). For each of the sectors a simple equation is used to calculate the damage cost, taking into account 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 GIS. According to their type, the input data are based on three main forms: point, line, and polygon. For each type of data separate databases were established. The developed application was tested for three flood areas in Slovenia. According to the results it was adjusted to be used by various groups of users. For now, this application enables calculation of annual expected damage for the territory of the Republic of Slovenia. However, with an appropriate modification and adjustments of the methodology and KRPAN (depending on the available data in other countries), both the methodology and application could be transferred to other countries.

1. Introduction

Reducing the risks of adverse consequences associated with floods is one of the main purposes of the Directive 2007/60/EC on the assessment and management of flood risks. Therefore, in all EU Member States various activities are being carried out in order to reduce flood risk. One of the activities that Member States put a lot of emphasis on is flood damage assessment. According to Merz et al. [2010], in this way decision and policy makers can receive important information for effective flood risk management.

Not only in Europe, but also elsewhere in the world, different methodologies have already been developed for flood damage estimation. Methodologies differ from one another depending on whether damage is estimated based on the past flood events (empirical data) or whether one is estimating the potential damage in the future (synthetic data) [Meyer et al. 2013]. Due to different purposes of use and data availability different models for estimation of expected or potential flood damage were developed and applied [Jongman et al. 2012]. For example, FLEMOps and FLEMOcs [Thieken et al. 2008; Kreibich et al. 2010] were developed in Germany for direct monetary estimation of damage in the private and commercial sector, respectively. In Croatia, the NACER model was developed for assessing flood damage for 7 different sectors [Vidmar et al. 2015; Zabret et al. 2018]. For estimating flood damage at the macro level, a pan-European model was developed by EU's Joint Research Centre [Huizinga et al. 2007]. Despite a number of already developed models, their transferability is questionable and difficult. Kreibich and Neuhold [2012] have shown that direct transfer of the model that was developed for a specific area can cause large errors in damage assessment for a different area.

Therefore, in 2014 a methodology for Slovenia was developed [IzVRS 2014]. This methodology was designed to enable calculation of expected flood damage before and after flood protection measure implementation (i.e. benefits of measures) for four sectors: human health, the environment, cultural heritage, and economic activity. However, in 2017 the Slovenian Ministry of the Environment and Spatial Planning recognized the need to upgrade the methodology and develop an application for calculating the expected annual damage. The need to improve the methodology was identified especially in the fields of cultural heritage, public infrastructure, watercourses, and water infrastructure. Moreover, the latest flood damage data should also be considered.

In this paper, we present the application KRPAN which was developed based on the upgraded methodology for assessing the benefits of constructional and non-constructional measures to reduce flood risk. Data that are used for the calculation are described in detail. For now, the application enables calculation of annual expected damage for the territory of the Republic of Slovenia. However, with an appropriate modification and adjustments of the methodology and KRPAN (depending on the available data in other countries), both the methodology and application could be transferred to other countries.

2. Methodology

The purpose of both the original methodology [IzVRS 2014] and the upgraded methodology is to support strategic decision making about the measures for reducing flood risk at the level of the state. The general equation for calculating the expected damage (*ED*) remained the same:

$$ED = M \cdot D \cdot E \cdot Vu \cdot Va$$

where: M is the magnitude 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 at 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.

However, there are four main differences in comparison with the original method:

1) Calculations are mostly based on the same spatial layers as those used in the original method, but in the upgraded method, this application allows for an easy and quick calculation of the benefits of constructional and non-constructional measures to reduce flood risk is enabled for users.
2) Results can be displayed in space for all sectors (in GIS).
3) The method allows the inclusion of additional parameters of damage that are linked to the statistics and are not geolocated.
4) KRPAN enables rapid analysis and production of various variant solutions.

KRPAN can be used for calculating the expected damage in any selected area. Moreover, if the user has flood hazard maps with the dimension of floods for a certain return period (e.g., 10-, 100-, 500-year return period), KRPAN calculates the expected annual damage. The expected annual damage (*EAD*) is defined as the area under the curve, which is determined with at least 3 points (Fig. 1).

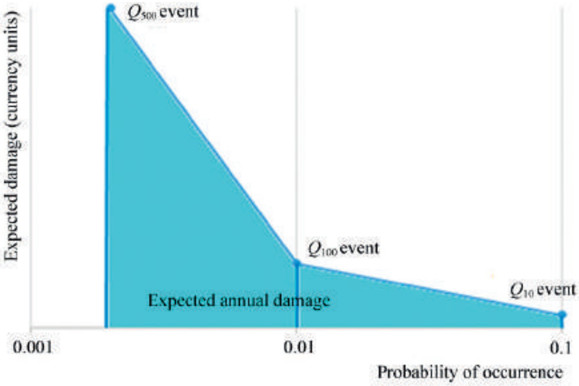


Fig. 1. Example of expected annual damage curve based on three points [Vidmar et al. 2019]

To evaluate the benefit of a planned or an implemented measure, one has to calculate the difference between the expected annual damage before the measure implementation and after its implementation (Fig. 2).

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. Also intangible damages such as environmental goods and services that have no market prices are covered. They are included by using the Contingent Valuation Method from the literature [Markantonis et al. 2013; IzVRS 2014]. 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]. Depth-damage curves, which are used for calculation of tangible damage to structures, equipment and other fixtures of residential buildings are adopted by 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.

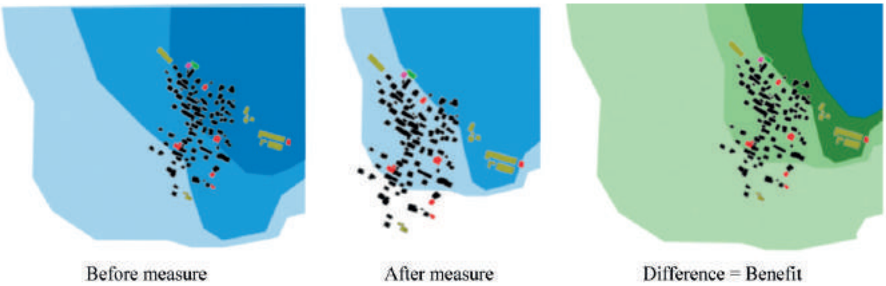


Fig. 2. Scheme of flood protection measure benefit [Vidmar et al. 2019]

3. KRPAN application

Both the methodology and KRPAN were developed based primarily on the data availability. The key process was the optimization of large-scale databases, since one of the main project goals was to develop an application that will operate on average-performance personal computers. This would not have been possible if the relational database had not been established. The relational database allows periodic updating of input data. All GIS tools that are necessary for the operation of KRPAN are freely available (e.g. SAGA [Conrad et al. 2015], GDAL) and built in the application. However, the geolocated redords can be opened and edited in any GIS software (e.g. Google Earth).

KRPAN application consists of several spatial modules (Fig. 3, Tab. 1): KrpaK, KrpaP, KrpaL, KrpaT (which altogether represent KrpaZ), and KrpaV.

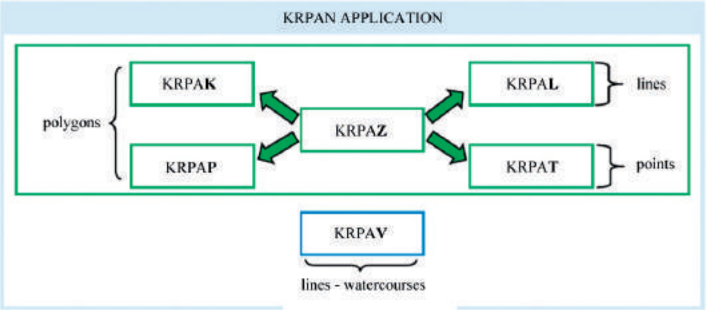


Fig. 3. Scheme of KRPAN application modules [Vidmar et al. 2019]

3.1. Input data

To enable KRPAN to operate in a GIS environment, we first divided the input data according to the data types: lines, points, polygons. Below, each module is described more in detail.

Table 1. Modules of KRPAN application

Module	Type of spatial layer	Source of data
KrpaP	polygons	Building Cadastre, Register of Spatial Units, Real Estate Register, Land Use, Central Residential Register
KrpaL	lines	Cadastre of Public Infrastructure
KrpaT	points	Central Residential Register, Slovenian Business Register, IPPC and SEVESO
KrpaK	polygons	Intangible Cultural Heritage of Slovenia
KrpaV	lines	Hydrology

3.1.1. KrpaP – polygons

For the entire Slovenian territory, the KrpaP spatial layer was established. To reduce the amount of data in the layer, the only attribute data is "NR", i.e. the sequence number of each polygon. When using the application, other attributes are added for the calculation area (Fig. 4). This kind of an approach to optimizing the amount of data was necessary to enable using KRPAN on average personal computers. However, the KrpaP spatial layer consists of 1,343,060 complex polygons.

3.1.2. KrpaL – lines

KrpaL was established similarly – the only attribute data in the spatial layer is the sequence number "NR" of each line element. When using KRPAN for calculating the expected damage, other attributes are added for elements located in the calculation area. However, even after the optimization, the line spatial layer KrpaL contains more than 110,000 line elements.

3.1.3. KrpaT – points

KrpaT is the module for spatial calculation of potential flood damages for elements which are in space represented by points. Points graphically represent the locations of cen-

Fig. 4. Relational database of polygon data type [Vidmar et al. 2019]

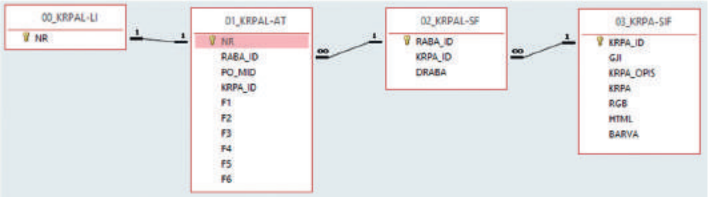


Fig. 5. Relational database of line data type [Vidmar et al. 2019]

troids of the buildings, to which other descriptive data or attributes of flood damages are linked. Point entities are, for example, personal vehicles, companies, and replacement housing. The basis for establishing graphical module KrpaT were the centroids of buildings.

3.1.4. KrpaK – cultural heritage

KrpaK is a polygon layer, which was prepared on the basis of data from the Slovenian Register of Immovable Cultural Heritage. In the layer, tangible and intangible values were calculated for each element. When performing calculation of damage using KRPAN, the values of elements are taken into account in proportion according to how much of the element is located in the calculation area. Figure 6 shows an example of cultural heritage data, which were included into the calculation procedure at Vipava case study.

3.1.5. KrpaV – watercourses

KrpaV consists of hydrological line data and the code list prepared based on these data. Since the KrpaV module is separated from other line data modules and because the data range enables additional attributes, some original data on the hydrology are visible in the output files. This is important and helpful for users of KRPAN, who are in this way able to determine the sections of the watercourses that will be regulated and/or protected against flood events with a certain return period. Watercourses are classified into 5 different torrential areas and 2 classes of watercourse widths. Moreover, potential damages can be calculated for discharges with 10-, 100- or 500-year return periods. The values for calculating flood damage in the watercourses were determined based on the damages recorded in the past flood events (Fig. 7).

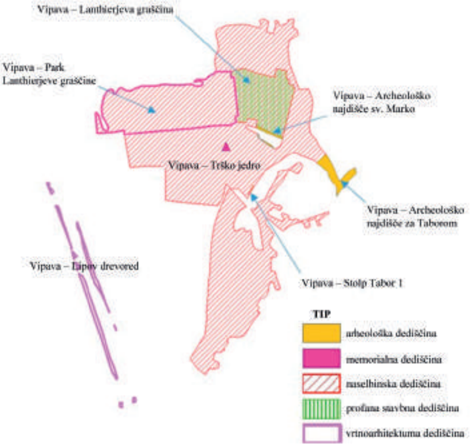


Fig. 6. Display of elements of cultural heritage at Vipava case study [Vidmar et al. 2019]

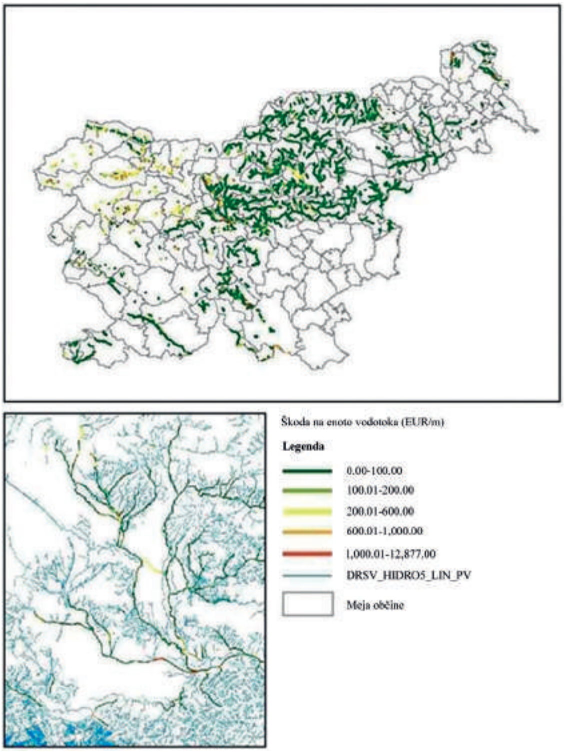


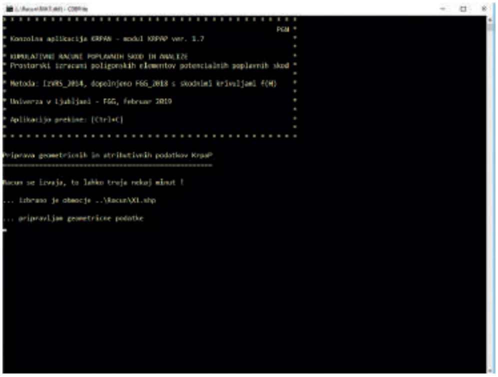
Fig. 7. Recorded flood damage on watercourses in past flood events; the damage is shown in EUR/metre of a watercourse [Vidmar et al. 2019]

3.2. Calculation procedure

Calculation of expected damage is based on pre-prepared spatial layers that are intersected by the flood affected area. The calculation procedure can be divided into two main steps: (1) definition of the calculation area, and (2) calculation in KRPAN. In the first step, the user defines the calculation area by using Google Earth (Fig. 8) or any other GIS software. Also national flood hazard maps can be used for the definition of the area concerned. Flood hazard maps are used to analyse the benefits of the proposed flood protection measures. In this case, the user will have to carry out two calculations, i.e. for the flooded area before implementation of the measure, and for the flooded area after the implementation of the measure. The difference in flood damage is called the benefit of the measures.

In the second step, the user continues with the calculation in KRPAN. KRPAN enables calculation of the expected flood damage for the cases when water levels are available and also for the cases when they are not. In the first case, damage is calculated using damage curves. When the water depth is not known, KRPAN adopts the default average depth of floods for the whole country (i.e. 0.62 m for Slovenia). The application is designed as a console application (Fig. 9), which means that it is used via a text-only computer interface (command-

Fig. 8. Example of a selected calculation area in Google Earth [Vidmar et al. 2019]



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*                                                                  PGM *
* Konzolna aplikacija KRPAN - modul KRPAP ver. 1.7                     *
*                                                                      *
* KUMULATIVNI RACUNI POPLAVNIH SKOD IN ANALIZE                          *
* Prostorski izracuni poligonskih elementov potencialnih poplavnih skod *
*                                                                      *
* Metoda: IzVRS_2014, dopolnjeno FGG_2018 s skodnimi krivuljami f(H)   *
*                                                                      *
* Univerza v Ljubljani - FGG, februar 2019                             *
*                                                                      *
* Aplikacijo prekine: [Ctrl+C]                                         *
*                                                                      *
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Priprava geometricnih in atributivnih podatkov KrpaP
=====================================================

Racun se izvaja, to lahko traja nekaj minut !

... Izbrano je obmocje ..\Racun\X1.shp

... pripravljam geometricne podatke
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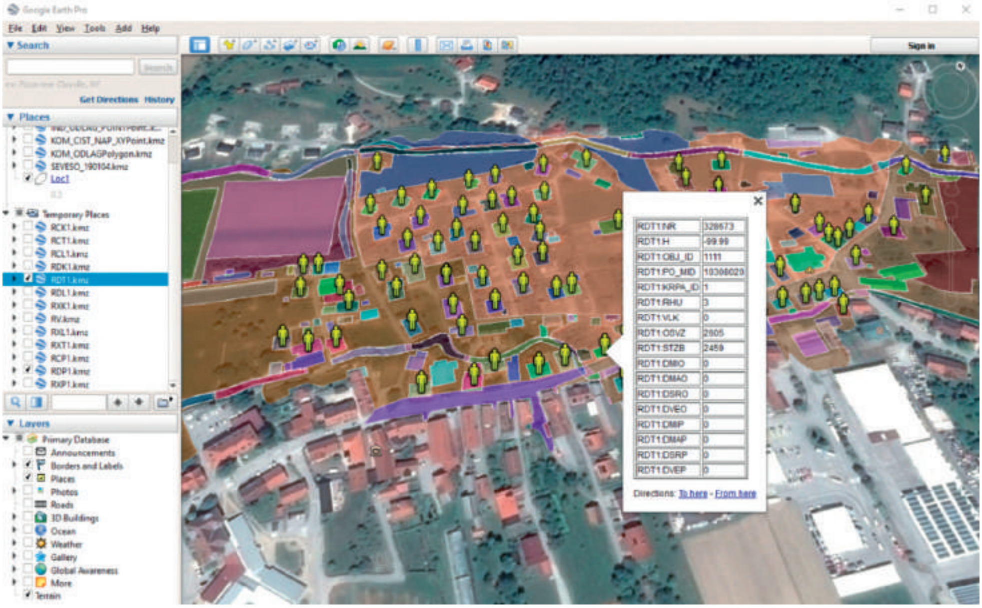
Fig. 9. KRPAN console application during the calculation [Vidmar et al. 2019]

line interface, CLI). The reason for selecting this kind of application is in complex background tasks of data processing. It is well known that CLI programs allow faster completion of tasks and they consume a lot less computer system resources than graphical user interfaces [e.g. Mauro 2018].

3.3. Results

The result of the calculation, i.e. expected flood damage, can be displayed in two ways: (1) in GIS, and (2) in spreadsheet programs such as MS Excel. Figure 10 shows the graphical representation of the results in Google Earth. For each of the selected elements a table can be generated showing the basic attribute data (basic information on the structure, zoned land use, damage class). Beside this, the amount of damage for a certain flood event can be shown for each element just by clicking on it.

Table 2 shows flood damage calculation by taking into account the dimension of floods occurring with probabilities of 10-, 100-, and 500-year return periods. In the bottom right corner of the table, the total expected annual damage is calculated. To evaluate the benefits of the planned measures to reduce flood risk, the user has to make two calculations; first for the size of floods before the measure implementation and second for the size of floods after the implementation. The difference between EADs is the benefit of a measure.



RDT1:NR	328673
RDT1:H	-99.99
RDT1:OBJ_ID	1111
RDT1:PO_MID	10308020
RDT1:KRPA_ID	1
RDT1:RHU	3
RDT1:VLK	0
RDT1:OSVZ	2805
RDT1:STZB	2459
RDT1:DMIO	0
RDT1:DMAO	0
RDT1:DSRO	0
RDT1:DVEO	0
RDT1:DMIP	0
RDT1:DMAP	0
RDT1:DSRP	0
RDT1:DVEP	0

Fig. 10. Display of the assessed flood damage in the Google Earth application at the element level of detail [Vidmar et al. 2019]

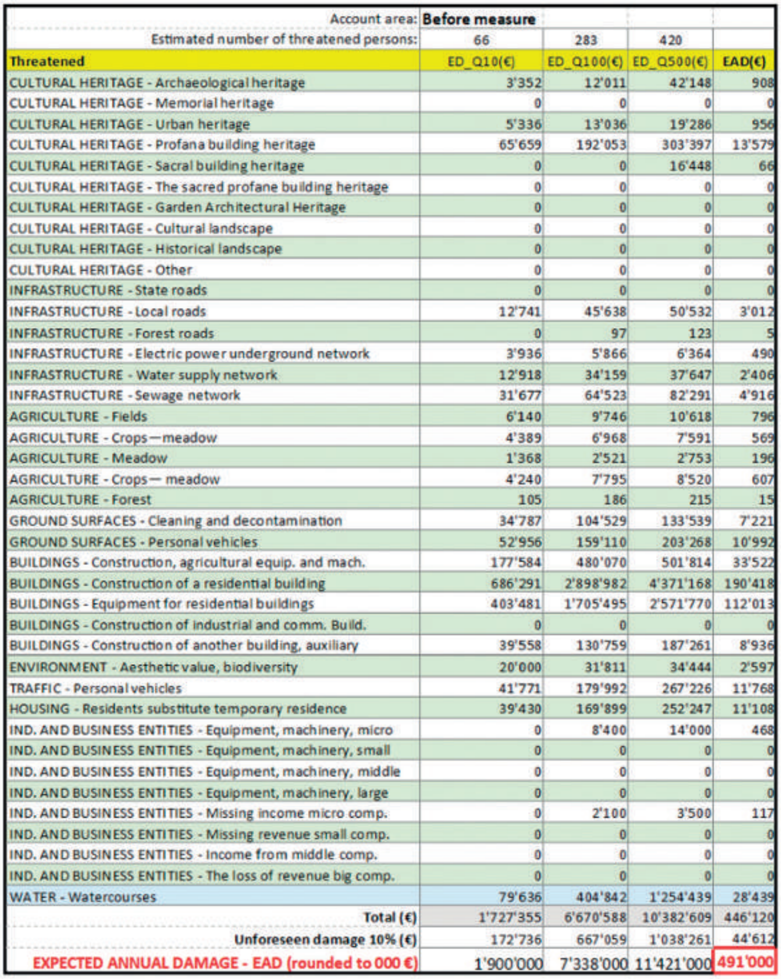
During the project of upgrading the methodology, several calculations at different case studies in Slovenia have been made (e.g. Vipava River, Dravinja River). On average, the largest percentage of the estimated flood damage is the damage to building structures (approx. 60%), followed by economic damage (approx. 30%). Damages in other sectors do not exceed 10% in total.

The adequacy of the proposed upgraded methodology, and consequently of KRPAN, was checked. For example, for damages to building structures we compared the results from KRPAN (1) with those of the NACER model and (2) with the AJDA data (damages recorded in the past flood events). In KRPAN the price for construction was set at 800 EUR/m^2 by taking into account the vulnerability factor. This is comparable with the price used in the NACER model for the Republic of Croatia, where the value was 780 EUR/m^2 [Brilly et al. 2014]. Moreover, the selected price in KRPAn is comparable with the costs reported in the restoration project after the flood event in Kostanjevica na Krki, Slovenia.

4. Conclusions

One of the main advantages of the presented upgraded methodology and the KRPAN application is their transferability to the entire Republic of Slovenia. The calculation procedure is relatively easy, fast and user friendly. Also users with no or little experience in using

Table 2. 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 before the implementation of the measure; the expected annual flood damage is calculated in the last column (*EAD*)



Account area:	**Before measure**			
Estimated number of threatened persons:	66	283	420	
Threatened	ED_Q10(€)	ED_Q100(€)	ED_Q500(€)	**EAD(€)**
CULTURAL HERITAGE - Archaeological heritage	3'352	12'011	42'148	908
CULTURAL HERITAGE - Memorial heritage	0	0	0	0
CULTURAL HERITAGE - Urban heritage	5'336	13'036	19'286	956
CULTURAL HERITAGE - Profana building heritage	65'659	192'053	303'397	13'579
CULTURAL HERITAGE - Sacral building heritage	0	0	16'448	66
CULTURAL HERITAGE - The sacred profane building heritage	0	0	0	0
CULTURAL HERITAGE - Garden Architectural Heritage	0	0	0	0
CULTURAL HERITAGE - Cultural landscape	0	0	0	0
CULTURAL HERITAGE - Historical landscape	0	0	0	0
CULTURAL HERITAGE - Other	0	0	0	0
INFRASTRUCTURE - State roads	0	0	0	0
INFRASTRUCTURE - Local roads	12'741	45'638	50'532	3'012
INFRASTRUCTURE - Forest roads	0	97	123	5
INFRASTRUCTURE - Electric power underground network	3'936	5'866	6'364	490
INFRASTRUCTURE - Water supply network	12'918	34'159	37'647	2'406
INFRASTRUCTURE - Sewage network	31'677	64'523	82'291	4'916
AGRICULTURE - Fields	6'140	9'746	10'618	796
AGRICULTURE - Crops—meadow	4'389	6'968	7'591	569
AGRICULTURE - Meadow	1'368	2'521	2'753	196
AGRICULTURE - Crops— meadow	4'240	7'795	8'520	607
AGRICULTURE - Forest	105	186	215	15
GROUND SURFACES - Cleaning and decontamination	34'787	104'529	133'539	7'221
GROUND SURFACES - Personal vehicles	52'956	159'110	203'268	10'992
BUILDINGS - Construction, agricultural equip. and mach.	177'584	480'070	501'814	33'522
BUILDINGS - Construction of a residential building	686'291	2'898'982	4'371'168	190'418
BUILDINGS - Equipment for residential buildings	403'481	1'705'495	2'571'770	112'013
BUILDINGS - Construction of industrial and comm. Build.	0	0	0	0
BUILDINGS - Construction of another building, auxiliary	39'558	130'759	187'261	8'936
ENVIRONMENT - Aesthetic value, biodiversity	20'000	31'811	34'444	2'597
TRAFFIC - Personal vehicles	41'771	179'992	267'226	11'768
HOUSING - Residents substitute temporary residence	39'430	169'899	252'247	11'108
IND. AND BUSINESS ENTITIES - Equipment, machinery, micro	0	8'400	14'000	468
IND. AND BUSINESS ENTITIES - Equipment, machinery, small	0	0	0	0
IND. AND BUSINESS ENTITIES - Equipment, machinery, middle	0	0	0	0
IND. AND BUSINESS ENTITIES - Equipment, machinery, large	0	0	0	0
IND. AND BUSINESS ENTITIES - Missing income micro comp.	0	2'100	3'500	117
IND. AND BUSINESS ENTITIES - Missing revenue small comp.	0	0	0	0
IND. AND BUSINESS ENTITIES - Income from middle comp.	0	0	0	0
IND. AND BUSINESS ENTITIES - The loss of revenue big comp.	0	0	0	0
WATER - Watercourses	79'636	404'842	1'254'439	28'439
Total (€)	1'727'355	6'670'588	10'382'609	446'120
Unforeseen damage 10% (€)	172'736	667'059	1'038'261	44'612
EXPECTED ANNUAL DAMAGE - EAD (rounded to 000 €)	1'900'000	7'338'000	11'421'000	**491'000**

GIS tools are able to use KRPAN. However, results still need to be evaluated from objective and professional points of view. Besides, some of the input data were not available or had to be generalised. Therefore, one should have in mind that the result is still an estimate of the expected damage if a flood event with a return period T occurs in a specific area.

Just like the original method, the upgraded method and the KRPAN application are primarily intended to support strategic decision making about the measures for reducing flood risk at the level of the state. Some constructional or non-constructional measures to reduce flood risk may not be of benefit to a wider society, but are important for the local community, and *vice versa.* Therefore, an objective expert analysis of KRPAN's results is necessary.

During the project of upgrading the methodology and developing KRPAN we faced many challenges and some of them remain to be solved, such as automatic updating of data in KRPAN. KRPAN is designed in a way so that it can be used also outside Slovenian territory. However, before use, spatial data must be appropriately processed and adjusted according to the characteristics and availability of databases for the area concerned. We believe that with appropriate modifications and adjustments of the methodology and KRPAN (depending on the available data in other countries), both the methodology and application could be transferred to other countries.

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