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FOREWORD TO THE SPECIAL ISSUE OF THE JOURNAL OF ENVIRONMENTAL GEOGRAPHY ON CLIMATE CHANGE ADAPTATION IN THE DANUBE REGION

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The Danube Region represents one fifth of the European Union’s total area and is home to more than 100 million inhabitants. The region is comprised of 9 EU (*Austria, Bulgaria, Croatia, Czech Republic, Germany, Hungary, Romania, Slovakia and Slovenia*) and 3 accession countries (*Bosnia and Herzegovina, Montenegro, Serbia*) and also involves 2 neighbourhood countries (*Moldova and Ukraine*). The states show significant regional disparities in economic and social development. In order to increase growth and strengthen cooperation at a macro-regional level the European Union adopted the EU Strategy for the Danube Region (EUSDR) in 2011 under the period of the Hungarian EU Presidency. EUSDR is established with eleven priority areas to harmonise development policies connecting these 14 countries.

Water is one of the most important natural resources, basic elements of the human life and its quality determines the quality of our life. EUSDR Priority Area 4 (PA4; https://www.danubewaterquality.eu/) of the EUSDR aiming at to maintain and restore the quality of waters, to ‘safeguard Europe’s water resources’, furthermore to assist in the implementation of the EU Water Framework Directive (WFD) and the Urban Waste Water Treatment Directive.

The Environmental Risks Priority Area (PA5; https://www.danubeenvironmentalrisks.eu/) of the Danube Region Strategy coordinated by Hungary and Romania has three major objectives to follow during its work in close cooperation with the International Commission for the Protection of the Danube River (ICPDR) and shares the responsibility for the realization of them. First, PA5 addresses the challenges of water scarcity and droughts based on the 2013 update of the Danube Basin Analysis and the ongoing work in the field of climate adaptation. Secondly, support to implement Danube wide flood risk management plans – under the Floods Directive – to reduce flood risks significantly by 2021. Third, it works to update the accidental risk spots’ inventory at the Danube River Basin level. The most significant activity in the field of environmental risks is to facilitate the flood protection of the Region and to enhance the flood safety of the whole Danube Basin. In order to secure the long-term management possibilities, the technical education needs consolidation and a training scheme is under elaboration by the PA5. Though the emphasis is on high water regime, PA5 still considers drought and ice management as equally potential scarcities. We aim to step forward in the awareness and preparedness level of the inhabitants with pilot sites for coordination of operative flood management and civil protection plans. To achieve the goals EUSDR PA5 heavily support project preparations and executions, creating informational material and provide dissemination via the website, plus organizing and participating on project kick-off meetings, consultations and project development workshops, seminars. PA4 and PA5 are working closely to gain additional values.

The EUSDR PAs are driven by a mutually accepted action plan where the countries endorsed the main topics they are collaborating on. Significant policy impact and technical progress is traceable regarding climate change adaptation in PA5 Action-7 “Anticipate regional and local impacts of climate change through research” and Action-8 “To develop spatial planning and construction activities in the context of climate change and increased threats of floods”.

EUSDR PA5 is intended to harmonize EU-wide, Danube region and sub-regional level activities. Therefore, PA5 Hungarian coordination gave its opinion in December 2017 to the update of EU Strategy on Adaptation to Climate Change carried out by DG CLIMA in order to secure feedback to the role of EU macro-regional strategies in climate change adaptation. Cooperation started at the end of 2017 with the other 3 macro-regional strategies of EU on the field of risk management and climate change issues, first with a workshop in Budapest (November 2017) and culminated in the jointly organized conference session of the EU Civil Protection Forum 2018 in Brussels (March 2018). The Coordination also involved in the peer-review of the „Adaptation policies and knowledge base in transnational regions in Europe” ETC/CCA technical paper.

Closer cooperation started with Global Water Partnership CEE from the second half of 2017 related to their Integrated Drought Management Programme for the better management of drought and water scarcity issues in the DRB. EUSDR PA5 joined to the initiation of Global Water Partnership and carries out a common European drought and water scarcity EU level policy review in 2018.

ICPDR “Climate Change Adaptation Study Update 2018” process was elaborated in 2017. PA5 contributed to the first review of the document and later on contributed to the preparation of the Danube Region Climate Change Adaptation Strategy.

EU SDR PA5 Hungarian coordination announced the Call for Paper in March 2018 of “Climate Change Adaptation in the Danube Region”, as financing and launching the special issue of the Journal of Environmental Geography thanks to the Interreg Danube Transnational Programme DTP-PAC1-PA5 project (Fig. 1.). Thus, novel scientific results and best practices have been collected from different fields of climate change adaptation. As an important element of our task, the issue also highlights areas where transboundary cooperation is a great potential– since being the core element of the EUSDR.

Fig. 1 Project financed by European Union fund (ERDF) and Hungary

Dear Reader, we have seven great articles in this special issue of the Journal, which are proud to hand over for the knowledge benefit for all of us. It is interesting to follow the development of the research activities in individual institutes and joint projects in the topic of climate change adaptation that is one of the most urging issues in the Danube Basin and the actually in the entire World nowadays. Wish you a pleasant time to browse!

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CHANGES IN FLOODPLAIN VEGETATION DENSITY AND THE IMPACT OF INVASIVE *AMORPHA FRUTICOSA* ON FLOOD CONVEYANCE

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Abstract

Flood conveyance of floodplains is significantly influenced by the riparian vegetation cover, since vegetation affects flow velocity, therefore has a considerable impact on flood height and rate and pattern of sedimentation. However, climate change promotes the spread of invasive species, and their rapid growth results in dense vegetation stands, thus they have a significant impact on floodwater hydraulics. The aims of the present study are (1) to analyse the long-term changes in land-use and vegetation density on the Lower Tisza River, (2) to evaluate the role of the invasive *Amorpha fruticosa* in increasing vegetation density, and (3) to model the effect of dense floodplain vegetation on flood level and flood conveyance. Long-term (1784-2017) changes of land-use suggest that in natural conditions the study area was occupied by wetlands (92%), thus water covered the area for almost the whole year. In the 19th century, after levee constructions the wetlands were replaced by meadows and pastures (94%), then by the end of the 20th century planted and riparian forests replaced these land-covers. As a result, the mean roughness (0.14) of the floodplain has increased threefold until the early 21st century. Today forests are invaded by *Amorpha fruticosa*, which increases the vegetation density by 3% in riparian forests, by 23% in forest plantations, and by up to 100% in abandoned pastures and arable lands. According to the results of HEC-RAS *(Hydrologic Engineering Center's River Analysis System)* and CES *(Conveyance Estimation System)* models, if floodplain vegetation was managed and *Amorpha fruticosa* was cleared from the floodplain, peak flood level would decrease by 15 cm. Due to dense vegetation, the flood conveyance decreased by 4-6%, and the presence of *Amorpha fruticosa* reduced the flood flow velocities by 0.014-0.016 m/s. Accordingly, clearance of the floodplain from *Amorpha fruticosa* would have positive effects on flood protection, since peak flood stages would decrease and flood waves would shorten.

Keywords: vegetation, roughness, floodplain, forests, *Amorpha fruticosa*

INTRODUCTION

The climate change and the resulted hydro-climatological extremities facilitates the spread of invasive species, thus they appear in large number and due to their rapid growth they form very dense vegetation stands, thus they have a significant impact on the ecosystem (Didham et al., 2005) and on vegetation density (Delai et al., 2018), resulting in changes in floodwater hydraulics.

One of the most important elements of effective floodplain management and flood protection is providing unobstructed flood conveyance on floodplains (Samuels et al., 2002). Flood conveyance of floodplains is influenced by several local factors, e.g. water surface width, the floodplain's surface roughness, built-in structures, and floodplain aggradation (Rátky and Rátky, 2009). The roughness of the floodplain's surface is significantly influenced by vegetation, as plants could alter flow conditions and affect flow velocities (Osterkamp and Hupp, 2010; Takuya et al., 2014; Devi and Kumar, 2016). As a result, dense vegetation significantly reduces flow velocity, which combined with accelerated sedimentation, deteriorates the flood conveyance on floodplains (Chow, 1959). This could result in increased flood levels, thus increased flood risk (Wang et al., 2015).

The impact of vegetation on flow conditions is complex, as it depends on the density and height of the vegetation, on its phenological phase, morphological and structural characteristics (Chow, 1959; Wang et al., 2015; Vargas-Luna et al., 2015). Vegetation density is primarily determined by the species (Antonarakis et al., 2010), the number and rigidity of stems (Freeman et al., 2000; Galema, 2009), and the density of foliage (Ree and Crow, 1977; Järvelä, 2004; Antonarakis et al., 2010), thus it can vary by season (Burkham, 1976; Coon, 1998). The denser vegetation and more rigid stems create greater obstructions to flood flow, resulting in reduced flow velocity. In extreme cases (very dense vegetation and low water slope) the flow velocity can be reduced to 0 m/s (Sándor and Kiss, 2007). Decrease in flow velocity depending on the height of the vegetation cover, as if the height of inundation exceeds the height of the vegetation, the flow velocity can recover to normal, since there is no obstruction in the flow direction (Galema, 2009).

Floodplains provide optimal conditions for the spread of invasives, since these species survive periodical inundations, and their seeds can travel large distances by the floods invading farther areas (Pyšek and Prach, 1994). Invasive species tolerate burial by deposits (Schnitzler et al. 2007), extreme hydrological conditions, and they favour sunlight (Dumitraşcu et al., 2012). Human activities on floodplains also promote their dispersal, as new invasive species are often introduced, besides deforestation and abandonment of lands could help their invasions too (Pyšek and Prach, 1993; Planty-Tabacchi et al., 1996; Szigetvári, 2002; Mihály and Botta-Dukát, 2004).

High and long-lasting floods could be such a high magnitude of disturbing effects, that native species cannot necessarily tolerate (Catford and Jansson, 2014; Garssen, et al. 2015). On the Lower Tisza River in Hungary, for instance, floodplains can be inundated by 6-8 m high floods for 1-3 months, which has promoted the dispersal of invasive species, such as *Amorpha fruticosa*, *Echinocystis lobata* and *Vitis vulpina*. Nowadays, these species form very dense, impenetrable shrubbery in many areas on the floodplain (Fig. 1).

Fig. 1 (a) Mainly invasive species form impenetrable shrubbery and (b) Amorpha fruticosa bushes under a Poplar plantation (Lower Tisza River, Hungary)

Along the Tisza River *Amorpha fruticosa* causes the greatest problems, as it spreads very aggressively on the floodplain (Mihály and Botta-Dukát, 2004), thus its presence reduces flood conveyance considerably (Sándor and Kiss, 2007; Delai et al., 2017). *Amorpha fruticosa* originates from south-eastern North America, and it was introduced in Hungary at the end of the 19th century in order to stabilize riverbanks and to protect them from intensive erosion (Simonkai, 1893; Szigetvári and Tóth, 2012). The *Amorpha* forms 3-4 m high shrubbery (Mihály and Botta-Dukát, 2004), and according to previous measurements in these very dense shrubbery the flood flow velocity decreases to 0 m/s (Sándor and Kiss, 2007). Former researches were limited to the estimation of vegetation density (Chow 1959; Barnes 1967; Acrement and Schneider, 1989), they did not consider the role of invasive species, and they did calculated the influence of different floodplain management methods on flood conveyance, on peak flood levels, and did not model the role of invasive species on increasing flood hazard.

The aim of the present study is (1) to determine the long-term land use changes on the floodplain of the Lower Tisza River, and the effect of these changes on vegetation density; (2) to evaluate the role of the invasive *Amorpha fruticosa* in increasing vegetation density, and finally (3) to calculate the extent of flood level increase caused by the dense floodplain vegetation. The ultimate goal is to model the effect of two floodplain management scenarios on flood conveyance, thus what would happen if *Amorpha fruticosa* was cleared from the floodplain vegetation. The results of two different models (HEC-RAS and CES) will be compared to evaluate the reliability of the results.

STUDY AREA

The Tisza River is the second longest river in Hungary (length: 962 km, catchment area: 157,200 km^2). Since the middle of the 19th century the river has been significantly regulated, the formerly 5-10 km wide natural floodplain have been confined by artificial levees, thus today the active floodplain is just 1-4 km wide. Some bends have been cut off shortening the Tisza River by 457 km (32%). These affected the hydrology ad hydraulics of the river, the slope of the channel and the land-use of the floodplains.

The Tisza River is characterized by two floods, caused by early spring snow-melt and early summer rainfalls. The mean discharge of the Tisza River at Szeged gauging station is 810 m^3/s (maximum 4,346 m^3/s; Lászlóffy, 1982). As a result of the regulation works, flood levels have increased by 200-350 cm (Rakonczai and Kozák, 2009). The duration of floods on the Lower Tisza River is 54 days/year on average (Kiss 2014). Since the Tisza is a lowland river, its flood can be simultaneous with the floods of the tributaries or of the Danube, and they can block each other, thus long-lasting ad high floods could develop.

The mean water slope of the Tisza River is only 2.9 cm/km in the Hungarian section (Lászlóffy, 1982; Kiss, 2014). The bedload is fine sand (9,000 t/year; Lászlóffy, 1982), and the river transports a great amount of suspended silt and clay sediment (18.7 t/year; Lászlóffy, 1982). The average flow velocity is 0.1-0.15 m/s (Kiss, 2014).

The changes in vegetation density and flood conveyance were analysed on a 10 km long section (180-190 rkm) of the Lower Tisza River, north from the city of Szeged, at Algyő. The boundaries of the study area are not the borders of the natural floodplain, but the artificial levees built in the 19th century (Fig. 2). The mean channel width is 160 m, while the mean water depth is ca. 14 m, but during floods it could be as much as 19-20 m (Lászlóffy, 1982).

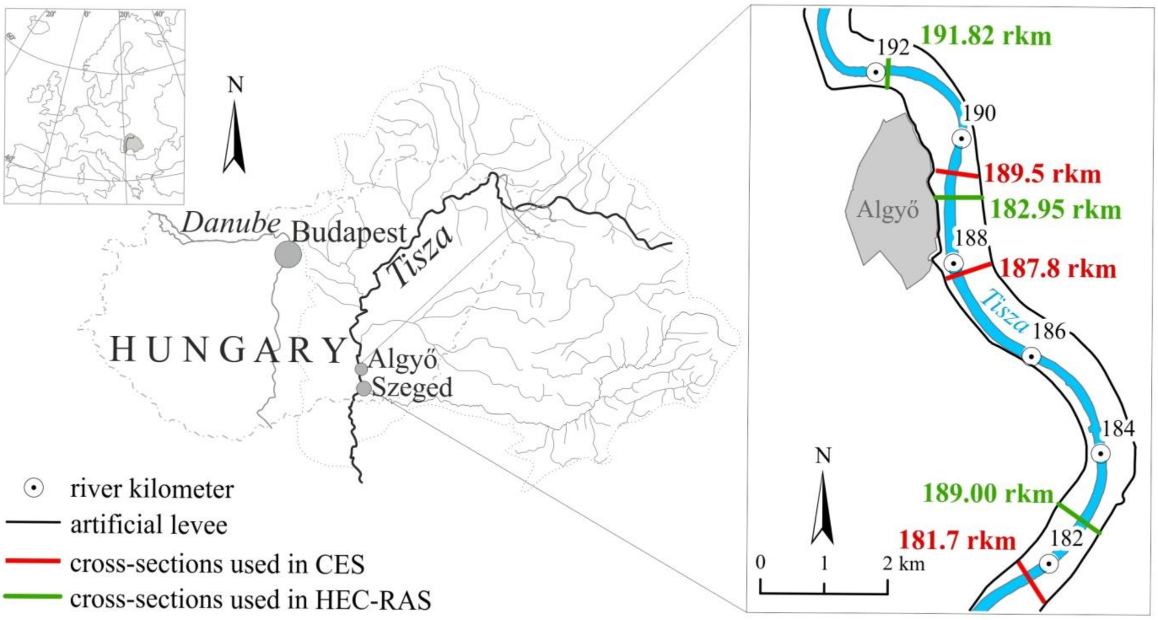

Fig. 2 Study area and the location of cross-section used in HEC-RAS and CES models

METHODS

The long-term land-use changes of the study area were analysed since the end of the 18th century, based on 1:28,000 scale maps of historic Military Surveys (1784, 1861-1864 and 1881-1884), a 1:10,000 scale topographic map (1980s), and Google Earth image (2017) were used. As a first step, the territory of the different land-use categories was determined on the geo-corrected spatial database. To evaluate the long-term impact of vegetation on surface roughness, the average roughness values (n_{1-n}) determined by Chow (1959) were assigned to each land-use category (Table 1). Then the average vegetation roughness of the study area at a given year (n_{year}) was weighted by the territory of each land-use category (A_{1-n}):

$$n_{year} = \frac{(A_1 \times n_1)+(A_2 \times n_2)+\cdots(A_n \times n_n)}{100} \qquad \text{Eq. 1}$$

Table 1 Applied land-use categories and their mean roughness values (Chow, 1959)

vegetation roughness category	land-use category	roughness coefficient
n_1	wetland	0.017
n_2	bare surface	0.018
n_3	forest	0.100
n_4	meadow, pasture	0.030
n_5	meadow, pasture with sparse trees and shrubs	0.050
n_6	orchard	0.050
n_7	arable land	0.040
n_8	artificial surface	0.013

As there are no previous data on the extension and density of the invasive *Amorpha fruticosa*, we mapped its density during the winter of 2017/2018 in three woody land-use categories: in forest plantations, in riparian forests and in abandoned arable lands, meadows and pastures where *A. fruticosa* has started to spread aggressively. The selected 15 plots represent the three land-use category quite well.

To determine vegetation density we used Warmink's (2007) photograph based Parallel Photographic (PP) Method, which could be used to calculate the area occupied by vegetation in a given volume. During the measurements photographs were taken in a quadrate (2 m x 3 m) in front a 2 m high and 3 m wide white screen (Fig. 3a), thus in a given quadrate the dark stems were well separated from the white background (Fig. 3b). After converting the photographs into black and white images (Fig. 3c), the area occupied by vegetation in front of the screen was be calculated. Inserting these calculated values into Equation 2 the vegetation density *(Dv_{PP})* in each quadrate was calculated (Warmink, 2007):

$$Dv_{PP} = -\frac{1}{L} * ln(1 - A_{tot}) \qquad \text{Eq. 2}$$

where L is the length of the white screen (3 m), and A_{tot} is the ratio of black pixels represented by vegetation. The Dv_{PP} is a non-dimensional value between 0.0 and 1.0. The vegetation density was calculated for two conditions: representing (1) the actual vegetation with *A. fruticosa*, and (2) an ideal, well-maintained condition without *A. fruticosa*. To calculate the latest, the *Amorpha fruticosa* stems were erased from the black and white images (Fig. 3d), and then vegetation density was re-calculated using Eq. 2.

The calculated vegetation density values were used in HEC-RAS (Institute for Water Resources, U.S. Army Corps of Engineers) and CES (UK Environmental Agency) models. The aim was to determine how flood conveyance would change in relation with vegetation density. During the modelling, we used the data of the 2006 record high flood (max. height: 1,062 cm; max. discharge: 2,720 m^3/s).

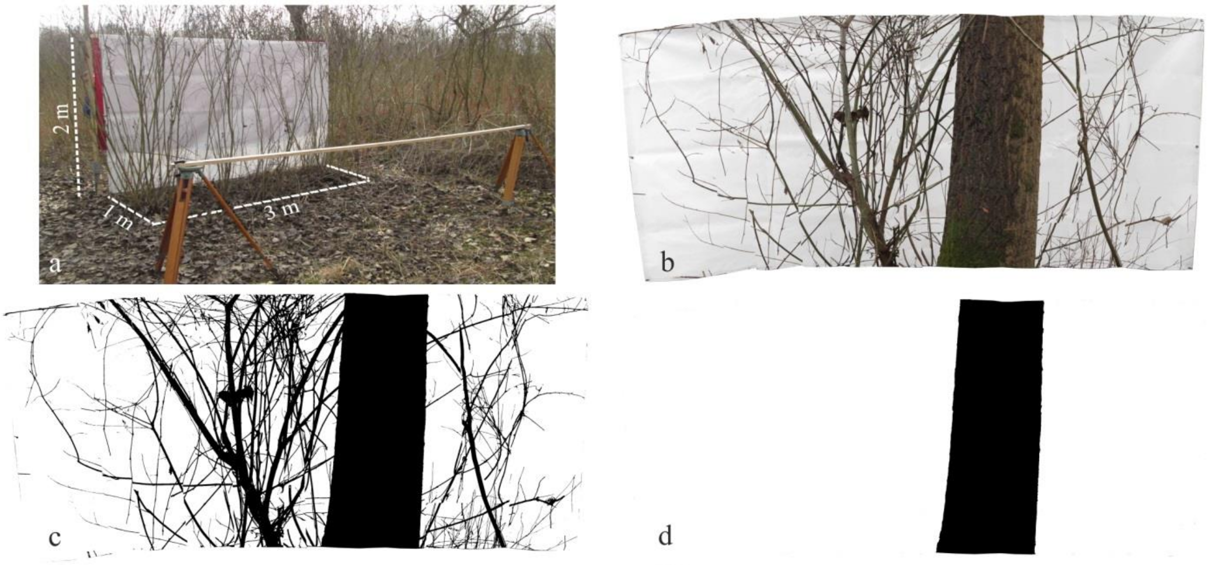

Fig. 3 Photographs of vegetation were taken from a track in front a whitescreen (3a), then the photos were mosaiced (3b). Finally black and white images were used to evaluate the vegetation density with Amorha (3c) and without it (3d).

In HEC-RAS, during the first run, the actual vegetation density values (n=0.23) were used to model flood levels, with ±10 cm accuracy. In the second run the vegetation density data of "ideal, well-maintained condition without *A. fruticosa*" was applied in the 10 km long section of the floodplain. This ideal conditions equals to *'pastures with high grass, cultivated areas with mature row crops, scattered brush, and cleared land with tree stumps and no stumps'*, where n=0.035 (Chow, 1959). The hydraulic effects of the decreased surface roughness were calculated at three cross-sections, at the upstream end, at the middle and at the downstream end of the 10 km long reach (Fig. 2). Finally, the temporal and spatial changes of the flood wave were analysed.

In the CES model the hydraulic changes also at three cross-sections were analysed, however no temporal analysis could be made, thus the model run just during the peak of the flood. The selected cross-sections were close to the ones in HEC-RAS (Fig. 2), but they were not identical. The surface topography was extracted from the 1:10,000 scale topographic map, while channel topography was provided by the Lower Tisza District Water Directorate (ATIVIZIG). The CES model – similarly to HEC-RAS – was run for two scenarios, (1) with the actual vegetation roughness with *Amorpha*, and (2) with ideal conditions without it.

RESULTS

Land-use of the floodplain along the Lower Tisza River has changed considerably in the last two hundred years (Fig. 4-5). At the time of the first survey (1784) the conditions refer to almost natural state, as it reflects the environment before the river regulation works and

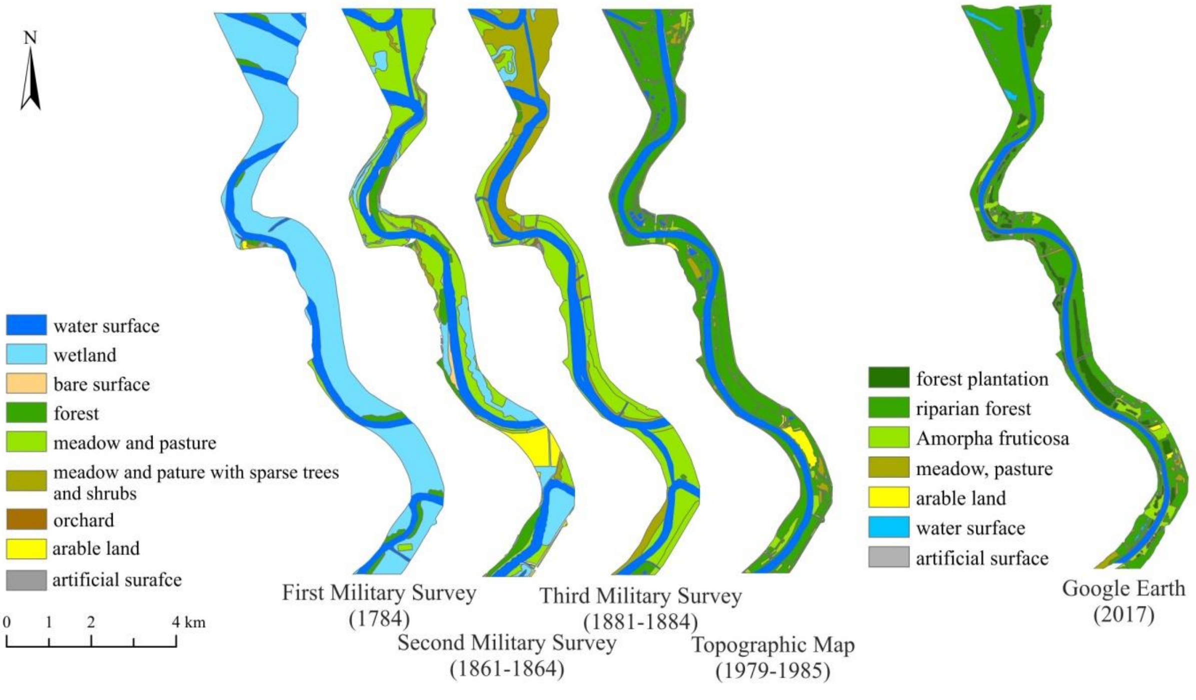

Fig. 4 Land-use changes of the study area since the late 18th century

artificial levee constructions. Most of the area (92%) was occupied by wetlands, where water covered the area almost permanently. The proportion of forests was only 5%, and their patches grow along the channel, where the overbank aggradation created higher surfaces. In the mid-19th century channel regulation works started. By the time of the second survey (1861-1864) two meanders were already cut off in the upstream part of the study area, though the third one in south was still untouched. Therefore, the artificial levee system at that time was not located at the same place as the present-day system. The proportion of wetlands decreased drastically (22%), and they were replaced by meadows and pastures (56%). The forests expanded moderately (9%), but they were still located along the riverbanks. Longer flood-free periods enabled some areas to be cultivated (proportion of arable lands: 7%). Two decades later (1881-1884) most of the wetlands had already disappeared (2%). Almost the whole study area was occupied by meadows and pastures (94%), but almost on half of their area trees started to grow. In contrast, the proportion of forests had decreased to 2%. One hundred years later (1980s) the vegetation cover of the study area had changed considerably, as the area of pastures and meadows became afforested, therefore their proportion decreased to 11%. Because of extensive poplar plantations, the proportion of forests increased to 78%. Nowadays (2017) the forested area of the floodplain increased further on (86%). Only some arable lands and grasslands remained (8%), however, according to our field survey three fourth of them have been abandoned and they are densely covered by *Amorpha fruticosa*.

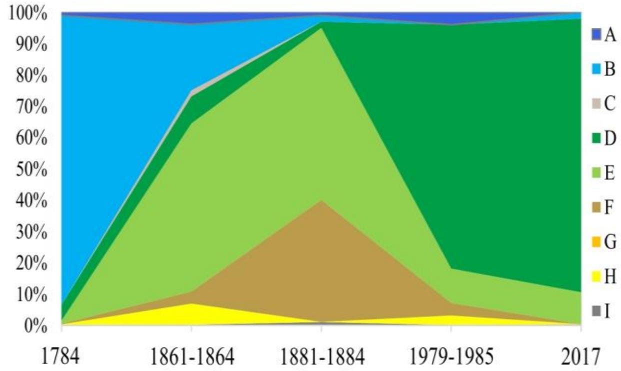

Fig. 5 Proportional changes of land use-categories since the late 18th century. I: 1784; II: 1861-64; III: 1881-84; IV: 1979-85; V: 2017; A: water surface; B: wetland; C: bare surface; D: forest; E: meadow and pasture; F: meadow and pasture with sparse trees and shrubs; G: orchard; H: arable land; I: artificial surface

Roughness values defined in the literature weighted by the proportion of land-use categories (see Table 1) reflect that the vegetation roughness of the floodplain has been increased since the late 18th century (Fig. 6). The vegetation roughness increased especially in the 1980s due to forest plantations, and nowadays because of the presence of *Amorpha fruticosa*. Overall, the mean vegetation roughness of the study area has increased from n=0.021 to n=0.14, thus it increased by seven times since the late 18th century.

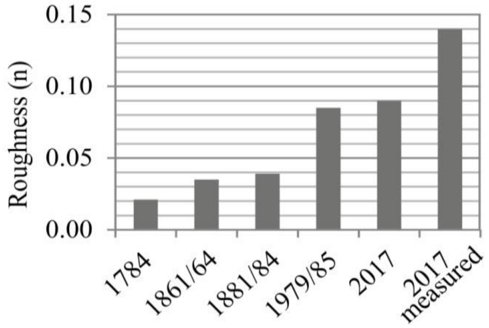

Fig. 6 Mean vegetation roughness of the study area based on land-use categories (1784-2017) and on PP-method (2018)

The role of Amorpha fruticosa in increasing vegetation density: results of Parallel Photographic Method

In the study area three woody vegetation types were identified and studied in detail. At present, riparian forests cover 71% of the study area. Due to the shading effect of the older trees, the abundance of *Amorpha fruticosa* is the smallest in these forests. Therefore, the invasive species increases vegetation density only by 3% on average (0-10%), depending on the amount of sunlight reaching the surface and the rate of disturbance. In these almost natural riparian forests the vegetation roughness is 0.13 on average (min: 0.06, max: 0.22), but without *Amorpha fruticosa* it would be 0.12.

Forest plantations occupy 15% of the floodplain, with trees of different age. Generally, in the first years after the plantations the undergrowth vegetation is managed to support the growth of the trees, but when the poplars grow above 3-4 m, the undergrowth is not managed any longer. Since the coverage of the foliage of planted forests is less closed, more sunlight could reach the surface, therefore older plantations, depending on the lack of management, could be invaded by non-native species. In the study area, *Amorpha fruticosa* increases vegetation density by 23% on average. The vegetation roughness of these forests is 0.10 (min: 0.07, max: 0.15), while without *A. fruticosa* vegetation roughness would decrease to 0.08.

In the floodplain of the Lower Tisza River *Amorpha fruticosa* increases vegetation density by the greatest degree on abandoned arable lands, meadows and pastures. The abandonment of these areas accelerated after the flood in 2006, when the floodplain was covered by ca. 6-8 m height water column for one week, and the inundation itself lasted for 104 days (Kiss 2014). This high and long flood destroyed the agricultural crops and destroyed some of the natural undergrowth. In addition, the flood period had started in 1998; therefore, farmers gave up cultivating these floodplain lands because of the returning annual loss. On these abandoned lands *Amorpha fruticosa* increases the vegetation density by up to 100%, but in less-invaded areas it contributes to vegetation density by 76% on average (min. 50%). Due to the presence of *A. fruticosa* the average vegetation density of abandoned lands is 0.12 (min: 0.09, max: 0.16), while without invasive species this value would be only 0.03.

Flood conveyance as a function of vegetation: results of HEC-RAS and CES modelling

The results of the two scenarios (unmanaged floodplain with n=0.23, and managed floodplain with n=0.035) run in HEC-RAS model suggest that the most significant changes in water levels appeared in the upstream cross-section (191.82 rkm; Fig. 7) of the 10 km-long study reach. In case of the No. 2 scenario the vegetation of the 10 km-long floodplain section is managed (cleared from *Amorpha*), thus the floodplain vegetation creates fewer obstacles (resistance) against flood flow. Therefore, the velocity of the flood is accelerated. In this case, the peak flood level decreases by 15 cm compared to the “unmanaged” scenario (n=0.035). The greatest difference between the hydrographs was 18 cm in the falling limb of the floodwave.

At the downstream cross-section (182.95 rkm) of the modelled 10 km-long reach, the processes are different from those of the upstream cross-section (Fig. 8). In the No.2. scenario this cross-section is located at the downstream end of the managed section, at the border between the managed and unmanaged vegetation (n=0.23). Thus the flood flow collides with the dense vegetation, and forced to flow through it. The resistance is combined with the small slope of the river and the backwater effect of the Danube. Though the flood peaks of the two scenarios slightly differ (±1-2 cm), during the falling stage the differences in stages increases (6 cm), though it is within the error of the model (±10 cm).

The cross-section (189.00 rkm) located in the middle of the study area is in the middle of the managed floodplain section in case of No.2. scenario. Here the processes described at the upstream and downstream cross-sections are combined (Fig. 9). Water level changes are similar to the ones at the upstream cross-section, but the peak water level decreases just by 6 cm in No.2. scenario. The greatest difference (9 cm) between the hydrographs was detected also in the falling limb of the flood.

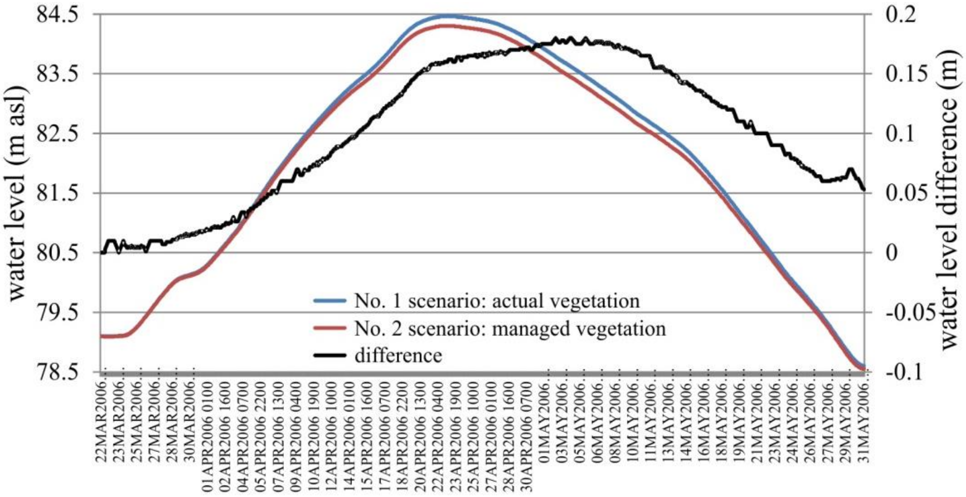

Fig. 7. Changes in water level at the upstream cross-section of the 10 km-long studied floodplain. The model was calibrated to the 2006 flood. The hydrograph of the No. 1. scenario (blue line) refers to the actual situation with unmanaged floodplain vegetation, while the No. 2. scenario refers to managed vegetation cover (red line)

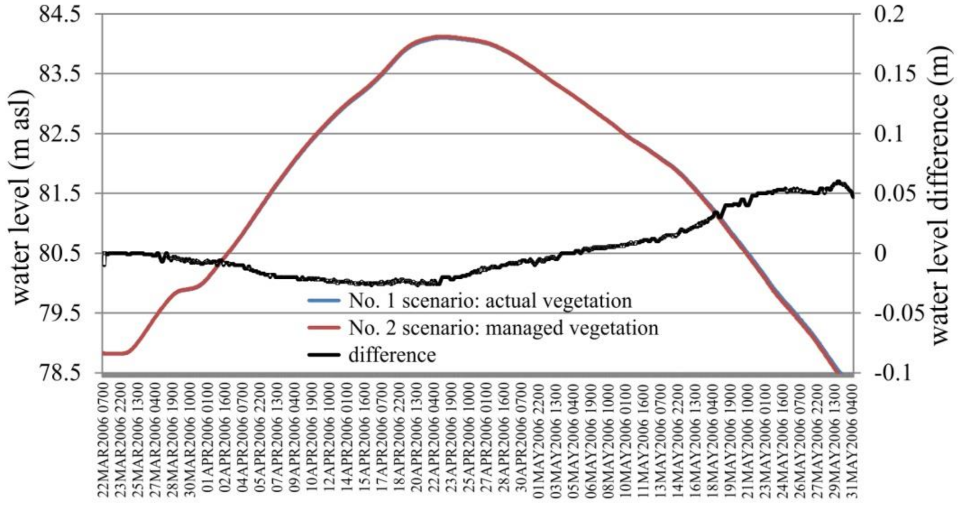

Fig 8 Changes in water level at the downstream cross-section of the 10 km-long studied floodplain. The model was calibrated to the 2006 flood. The hydrograph of the No. 1. scenario (blue line) refers to the actual situation with unmanaged floodplain vegetation, while the No. 2. scenario refers to managed vegetation cover (red line)

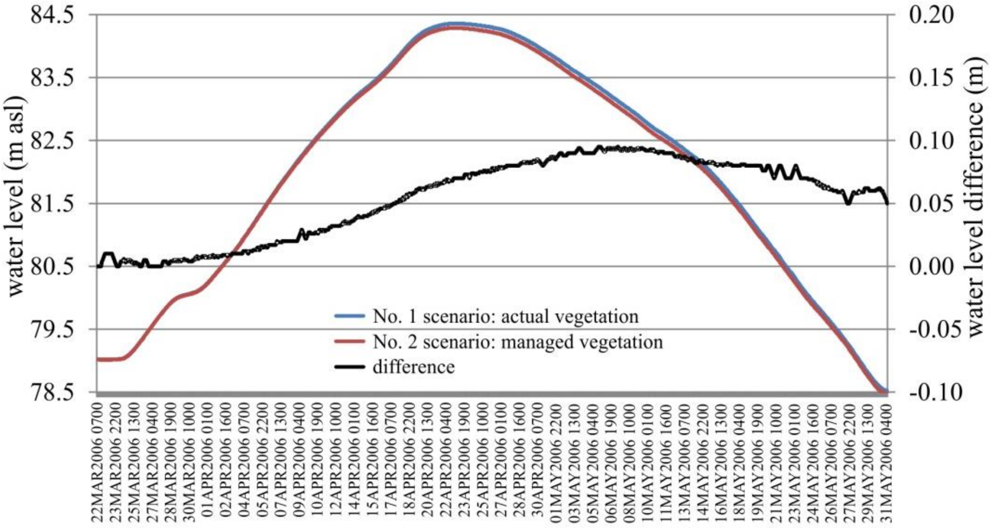

Fig 9 Changes in water level at the middle cross-section of the 10 km-long studied floodplain. The model was calibrated to the 2006 flood. The hydrograph of the No. 1. scenario (blue line) refers to the actual situation with unmanaged floodplain vegetation, while the No. 2. scenario refers to managed vegetation cover (red line)

The temporal differences in hydrographs are the greatest in the falling limb of the flood wave. It could be explained by the characteristic of the flood: the modelled 2006 flood has been the highest on the Tisza River and its peak lasted nearly for a week. This special characteristic was caused by back-water effect of the Danube, thus the flood wave of the Tisza River could fall just after the flood on the Danube had passed. Thus, the impoundment and the reduced flow velocity was just partly caused by the vegetation, but probably it was surpassed by the impounding effect of the Danube, Therefore the effect of vegetation roughness on flood flow could only became obvious in the falling limb of the flood wave, when the Danube had no longer had significant effect on the Tisza River.

The CES model gave similar result to the HEC-RAS model (Table 2; Fig. 10). The results of the three cross-sections slightly differed, because the rate of invasion by *Amorpha fruticosa* varied and the width of the floodplain was different too. At all three cross-sections *Amorpha fruticosa* contributed to vegetation density by the same rate (Dv_{PP} increased by 0.03). Because of the presence of *Amorpha fruticosa* the peak discharge of the flood resulted in higher water stage by 15.3 cm at the upstream and downstream cross-sections, while it was only 12 cm at the middle cross-section. Based in the CES model calculations the presence of *Amorpha fruticosa* decreased the mean flow velocity by 0.016 m/s. There is a slight difference in the decrease of discharge at a given (highest) water stage: at the upstream cross-section the discharge of the peak stage was decreased by 5.7% by the presence of the *A. fruticosa*, while at the downstream cross-section it was decreased by 6% respectively. The difference could originate from the floodplain width, as the floodplain is wider along the downstream section (770 m) than upstream (680 m). At the middle cross-section the invasive species decreased the mean flow velocity by 0.014 m/s, reduced the discharge of the peak stage by 4 %, and resulted in higher water stage by 12.1 cm of the same peak discharge.

DISCUSSION

In the present study we analysed the changes of vegetation cover on the floodplain of the Lower Tisza River, determined the role of the invasive *Amorpha fruticosa* in increasing the vegetation density of the floodplain, and modelled its role in reducing flood conveyance.

Long-term changes (1784-2017) of land-use on the floodplain of the Lower Tisza River suggest that at the end of the 18th century, before the river engineering works, most of the surface was covered by wetlands (92%). As a result of 19th century river regulation works the channel

Table 2 Main characteristics of the studied cross-sections, and the drop of water stages on case of managed floodplain, thus the clearance of Amorpha fruticosa (A.f.). HECpeak: during the peak flood modelled by HEC-RAS, HECfall: during the falling stage of the flood modelled by HEC-RAS, CES: during the peak of the flood modelled by CES

			land-use (%)		**vegetation roughness (Dv_{PP})**		**decrease in water levels (clearing A.f.)**		
Cross-section (rkm)	**floodplain with (m)**	**channel slope (cm/km)**	**forest**	**meadow, pasture**	**with A.f.**	**without A.f.**	**HEC peak**	**HEC fall**	**CES**
189.5	680	4	100	0	0.13	0.10	15	18	15
187.8	750	4	100	0	0.13	0.10	6	9	12
181.7	770	4	61	23	0.13	0.07	0	6	15

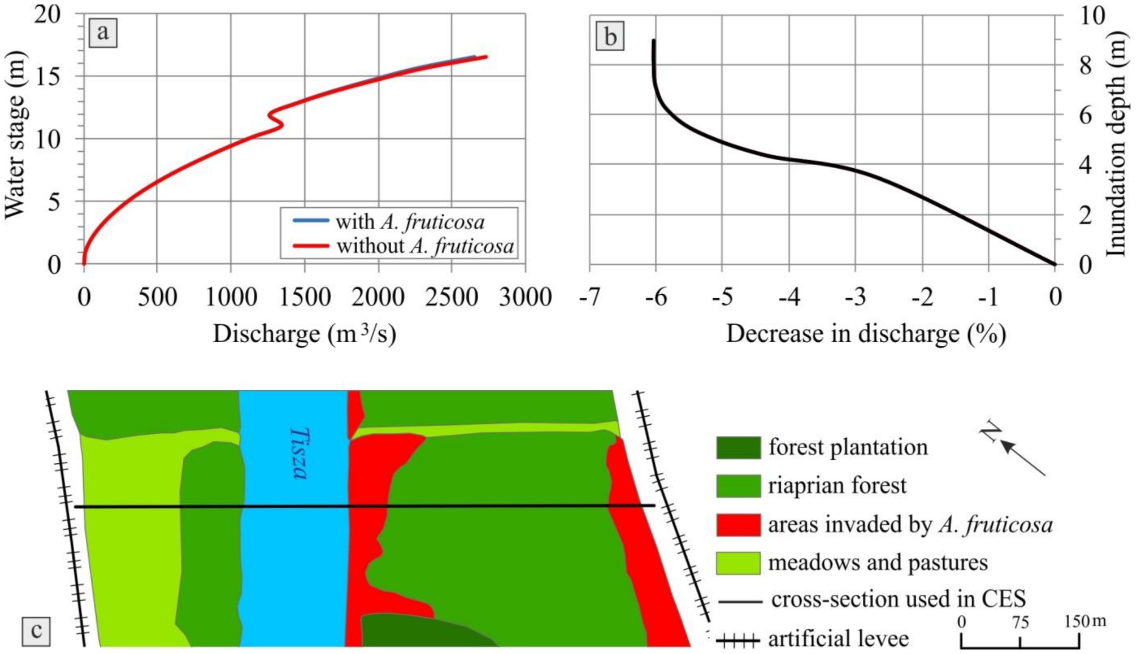

Fig. 10 Results of the CES modelling at the downstream cross-section (181.7 rkm). a) Discharge change at a given water level (from the lowest point of the channel bed) in the case of vegetation with and without Amorpha fruticosa; b) decrease in discharge on the floodplain due to the presence of Amorpha fruticosa; and c) land-use categories along the cross-section

incised, thus low water stages decreased (by 260-280 cm; Lászlóffy, 1982), which resulted in drier floodplain surfaces. Therefore, since the mid-19th century the wetlands were replaced by meadows and pastures (94%), and riparian forests (9%). Nowadays, most of the floodplain is covered by natural or planted forests (86%), while the proportion of meadows decreased to 2%. The vegetation roughness of the study area has increased fourfold since the late-18th century. This increased vegetation roughness has a significant impact on flood conveyance. Since similar land-use changes were observed on other floodplain areas of Hungary (Gábris et al., 2004; Sándor and Kiss, 2008; Oroszi and Kiss, 2006), it could be assumed that the vegetation has influenced hydrological conditions in a similar way.

However, the actual surface roughness is greater (0.14) than it was calculated from the land-use categories, due to the presence of invasive species, and because in the literature the impact of invasive species on vegetation density was not considered. Most of the meadows, pastures and arable lands are strongly invaded by *Amorpha fruticosa*, therefore 8% of floodplain surfaces are covered exclusively by *A. fruticosa*, but it has spread in riparian and planted forests as well.

Results of vegetation density calculations were used in HEC-RAS and CES models, to determine the role of two different floodplain management methods on flood conveyance. In the No.1. scenario the actual vegetation density (with *Amorpha fruticosa*) was applied, while in the No.2. scenario the Amorpha was cleared from the area, thus the floodplain vegetation was managed. The comparison of the two scenarios in HEC-RAS suggests that if the floodplain was managed properly and it was cleared from *Amorpha fruticosa* on the studied 10 km long reach of the river, at the upstream section water flow would accelerate because of reduced surface roughness, which would decrease water levels. Therefore, the level of the peak flood could be reduced by 15 cm according to the HEC-RAS and by 12-15 cm according to the CES. The downstream section of the managed floodplain is followed by an unmanaged area, therefore, its increasing vegetation roughness could decrease the flood conveyance and flow velocity by impounding the flood, thus at this section higher peak levels could occur (but it was under the error limit of the model). At the middle section the effects described above (i.e. increased and decreased flood conveyance) combined, therefore here the flood conveyance would be just slightly better, thus the drop of peak flood level is moderate (9 cm).

CONCLUSION

In the present study, we analysed vegetation density and its effects on flood conveyance with different methods. The Parallel Photographic (PP) Method was used to calculate the actual vegetation density in different land-use categories. The resulted vegetation roughness values are 1.5-fold higher than values given in the literature for the given land-use category. This can be explained by the very dense population of invasive species, since these species were not taken into account in the vegetation roughness values defined in the literature (Chow 1959), they gave only empirical values for natural vegetation cover. With the PP method, however, the vegetation density could only be measured in a small quadrate (6 m^2) and up to a height of 2 m; although during floods the floodplain is inundated by 6-8 m high water column. Further disadvantages of the PP method are low time efficiency and errors occurring during taking the photographs. In sunshine, the shadows of the stems and branches can modify the ratio of black and white pixels, the white screen can lean in wind, and the snow cover on the branches (since photographs were taken in winter) can also modify the number of black pixels. During photoprocessing errors can occur when the non-vertical stems are photographed from different angles, therefore after the photos are assembled these stems can appear several times on the photos. Based on our experience, however, these errors do not cause significant differences in the results.

Flood conveyance was analyzed in two hydraulic models. The advantage of the HEC-RAS model is that a real flood event could be modelled, and the spatial and temporal effects of various floodplain vegetation on flood conveyance could be analysed. Disadvantage of the model is that its setting up is time and data consuming. Besides, the characteristics and roughness values of the floodplain and of the channel, the hydrographs of a particular flood event are also needed along a long river reach (in our case it was 200 km) to keep the model stable.

Great advantage of CES model is that it is very easy to use, and it does not require large amount of input data. The hydrological processes on the floodplain, however, could be analysed only at during the flood peak and along one section, thus temporal and spatial changes in the processes could not be studied. Accordingly, the selection the most suitable cross-section on the floodplain is very important.

From the point of view of floodplain management it can be stated that by adequate vegetation management (i.e. removing invasive species, restoration of land-use with lower surface roughness) of longer floodplain sections flood stages could be decreased. The length of the managed area, however, may vary depending on the slope of the floodplain and the areal extension of impounded flow, since in short managed sections the effect of impoundment may distinguish the effect of better flood conveyance. Accordingly, clearing vegetation in patches would not have any detectable effect on flow conditions. The analysis, however, should be repeated on floodplain sections with different hydrological conditions, since the effect of vegetation on flood conveyance may vary based on slope, floodplain width and flood characteristics. Overall, reducing vegetation roughness coefficient by properly managing floodplains would have a positive impact on flood hazard, since flood waves would accelerate and peak flood stages would decrease.

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CLIMATE CHANGE IMPACTS ON THE WATER RESOURCES IN THE DANUBE RIVER BASIN AND POSSIBILITIES TO ADAPT – THE WAY TO AN ADAPTATION STRATEGY AND ITS UPDATE

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Abstract

As the Intergovernmental Panel on Climate Change reported in 2013, climate change will have significant impacts on all water sectors. Since water is essential for live, culture, economy and ecosystems, climate change adaptation is crucial. Therefore, a legal and political framework was established by the commissions of the European Union, the United Nations and on national levels. For the Danube River Basin (DRB), the International Commission for the Protection of the Danube River got the mandate to develop an adaptation strategy in 2012 and to update this strategy in 2018. The natural science basis on which the adaptation strategy and its update are based on are two studies, conducted in 2011/2012 and updated and revised in 2017/18. Numerous documents from actual research and development projects and studies dealing with climate change and its impacts on water related issues were analysed in detail and the results summarised. It is agreed that temperature will increase basin-wide. The precipitation trend shows a strong northwest-southeast gradient and significant changes in seasonality. Runoff patterns will change and extreme weather events will intensify. However, the magnitude of the results shows a strong spatial variability due to the heterogeneity of the DRB., It is assessed that these changes will have mostly negative impacts on all water related sectors. Based on the scientific findings an approach for an improved basin-wide strategy on adaptation to climate change is developed. It includes guiding principles and five categories of adaptation measures targeting different objectives.

Keywords: Climate Change, adaptation strategy, Danube River Basin, water sector

INTRODUCTION

Climate change will have various impacts on ecosystems and consequently on human life (IPCC, 2007; IPCC, 2013). Impacts on water will cause changes in water availability, water temperature, water quality and in extreme hydrological events like floods and droughts and accordingly trigger changes in all water related areas (IPCC, 2013). Thus, adaptation to these changes will become one of the major challenges of the 21st century in river basins. In order to be prepared for possible consequences of climate change, the United Nations Framework Convention on Climate Change (UNFCCC) asks Parties of the Kyoto Protocol to develop implement and regularly update programmes of measures for climate change adaptation on a national and regional level (United Nations, 1998). Several European and UN directives and guidelines are explaining the necessity of adaptation to climate change and are supporting the development of strategies (EEA, 2017; EC, 2009; UNECE, 2009). Moreover, the EU water framework directive (WFD) requires an integrated river basin management across administrative or political boundaries and demands to consider possible climate change impacts. Nevertheless, adaptation strategies for the large river basins in Europe hardly existed until 2012. Therefore, a programme of pilot projects and a platform for exchanging experience was established to foster the implementation of transboundary adaptation activities in river basins. For the Danube as Europe’s second largest River basin, in December 2012 the International Commission for the Protection of the Danube River (ICPDR) adopted the Strategy on Adaptation to Climate Change (ICPDR, 2013), being the first large river basin with a climate change adaptation strategy. An update will be finished by beginning of 2019.

On the way to the ICPDR strategy and its update, one objective is to develop a comprehensive scientific knowledge base that gives an overview of future climate change and its impact in the DRB. To achieve this, a total of 89 and 73, respectively, research and development projects, studies and scientific papers were analysed. This revealed significant, regionally varying changes in all water related sectors. The second objective is to compile a catalogue of adaptation measures suitable for the DRB to meet the challenges of climate change. Basis for this catalogue was the analysis of already existing climate change adaptation strategies as well as close collaboration with stakeholders from the riverine countries, environmental organisations and water dependant industries. Five groups of measures were identified:

preparation measures, ecosystem based measures, behavioural and managerial measures technological measures and policy approaches. The catalogue of measures is made available as a user friendly online tool. The stakeholder dialogue and the analysis of adaptation activities such as National Adaptation Strategies pointed out communalities, options for cooperation and challenges among the countries of the DRB, which need to be further taken into consideration. To make the studies comparable, the same methods (data acquisition, uncertainty assessment) were used. The methodology of the studies and the integration of the results in the ICPDR Strategy on Adaptation to Climate Change and its update are content of this publication.

THE STUDY AREA: THE DANUBE RIVER BASIN

The Danube is Europe's second largest river with a length of 2,857 km from its source in south-western Germany to its delta at the Black Sea in Romania and the Ukraine and can be divided into the Upper Danube River Basin (UDRB) until the gauge Bratislava in Slovakia, the Middle Danube River basin (MDRB) until the Iron Gate at the border between Serbia and Romania, and the Lower Danube River basin (LDRB) from the Iron gate to its delta (Fig. 1). The catchment has a total area of 801,500 km^2 and encompasses several mountain areas like parts of the Alps, the Carpathian Range and the Dinaric Mountains. The climatic conditions range from temperate zones in the western parts to a continental climate with hot summers and cold winters in the central and eastern basin. The southern and south-western parts are influenced by Mediterranean climatic conditions with warm, dry summers. Furthermore, orographic conditions also determine the climate in the DRB. Average temperature increases from the western parts to the eastern parts of the basin and reaches +12°C in the lowlands of the Sava River, whereas the coldest temperatures can be found on the mountain peaks in the Alps and the Carpathians. Precipitation falls throughout the year and reaches a maximum in the summer months in almost all regions except the south-western parts with long dry periods during summer. However, the amount of precipitation strongly varies in the basin between a minimum of 350 mm/a in the lowlands of the Black Sea and a maximum of 3,500 mm/a in the Alps. The runoff characteristics change along the way through the riparian countries, determined by the passages through flat basins and mountain regions and the climatic conditions. Close to its source in Western Germany, the Danube shows pluvial characteristics which are then altered by the inflow of the rivers from the Alps to a pluvio-nival runoff regime. After the influence of the Inn, the Danube is dominated by snowmelt, changing the regime to a single-peak mountain-snow regime with a maximum in early summer. After the inflow of rivers originating in the Carpathians with a snowmelt peak in spring, and due to the continental climatic conditions with drier summers, the runoff regime of the Danube shows a two-peak maximum from the Carpathian rivers (first) and the Alpine rivers (second), while the minimum in October is coincident. The further inflows of Drava, Tisza and Sava result in a single maximum of the Danube in April and one minimum in October. The regime characteristics of the Danube do not considerably change until the outflow in the Black Sea. The mean average discharge of the Danube increases from approximately 2,000 m^3/s in Bratislava, to approximately 5,500 m^3/s at the Iron Gate and reaches finally approximately 6,500 m^3/s at the Danube Delta, fed by the main tributaries of the rivers Inn, Drava, Tisza and Sava. The DRB provides water resources for 83 million people in 19 countries (Fig. 1), which makes it the most international river basin in the world (ICPDR, 2014). In this region, water is used in

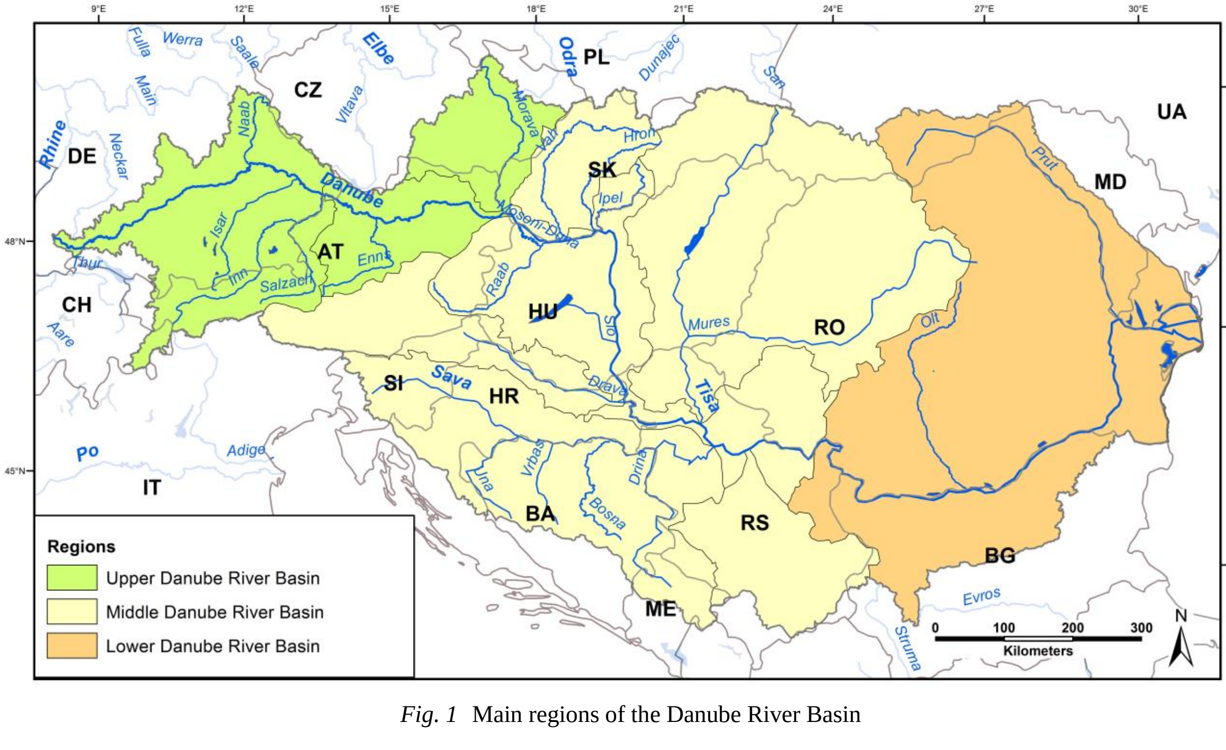

Fig. 1 Main regions of the Danube River Basin

various ways, ranging from agriculture to energy production and navigation. Despite these important water use functions, the Danube River Basin is characterized by a wide range of different natural conditions, contains several highly valuable ecosystems, e.g. the UNESCO World Heritage Site of the Danube Delta as the world's largest wetland and provides habitats for over 2,000 plant species and 5,000 animal species (ICPDR, 2014).

DATA BASE AND ANALYSIS METHOD

In the following the creation of the scientific knowledge base and the methods of assessing the regional impacts of climate change on water-related issues and adaptation activities in the Danube River Basin (DRB) are presented. On this basis the ICPDR Strategy on Adaptation to Climate Change was developed. There have been two project periods. The initial Danube Study was conducted in 2011 and completed in 2012 (Prasch et al., 2012). It provided a comprehensive overview on climate change impacts on the DRB and adaptation measures. The Danube Study was revised and updated in 2018 (Stolz et al., 2018) due to significant developments in climate modelling and new scientific findings concerning the impacts on water related issues. In this project phase only research and development projects, studies and adaptation activities which were conducted between 2012 and July 2017 were taken into account. For means of comparability the same methodology of the analysis and zoning of the DRB were applied in both studies. Only documents, reports and papers which have been published and are accessible through libraries or internet in English, German or French could have been taken into account.

Research and development projects

In order to reach a common, basin-wide understanding of the scale and magnitude of climate change pressures and impacts on water resources, research and development projects and studies dealing with climate change in the DRB or parts of the basin were compiled by online search and participation in conferences and meetings. For the initial Danube Study, 89 projects and studies were selected for the analysis. A detailed list of them can be found in the Annex of the study (http://www.icpdr.org/main/activities-projects/climate-change-adaptation). For the update and revision of the Danube Study documents from 73 projects and studies, published between 2012 and 2017, were included (http://www.icpdr.org/main/resources/climate-change-adaptation-update-danube-study).

In a first step the spatial coverage, the present status of the project (ongoing or finalized), the studied time period and the applied methods are analysed. Projects dealing with climate change impacts in the entire DRB were not available for the initial Danube Study, but the DRB is part of large investigation areas of 25 projects, mostly funded by the European Commission 5th, 6th and 7th framework programmes. For the update and revision of the Danube Study only the study from Bisselink et al. (2018) was available dealing with climate change and its impacts in the entire DRB. Sub-regions or sub-catchments of the DRB are mainly covered by projects and regional studies which are funded either internationally by the Interreg programmes Alpine Space and CADSES (Central Adriatic Danubian South-Eastern European Space) as well as the South East Europe Transnational Cooperation Programme, several EU programmes, the UNDP (United Nations Development Programme), WWF (World Wildlife Fund) and the Worldbank, or nationally, in particular by Germany, Austria, Hungary and Romania.

To make statements about the impacts of climate change comparable the analysis of the used climate models and the modelling periods is of utmost importance. In the analysed documents, mainly the time periods from 1961 to 1990 and from 1971 to 2000 were taken as reference period. The modelled near-future periods vary significantly, but peaking for the period 2021-2050, whereas for the far-future period there is agreement to model the time span 2071-2100.

To assess the future development, models were run under scenario conditions, driven by Global and Regional Circulation Models (GCM resp. RCM), so that the spatial resolution of the simulation results varied between 0.3 and 2° (50-150 km) (GCMs), and between 20 and 50 km (RCMs). The IPCC SRES emission scenarios A1B, A2, B1 and B2 (Nakićenović and Swart, 2000) were chosen and applied as single runs, sometimes as ensemble runs. Some studies applied different dynamical and statistical downscaling methods to analyse the impacts of climate change in a better resolution than provided by the GCMs or RCMs between 1 km and 10 km. In the period from the initial Danube Study to its update the Representative Concentration Pathways (RCPs) (IPCC, 2013) were introduced by the IPCC to replace the SRES emission scenarios. These RCPs were used by some studies which are analysed for the update of the Danube Study.

In a next step, the water related impact fields, which have been investigated by projects and studies were analysed. Therefore, information on future trends of temperature and precipitation and meteorological extreme events were compiled, followed by possible effects on extreme hydrological events, on water availability and quality. In addition, possible impacts on different types of water use and land use like water supply and demand, agriculture, irrigation, navigation, water related energy production and forestry have been considered. And finally, impacts on biodiversity, ecosystems, soils/erosion, limnology and marine coastal zones in the field of ecology were composed.

For the analysis, the above described data are integrated in a database. All findings were classified into statements about the entire DRB, the UDRB, the MDRB and the LDRB (Fig. 1). Commonalities, contradictions and knowledge gaps were identified and finally, the uncertainty of future statements based on the analysed findings was assessed with a newly developed approach, which is presented and discussed in this paper.

Adaptation activities

Similar to the analysis of climate change impacts on the DRB, all relevant information of ongoing, adopted and planned adaptation activities in the water sector in the DRB were compiled and integrated into the data base. The national communications under the UNFCCC (5th or initial, 6th in the update of the study) and available National Adaptation Strategies provide an overview of the present and future impact of climate change and adaptation measures per country and at the EU level (UNFCCC, 2010; UNFCCC, 2014). Additionally, conventions, directives or plans in relation to the EU WFD, relevant reports and further activities on the administrative level in relation to climate change impacts and adaptation activities are considered, i.e. the EEA report (8/2009) “Regional Climate Change and Adaptation: The Alps facing the challenge of changing water resources” (EEA 2009) and EEA report (1/2017) ”Climate change, impacts and vulnerability in Europe 2016”. A detailed list of all analysed documents can be found in the Annexes of the Danube Studies (http://www.icpdr.org/main/activities-projects/climate-change-adaptation).

In the analysis of the adaptation activities the spatial coverage, the present status of the activity (ongoing or finalized), the possible impacts of climate change and the suggested or adopted adaptation measures are studied. Most activities are limited to single countries. National Communications under the UNFCCC are available for all countries of the DRB. Almost all countries already adopted National Adaptation Strategies (NAS) or are preparing one as illustrated in Figure 2. Conventions, declarations, guidances and programs mainly cover the entire DRB or larger parts of it.

The suggested or adopted adaptation measures of the activities are classified for different impact fields, analogously to the analysed impacts addressed in the analysed research and development projects. Therefore, measures to adapt to changes in extreme hydrological events, water availability and quality, in different types of water use and land use like water supply and demand, agriculture with irrigation, navigation and water related energy production were considered. Measures addressing biodiversity, ecosystems and marine coastal zones were composed in the field of ecology. Additionally, general water related adaptation measures were also considered.

Furthermore, the suggested measures are classified into the categories preparation measures, general measures, ecosystem-based measures, behavioural/managerial measures, technological measures and policy approaches following the UNECE (2009) and the EEA (2010; 2017), despite a sharp separation between these categories is sometimes difficult.

In order to obtain the best possible overview over adaptation activities, the analysis was carried out in close collaboration with experts and stakeholders, e.g. representatives from State Ministries for the Environment, for Hydrology and Water Management or for Regional Studies, from NGOs such as WWF, Global Water Partnership, Danube Environment Forum, and Water Research Centres and Institutes, from the DRB. Therefore, the (preliminary) study results were discussed during meetings, workshops and conferences.

Uncertainty assessment

Projections of future climate change and its impact are always associated with uncertainties (Vetter et al., 2017; Latif, 2011; Deser et al., 2010; Hodson et al., 2012). In order to draw the right conclusions from projections of future climate change for the development of adaptation strategies, it is important to assess the uncertainty of statements from numerous studies which content different methods, areas and time periods. No method exists how to compare the different degrees of certainty or uncertainty in statements. A new and pragmatic approach was developed, attempting to give a reliable estimation of the certainty of a parameter encompassing all projects and studies regarding a certain impact. Many factors are influencing the certainty of the statements about future climate change. For almost all projects and studies, different IPCC SRES emission scenarios and RCPs are

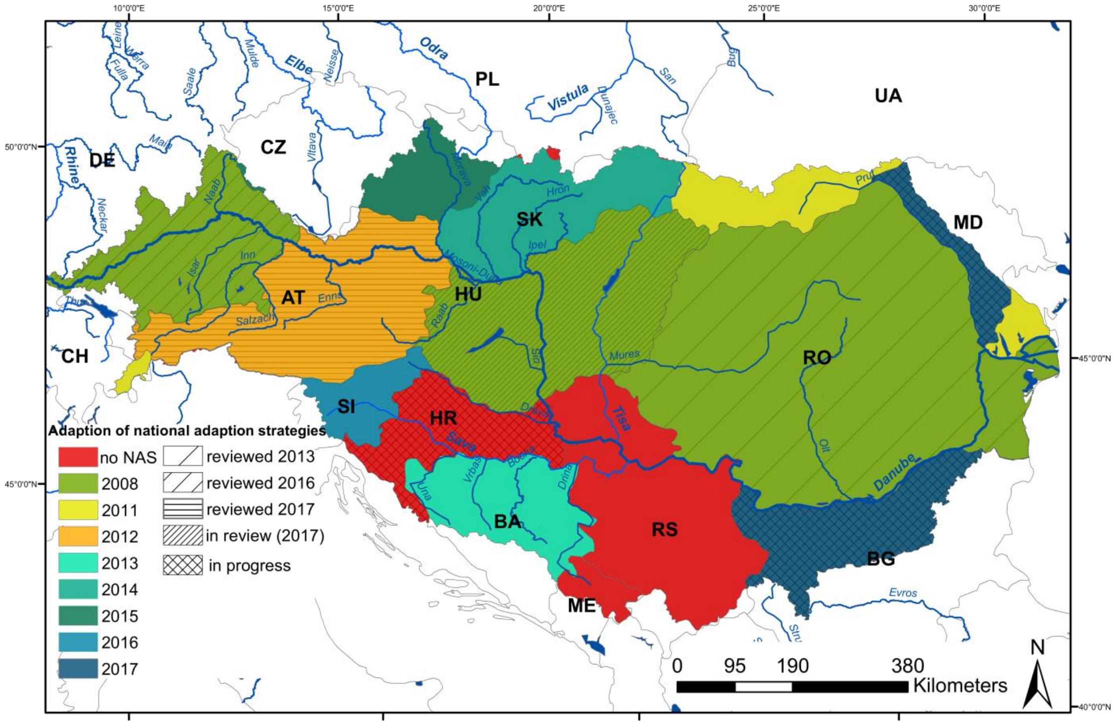

Fig. 2 Countries with National Adaptation Strategies in the DRB (as of 2018)

applied because of different assumptions about future socio-economic development and its consequences for greenhouse gas emissions. The models applied in the studies using the SRES scenarios also have varying outcomes, because of differences in the model structure, the downscaling techniques as well as the spatial and temporal resolution. This is the case for both, climatic and hydrological models. Further uncertainties of the model results are related to differences in validation and analysis methods. These influencing factors of uncertainty are enlarged when analysing several studies. For each impact field a different number of statements/results are available. Some issues are analysed very often, whereas for others only few statements are available. Among the statements itself there are variations, adding further uncertainty. Another source of uncertainty is that different documents frequently analyse different future time periods and use different reference periods. Moreover, different indices, e.g. when assessing floods, are used.

In order to assess the uncertainty of future climate change in this study, three variables are used. First, the statement of certainty for the analysed parameters is taken into account. Second, the level of agreement among the different statements is considered and third, the total number of studies providing statements to a parameter is included. Each certainty-category was calculated by the cube root of the product of the three variables presented by eight values (Fig. 3). If the agreement of the statements (x-axis), the certainty information (y-axis) and the number of studies analysed (diameter of circle) are large the impact is large and the overall certainty is categorized as very high, indicated with a green colour. However, if the number of projects is high, but the agreement of the certainty statement is low, the overall certainty is medium (yellow-orange), and if all three categories are low, the overall certainty is consequently low (red). This practical approach to provide an overall certainty category to the analysed parameters allows the consideration of the, partially little, available information about uncertainty when gathering information from several projects, which apply varying methods. Although this approach is simple, the resulting illustration in Figure 3 enables the comparison of the certainty of the analysed parameters. Nevertheless, this is a practical approach without a detailed statistical analysis, which is not possible because the available information from the analysed projects is mainly given in "soft" variables and not by numbers.

Figure 3 presents the revised and updated overview of certainties for projected climate change impacts of the analysed sectors in comparison to the certainties identified in the initial Danube Study. It has to be noted that forestry, agriculture, flood, low flow and runoff are located at the same similar certainty level, which is represented by the black dot. Although there is a different amount of publications available in the two studies, Figure 3 shows clearly that the degree of certainty increased significantly for most of the analysed water related issues. In the updated study, the scientific statements concerning the future development of precipitation led to a differentiation between mean annual precipitation and precipitation seasonality. It is highly certain, that seasonality changes, whereas the development of mean annual precipitation is unclear for the near future and reliable statements are only made for the far future.

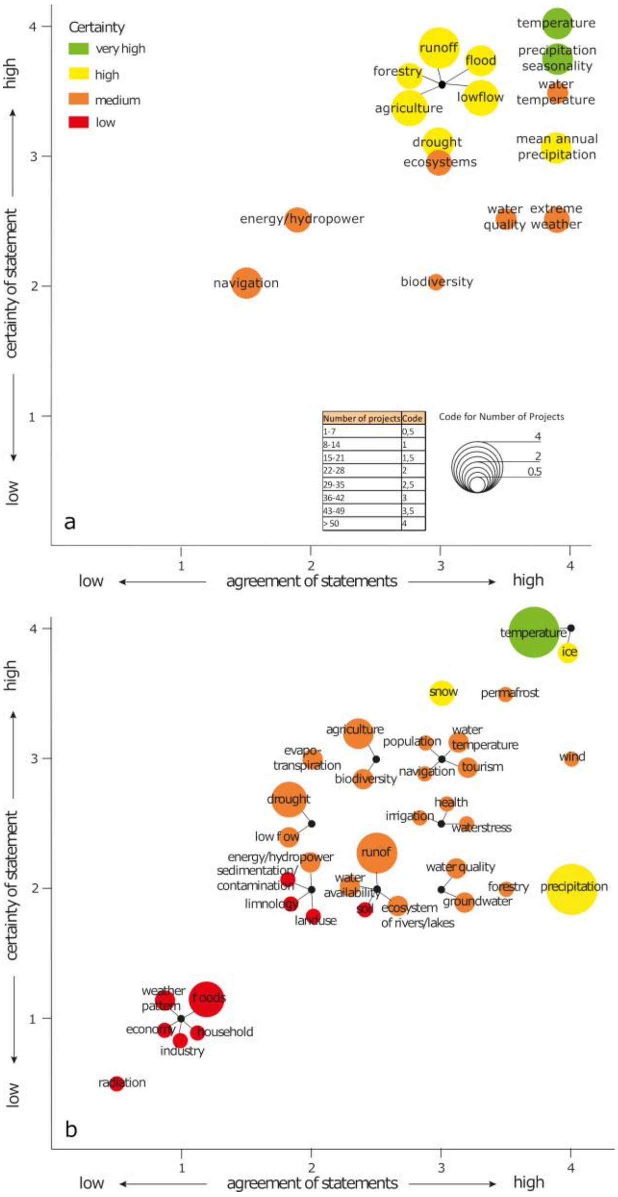

Fig. 3 Uncertainties identified in the update of the Danube Study (a) in comparison to the uncertainties identified in the initial Danube Study (b) (Revision and Update of the Danube Study, Final Report 2018). The legend of a also applies to b.

The certainty of impacts on navigation, ecosystems and biodiversity did not improve in comparison to the initial Danube study due to contradictory and vague statements. It has to be noted that not all water sectors analysed in the initial study are analysed in the update as well. Reasons therefore are that an insufficient amount of new finished projects and data dealing with these topics were published in the last five years.

A high level of certainty may allow the preparation of adaptation measures at an early stage and/or with more detail, whereas a low level of certainty may lead to more general types of measures (e.g. no-regret measures or win-win solutions).

RESULTS

In this chapter, the results from the updated Danube study are presented and differences to the initial study are highlighted. The results are solely based on the analysed studies, projects and adaptation activities that are described above. Furthermore, other factors such as social, demographic, and economic development are crucial for future adaptation strategies to climate change. However, they were not subject of the present study, but are indirectly considered in the analysed scenarios.

Future climate change in the DRB

The trend of a future increase in annual and seasonal air temperature with a gradient from northwest to southeast which was identified in the initial Danube Study is largely confirmed by the update of the Danube Study. This trend is highly certain and can be regarded as a hard fact. Since climate change does not stop at boarders and effects of climate change may largely vary within country borders (due to varying physiographic properties), for the update of the ICPDR Strategy on Adaptation to Climate Change it was decided to show the temperature and precipitation projections of the EURO-CORDEX project. The EURO-CORDEX ensemble runs are based on the new RCPs and provide data on a resolution of 0.11 degree (~12.5km) (Jacob et al., 2014). Thus it is possible to draw a more detailed picture of spatially distributed temperature and precipitation trends, which in turn serves as a sounder basis for the development of adaptation measures and strategies. Results from EURO-CORDEX projections use the period 1981-2010 as reference and define 2021-2050 as near future and 2071-2100 as far future. The range of increase of annual mean temperature for the near future period is between 1.1°C and 1.5°C and for the far future period 3.6°C and 4.7°C under RCP8.5 (Fig. 4). These figures show pronounced warming hotspots in mountain regions and in southeast Europe. Like in the initial Danube Study, EURO-CORDEX projections show, that the annual (Fig. 4a,b) and the summer (Fig. 4c,d) temperature increases are likely to be larger than the winter temperature increase (Fig. 4e,f).

The DRB is located in the transition zone between expected increasing (in Northern Europe) and decreasing (in Southern Europe) future precipitation. Documents analysed in the update of the Danube study confirm this general trend of wet regions becoming wetter and dry regions becoming drier (Fig. 5). The trend is more

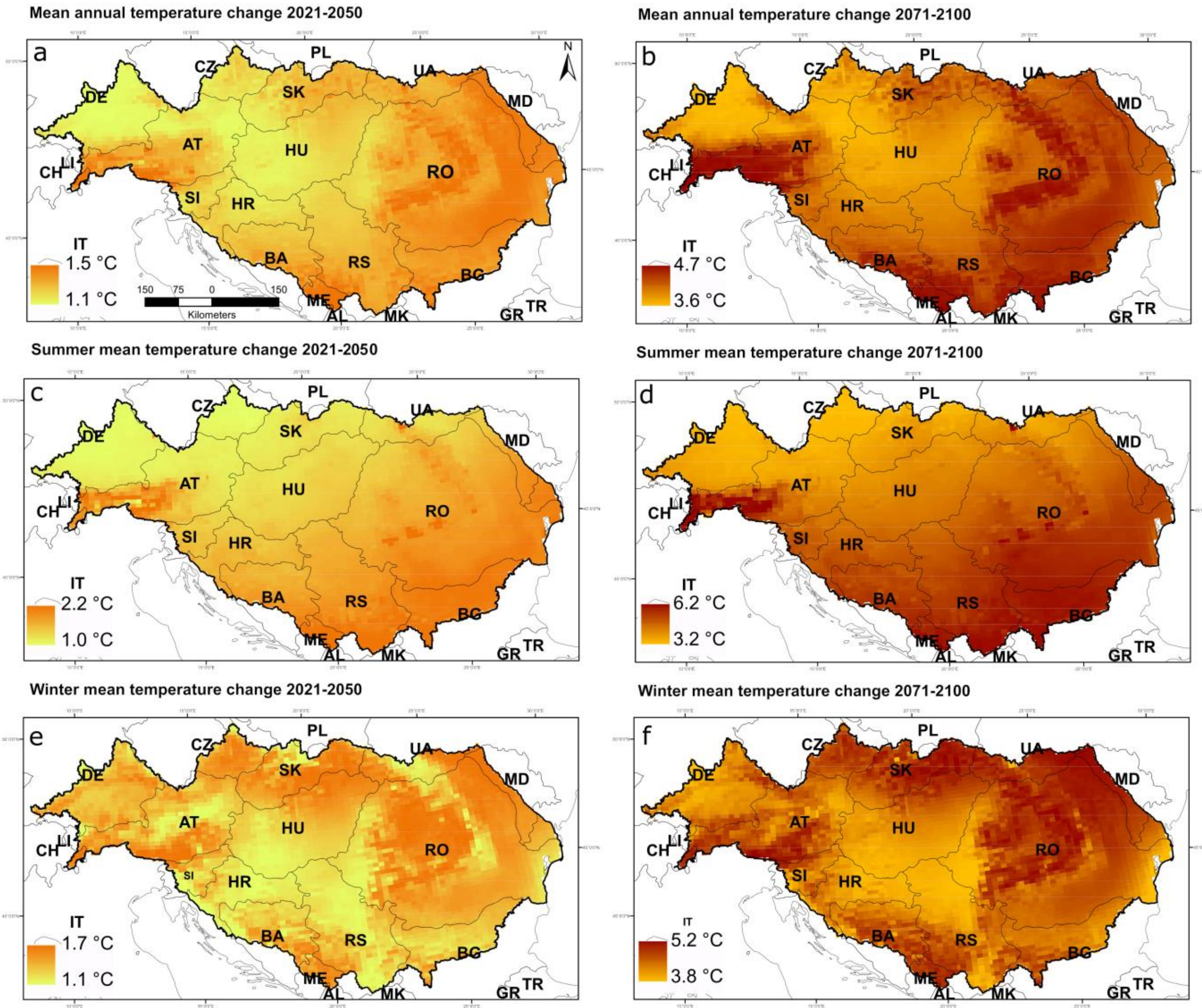

Fig. 4 Change of mean annual (a, b), summer (JJA) (c, d) and winter (DJF) (e, f) temperature in the Danube River Basin for 2021-2050 and 2071-2100 according to the EURO-CORDEX ensemble results under RCP8.5

obvious in the second half of the century. Although the mean annual precipitation in many regions will probably remain almost constant, a tendency for the next decades towards more precipitation (than in the last decades) in the northern parts of the basin and less precipitation in the southern parts is apparent (Fig. 5). The general trend of wet regions becoming wetter and dry regions becoming drier is also reflected in the alpine region, where the already drier south-eastern part of Austria is likely to become drier.

According to the documents analysed in both Danube Studies, trends in mean annual precipitation are rather insignificant until the middle of the century and become significant until the end of the century. However, the most significant change is projected in seasonal precipitation distribution. The summer months are likely to become drier (up to -58%) (Fig. 6) whereas the winter months show a tendency for increasing precipitation (up to +34%) (Fig. 7). The numbers indicate the maximum expected decrease and increase for larger regions in the Danube River Basin but numbers in particular regions may vary largely. The figures display the precipitation change from the EURO-CORDEX initiative in mm relative to the reference period 1981-2010. The comparatively clearest trends are increasing winter precipitation in mountain regions and decreasing summer precipitation in regions already suffering from too little precipitation. On the other hand, there are regions where summer precipitation is projected to increase due to increased frequency of thunderstorms and short heavy precipitation events. As for temperature trends, studies that are based on the newly implemented RCPs like from Bisselink et al. (2018) mostly confirm previous results. Furthermore, data from the EURO-CORDEX initiative provides a more detailed picture of spatially distributed trends.

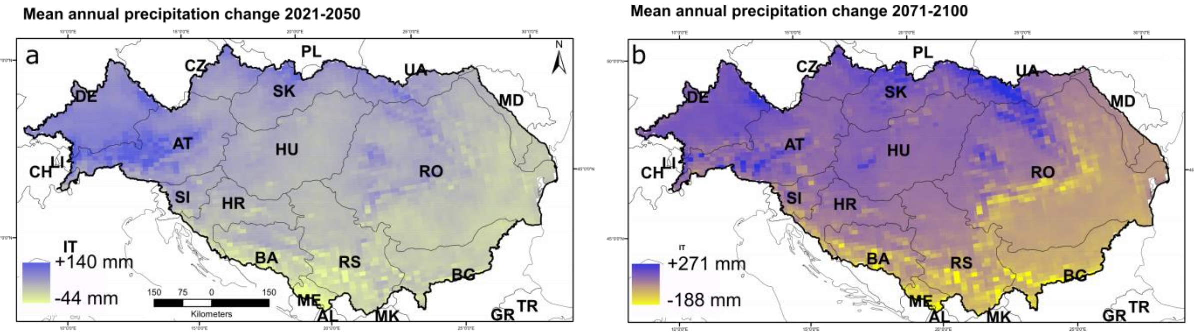

Fig. 5 Change of mean annual precipitation in the Danube River Basin for the periods 2021-2050 (a) and 2071-2100 (b) according to the EURO-CORDEX ensemble runs under RCP8.5

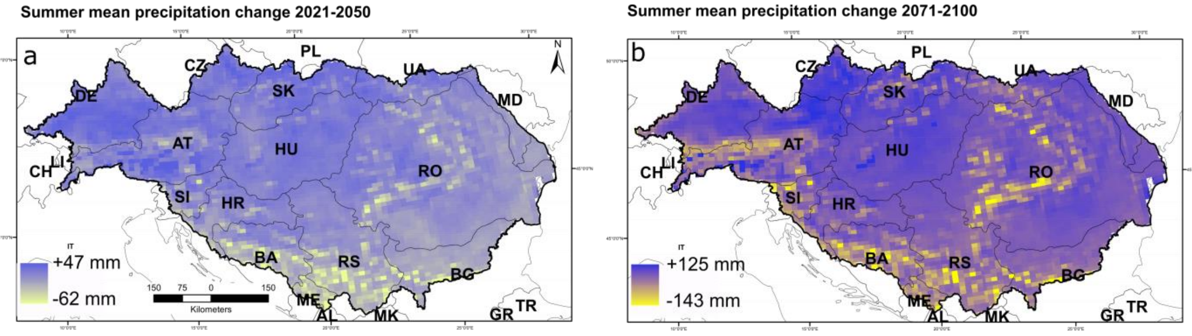

Fig. 6 Change of mean summer (JJA) precipitation in the Danube River Basin for the periods 2021-2050 (a) and 2071-2100 (b) according to EURO-CORDEX ensemble runs under RCP8.5

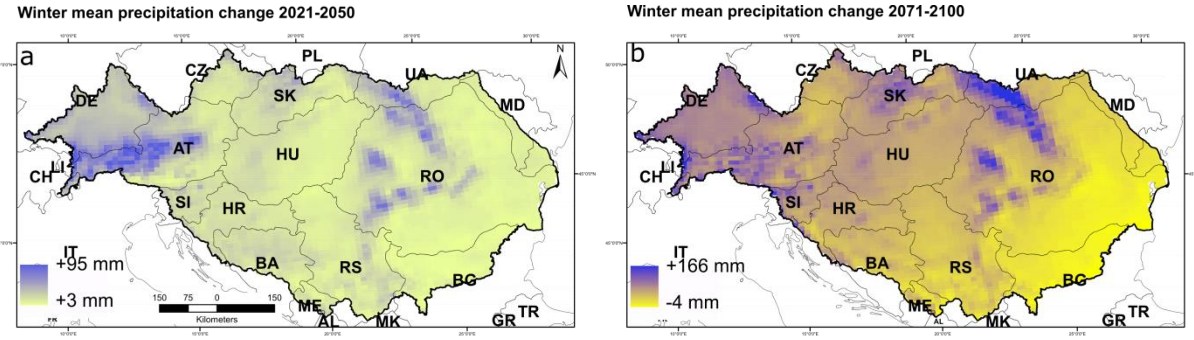

Fig. 7 Change of mean winter (DJF) precipitation in the Danube River Basin for the periods 2021-2050 and 2071-2100 according to EURO-CORDEX ensemble runs under RCP8.5

A future increase in extreme weather events is expected for the whole DRB. The simulations show both, a future increase in the intensity and frequency of dry spells, hot days and heat waves, as well as local and regional increases in heavy rainfall, although the latter is uncertain in spatial and temporal localisation. For the UDRB, an increased risk of storm-related heavy precipitation with high wind speeds is assumed. For the MDRB, it is expected that the occurrence of extreme precipitation days will be intensified in winter and reduced in summer. Due to the warming trends for the whole basin, fewer frost days are expected in winter. Generally, statements from the initial Danube Study are confirmed by the update. Nevertheless, most recently analysed documents show a more pronounced trend towards seasonality in the occurrence of extreme events. Therefore, the agreement concerning an increasing number of extreme winter precipitation events over Europe and especially in the North-East for the far future period must be emphasised. Statements regarding extreme summer precipitation especially in Eastern Europe are inconsistent.

Climate change impacts on water related issues in the DRB

The potential future climatic conditions in the DRB described above will impact the water resources and water-related issues. In the following the expected main impacts on each water sector according to the analysis of the studies are described and compared in a qualitative way. As for future climate conditions, the results of the updated Danube Study are presented and differences to the initial Danube study are highlighted (ICPDR, 2012; ICPDR, 2018).

(1) Water availability

In contrast to the initial Danube Study, most of the documents analysed in the update expect insignificant changes in mean annual runoff until the middle of the 21st century. However, they confirm a significant decrease in mean annual runoff until the end of the 21st century. This is valid for the entire DRB, also for the UDRB. Although this is the area with the highest water availability, water shortages are expected in unfavourable areas in the far future, which has not been reported in the initial study. The most crucial aspect regarding runoff is the change in seasonality, which applies to all of the regions in the DRB. Here, a decrease in summer runoff and an increase in winter runoff are expected due to shifts in precipitation seasonality. Changes of runoff conditions are in turn assumed to cause a decline in groundwater storage and recharge, particularly in summer. The already monitored decline of the past in the Hungarian Great Plain Area is likely to intensify in the future. Lake levels might decrease in summer. Furthermore, a decrease in soil water content is likely in the DRB, particularly in summer.

(2) Water use

The described possible future changes of water availability, extreme hydrological events and water quality will influence water use. Water demand is expected to increase in a warmer climate in agriculture, industry, energy production and general human consumption. In the field of agriculture more water might be required for livestock and irrigation, because of drier summers and a longer growing period because of higher temperatures.

The possible shortening of the growing season due to too high temperatures in the south-eastern DRB will increase the water demand for irrigation

The most remarkable difference in comparison to the initial Danube Study is that now negative impacts of climate change on agriculture are expected to exceed positive impacts in every sub region. Positive impacts like higher yields due to a longer vegetation period are now largely limited to the short and medium term future. In the far future the higher temperatures are affecting the vegetation period negatively. Moreover, a higher atmospheric CO_2 content is no longer mentioned as a positive factor for agriculture. Impacts which affect both, agriculture and forestry are a shift in species, invasive species, and pests, changing species composition and damages from extreme weather. In contrast, damages from snow and frost are assumed to be less. A changing climate will affect power generation as well. The reduced water availability in summer in combination with projected increasing water temperatures might become problematic for thermal electricity production, which is dependent on cooling water from rivers. Hydroelectric power generation is likely to decrease in the DRB on average and in summer, whereas in winter an increase due to more rain than snowfall is possible. However, hydropower generation in rivers may face problems due to flood events increasing in intensity and frequency and the resulting damages (Frik, 2018; Steininger et al., 2015). Additionally, a seasonal shift in power generation might be triggered by changing water availability, above all in mountain regions. The Danube is an important water way in Europe. Hence navigation may face challenges due to climate change effects on runoff conditions. While in winter navigation conditions might improve with less icing and higher water levels, in summer low flow conditions are likely to limit cargo loads and in worst case make the Danube impassable, just as it happened during this summer and autumn. The update of the Danube Study shows that increasing flood conditions are expected to be problematic for navigation. Possible consequences of this scenario are industrial production losses as well as increased difficulties in accessing water resources and higher costs for water resource use. Also conflicts between the different water users could arise and require potential solution options as for example, a hierarchy of water supply during water scarcity periods.

An increase in air and water temperature, combined with changes in precipitation, water availability, water quality and increasing extreme events may lead to changes in ecosystems, life cycles, and biodiversity in the DRB in the mid- and long-term. The habitats and ecosystems in the south-eastern region of the DRB and in the Hungarian Great Plain area are especially likely to become drier. As consequences, a rearrangement of biotic communities and food webs, the disappearance of species and the invasion of species might occur. Shifts and changes in aquatic and terrestrial flora and fauna, particularly in littoral communities and aquatic systems are likely. In the marine coastal zones, a redistribution and losses of marine organisms as well as the increase of invasive species and in toxic bloom events are possible impacts of rising sea surface temperatures. Higher sea levels could increase the salinization of estuaries and land aquifers and change ecological conditions at the coast of the Black Sea. Potential increasing water demand, e.g. irrigation for agricultural purposes in the entire DRB, especially in the south-eastern parts, may also deteriorate the ecological and chemical balance of freshwater bodies and could lead to an increase of contaminated surface and groundwater bodies.

Besides climate change impacts, anthropogenic impacts, political regulations and restrictions as well as the technological development will also trigger future changes in water quantity and quality in the DRB.

Comparing the results of both studies, the developments in climate change modelling and the resulting findings, show the necessity of an update of the scientific knowledge base, which is the basis for a successful implementation of adaptation measures and strategies.

Less water availability in summer is likely to cause longer, more frequent and more intense drought and low flow situation in the DRB. Particularly the south-eastern parts of the DRB, namely the Carpathian Area, the southern parts of Hungary and Romania, the republic of Serbia, Bulgarian and the Danube Delta region are likely to be confronted with severe droughts and water shortages. Contrary, there is no future trend for droughts in the Alpine head watersheds. However, a spread of affected areas to the north is expected. Like drought and low flow events, flood events in the DRB are expected to intensify and occur more often. The update of the Danube Study confirms statements of the initial study. Small and mountain catchments appear to be the most affected ones. With an increase of torrential rainfall an increase in flash floods is expected despite uncertainties.

Besides water quantity, also water quality is likely to be affected by climate change in the DRB. Increasing air temperature might cause increasing water temperature in the DRB. This in turn will change all temperature dependent chemical and biological processes and cause reduced water quality, especially during droughts in summer.

Adaptation measures for the water sectors of the DRB

To respond to the challenges created by climate change and the water related impacts, it is of great importance to consider the consequences which today's actions may cause as late as during the next 50 – 100 years. This needs adaptation strategies which are more ambitious than up to now. Nevertheless, there is consensus between the Danube countries and the European Union that adaptation to climate change is a central environmental policy issue. Due to the transboundary character of water and its relevance for various issues and water-related sectors such as its role for biodiversity and the ecosystem, energy, transport, agriculture, floods and droughts, integrated river basin management is key for an approach to climate change adaptation.

In this section, possible adaptation measures for the impacts of climate change on the water sector of the DRB as suggested by the analysed adaptation activities are presented. Measures with a high common agreement are selected. This means that they have been suggested by most of the analysed documents. Furthermore, they are valid for almost all impact fields. Adaptation should start with a priority on win-win, no-regret and low-regret measures that are flexible enough for various conditions. The adaptive approaches require enough flexibility so they can also be modified and adapted to local conditions. This way of working has the benefit of increasing resilience and decreasing vulnerability for the whole Danube ecosystem.

The adaptation measures can be classified into five different categories, targeting different objectives. Preparation and technological measures are aiming on monitoring and infrastructural issues; eco-system based measures should enhance the capacity of eco-systems to adapt, whereas behavioural and managerial measures aim to raise awareness and to encourage knowledge exchange. Policy approaches are most important for basin-wide transboundary solutions. Table 1 gives an overview on these measures. They are classified in the different categories, introduced above.

The smoothly formulated measures allow various realisations and there is no sharp separation possible between the categories of the measures. However, the measures not only have overlapping fields and linkages between the categories, but they are also linked between affected sectors and other relationships such as upstream – downstream dependencies. Positive and negative effects among them may be possible and conflicts may occur, even though the selected measures are no-/ low-regret or win-win-options, so that they have positive effects whatever the extent of future climate is, or other social, environmental or economic benefits are also met (European Climate Adaptation Platform, 2018). For instance, the expansion of protection areas as ecosystem based measure and policy approach could be conflicting with the construction and modification of infrastructure as technological measure, albeit environmental issues are likely to be considered in the adjustment of infrastructure and synergy effects might be found. An increase in water retention areas can lead to higher groundwater recharge, a reduction of flood peaks and positive effects for biodiversity, so that various sectors may profit such ecology with enabling biodiversity, navigation with reduced flood peaks or water related energy production with reduced losses during a flood. To prevent possible conflicts and to foster common goals, cross-sectoral, interdisciplinary and integral approaches and continuous communication, also among the Danube countries are necessary. Furthermore, the time horizon of the effects of adaptation options should be taken into account. While the long-term measures, e.g. reforestation, affect water retention not until several decades, short-time measures, e.g. water-saving techniques may be immediately effective.

Besides the presented measures, there are numerous options for adaptation to climate change, particularly for distinct sectors. The spatial coverage for applying adaptation measures ranges from local to catchment wide actions. In many cases coordination among bordering countries is of great necessity. The principal obstacles to

Table 1 Common adaptation measures to climate change impacts in the water sector in the Danube River Basin (ICPDR Strategy on Adaptation to Climate Change 2018 in preparation)

Preparation measures
Additional, intensified monitoring activities to follow and assess climate change and climate change impacts
Homogenous data production, digital mapping and a centralised database for data exchange and comparability among regions and countries
Identification of potential risk areas and hot spots
Implementation of forecasting and warning services (e.g. for extreme events such as floods and droughts)
Development of action plans or integration of specific issues into ongoing planning activities (e.g. to deal with water scarcity and flood situations)
Further research to close knowledge gaps, determine vulnerability or reduce uncertainty
Rules for water allocation in case of water scarcity under the aspect of benefit sharing
Toolbox preparation measures
Ecosystem based measures
Taking environmental implications and the conservation of biodiversity into consideration in all other measures
Sustainable management of land use practices for improving resilience, and for enhancing the capacity to adapt to climate change impacts
Implementation of green infrastructure to connect bio-geographic regions and habitats
Protection, restoration and expansion of water conservation and retention areas
Rehabilitation of polluted water bodies
Behavioural and managerial measures
Support education, capacity building, awareness raising, information exchange and knowledge transfer
Establishment of and support for an integrated risk management
Support of a water saving behaviour
Propagation of best practice examples
Application of sustainable methods (e.g. good agricultural practices)
Technological measures
Adjustment of (existing) infrastructure, e.g. construction and modification of dams and reservoirs for hydropower generation, agriculture, drinking water supply, tourism, fish-farming, irrigation and navigation
Development and application of water-efficient technologies
Efficient waste- and sewage-water treatment and water recycling
Policy approaches
Support of an institutional framework to coordinate activities
Harmonisation of international, basin-wide legal limits and threshold values
Implementation of restrictions (e.g. for development in flood risk areas)
Expansion of protection areas (e.g. for drinking water resources)
Adaptation of policies to changing conditions

install adaptation measures documented are a lack of knowledge, trained staff, reliable data and financial resources.

For a detailed listing of adaptation measures it is referred to the Danube Study (2012) and the update of the Danube Study (2018). To make the large number of measures better usable for stakeholders, an easy to use online toolbox is created. The toolbox allows the user to obtain detailed information on the measures of interest, which are divided into various groups such as impact fields, relevancy to the WFD, time horizon and others.

CONCLUSION AND OUTLOOK

Climate change will affect water resources in all parts of the DRB as the analysis of existing studies and research and development projects shows. Despite all water sectors and regions are affected, the effects of climate change vary depending on the region. This is due to the landscape diversity as well as the huge east-west and north-south gradient in the DRB. Therefore, adaptation measures have to be flexible enough to react to these heterogeneities. To deal with the uncertainties that come along with projections of future climate we presented a pragmatic approach to show the related uncertainty of the future development to the analysed climate parameters and impact fields. The update of the Danube Study confirmed the trends detected in the initial Danube Study., The improved climate models and modelling approaches (EURO-CORDEX) substantiate the results of the first Danube study. Temperature and precipitation development can be depicted in a higher resolution and with a higher certainty. Impacts of climate change on water related issues will be even more significant in almost all water sectors along with a stronger negative trend than in the first study.

The new certainty analysis shows a significant increase in certainty for most of the water sectors. Temperature development and seasonality in precipitation even tend to be highly certain. Despite all heterogeneities, climate change affects all regions and does not stop at national borders. Water connects all riverine countries, which is why a common strategy is highly important for a successful adaptation to climate change effects. Being a frontrunner and pioneer among transboundary river basin commissions in climate change adaptation activities, the ICPDR adopted the first ICPDR Strategy on Adaptation to Climate Change in the year 2012. Basis therefor was a comprehensive overview about future climate change in the DRB and its impacts on the water sectors as presented in the previous sections. Moreover, it was necessary to collect and analyse already existing adaptation strategies and actions. In order to get the most comprehensive overview possible, experts and stakeholders were consulted additionally. At the Danube Ministerial Meeting in February 2016 Ministers asked the ICPDR to foresee an update of its strategy. During the development of the update of the ICPDR Strategy on Adaptation to Climate Change in 2018, the following points emerged as highly relevant and have to be taken greater into account. First, the strategy needs to be developed in close collaboration with stakeholders, experts and country representatives. This increases acceptance and fosters the implementation. Second, the strategy is developed as a reference document that may be used by countries, regions, and organisations to develop their own individual adaptation strategy. In this context, we developed an online toolbox, which provides a huge amount of adaptation measures. Third, clear goals of the strategy need to be defined in order to make it more powerful. Fourth, the strategy is considered to be a “living” document. This means that it will be updated regularly in order to include the latest scientific results and experiences with the strategy. The principal objective is building resilience against climate change impacts on water resources through capacity building, transboundary cooperation and encouraging basin-wide approaches as well as benefit-sharing is a key priority and objective to address climate change in the Danube River Basin. Base is the update and revision of the Danube Study. Despite most of the results regarding climate change and its impacts from the initial study could be confirmed, science made advances in climate modelling allowing for more detailed climate change projections. This is particularly important for the highly heterogeneous DRB. Along with this, uncertainties could be decreased, which is highly relevant for planning and taking adaptation measures. Moreover, the continuous dialogue with experts, stakeholders and country representatives allowed identifying strengths and weaknesses of the existing strategy. Strengths are that it represents the first existing overall guideline for adaptations in a large catchment and gives an overview on climate change and its impacts in the entire DRB. In contrast to the strengths it shows no clearly addressed objectives and contains no summary for policy makers.

During the initial Danube Study as well as during the update some shortcomings had to be faced which made it quite challenging to create a comprehensive scientific database for an adaptation strategy in the DRB. A meaningful comparison of documents about climate change or adaptation was made difficult, since documents were not available, not available in English, or did not fulfil scientific standards. For some parts of the DRB there exist almost no studies about climate change and its effects on the water sector. Comparability was even made more difficult by the fact that methods and data used in the analysed documents are highly diverse and standards are not met. Moreover, international and interregional collaboration and also collaboration between institutions within one country could be expanded. When it comes to the implementation of adaptation measures, it has to be considered, that measures in one sector may have retroactive, positive or negative effects on one or more other sectors or even other regions or countries. To prevent possible conflicts and to foster common goals, cross-sectoral, interdisciplinary and integral approaches as well as trans-regional/national agreements are necessary. Integral approaches also aim to enhance synergy effects which should be sought. An example of a synergy effect is an increase in water retention areas which can lead to a higher groundwater recharge, a reduction of flood peaks and positive effects for biodiversity.

The updated ICPDR Strategy on Adaptation to Climate Change and the web-based toolbox provide a significant improvement. It increases the applicability of the strategy and gives the stakeholders support for the development of regional and national adaptation solutions. Furthermore, it underlines the necessity of transboundary and trans-sectoral collaboration and emphasizes the importance of specific adaptation measures depending on the characteristics of the sub-catchments.

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FUTURE PROJECTIONS OF WATER SCARCITY IN THE DANUBE RIVER BASIN DUE TO LAND USE, WATER DEMAND AND CLIMATE CHANGE

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Abstract

This paper presents a state-of-the-art integrated model assessment to estimate the impacts of the 2°C global mean temperature increase and the 2061-2090 warming period on water scarcity in the Danube River Basin under the RCP8.5 scenario. The Water Exploitation Index Plus (WEI+) is used to calculate changes in both spatial extent and people exposed to water scarcity due to land use, water demand, population and climate change. Despite model and data uncertainties, the combined effects of projected land use, water demand and climate change show a decrease in the number of people exposed to water scarcity during the 2°C warming period and an increase in the 2061-2090 period in the Danube River Basin. However, the projected population change results in a decrease of exposed people in both warming periods. Regions with population growth, in the northwestern part of the Danube River Basin experience low water scarcity or a decrease in water scarcity. The largest number of people vulnerable to water scarcity within the Danube River Basin are living in the Great Morava, Bulgarian Danube and Romanian Danube. There, the combined effects of land use, water demand and climate change exacerbate already existing water scarce areas during the 2°C warming period and towards the end of the century new water scarce areas are created. Although less critical during the 2°C warming period, adjacent regions such as the Tisza, Middle Danube and Siret-Prut are susceptible to experience similar exposure to water scarcity within the 2061-2090 period. Climate change is the most important driver for the increase in water scarcity in these regions, but the strengthening effect of water demand (energy sector) and dampening effect of land use change (urbanization) does play a role as well. Therefore, while preparing for times of increased pressures on the water supply it would be advisable for several economic sectors to explore and implement water efficiency measures.

Keywords: Danube river basin, water scarcity, global warming, land use change, water demand change, population change

INTRODUCTION

Growing human water demands due to population growth in many region of the world, socio-economic developments and climate change causes pressures on our freshwater resources. It is expected that the water supply cannot fulfil the water demands in coming decades (Vörösmarty et al., 2000; Stahl, 2001; Lehner et al., 2006; Alcamo et al., 2007; Arnell et al., 2011, 2013; Sperna Weiland et al., 2012; Gosling and Arnell, 2013; Hanasaki et al., 2013; van Vliet et al., 2013; Arnell and Lloyd-Hughes, 2014; Haddeland et al., 2014; Prudhomme et al.,2014; Schewe et al., 2014; Schlosser et al., 2014; Wada et al., 2014; Kiguchi et al., 2015), which means that water scarcity is rapidly increasing in many regions.

For Europe, water scarcity and drought events got special interest following the droughts in 2003 (ICPDR, 2015), which reflected the projected temperature extremes for future summers (Beniston, 2004). For transboundary rivers, like the Danube River Basin (DRB), river basin management is important as sharing water resources in times of future drought and water scarcity creates interdependencies that may lead to both sectoral and regional water conflicts (Farinosi et al., 2018). The DRB covers 10% of the territory of continental Europe with 80 million people in 19 countries (ICPDR, 2015; Malagó et al., 2017; Karabulut et al., 2016). Therefore, it is important to find a good balance between water availability and water demand for a wide range of sectors, such as irrigation, livestock, energy and cooling, manufacturing industry, navigation, as well for domestic uses. The water-energy-food-ecosystem (WEFE) nexus is a novel way to address these interlinked and often simultaneously water allocation strategies. Although not top priority yet, river basin management in the DRB, coordinated by the International Commission for the Protection of the Danube (ICPDR), is expected to become more important in future climate (ICPDR, 2015).

In present climate, potential water scarcity is predominantly appearing in the Pannonian Danube, in some subbasin of the Tisza, Middle Danube and Lower Danube (Karabulut et al., 2016; ICPDR, 2013). In addition, densed populated urban areas and areas with low natural water yield are also susceptible for localized water scarcity (Karabulut et al., 2016). Water stress is projected to increase in the southern and eastern parts of the DRB, especially in smaller tributary rivers due to a lack of summer precipitation (ICPDR, 2013, 2018). Although important to keep up with growing demands, human interventions, like reservoirs and water transfers, or other factors such as social, demographic, and economic development are not considered in most of these water resources modelling studies. Recent improved details in water use scenarios (Bernhard et al., 2018a, 2018b) and the availability of land use projections (Jacobs-Crisioni et al., 2017) open new opportunities for an integrated assessment of future climate, land use change and water consumption in relation to water resources.

The aim of this study is to provide a state-of-the-art integrated model assessment in relation to water scarcity in the DRB under global warming which is of high interest to inform and support climate policy makers for mitigation and adaptation strategies. In addition to the integrated impacts, the isolated impacts of land use, water demand and climate change will be examined.

METHODOLOGY

Hydrological model

LISFLOOD is a GIS-based spatially-distributed hydrological rainfall-runoff model (De Roo et al., 2000; Van der Knijff et al., 2010; Burek et al., 2013). Most hydrological processes in every grid-cell defined in the modelled domain are reproduced and the produced runoff is routed through the river network. Although LISFLOOD is a regular grid-based model with a constant spatial grid more detailed sub-grid land use classes are used to simulate the main hydrological processes. The model distinguishes for each grid the fraction open water, urban sealed area, forest area, paddy rice irrigated area, crop irrigation area and other land uses. Specific hydrological processes (evapotranspiration, infiltration etc.) are then calculated in a different way for these land use classes. Moreover, sub-gridded elevation information is used to establish detailed altitude zones which are important for snow accumulation and melting processes, and to correct for surface temperature.

LISFLOOD is successfully applied for applications for flood forecasting (Thiemig et al., 2015; Bisselink et al., 2016; Alfieri et al., 2013; Emerton et al., 2018) as well for studies dealing with climate change impact assessments in terms of water resources (Bisselink et al., 2018), streamflow drought (Forzieri et al., 2014), flood risk (Alfieri et al., 2015, 2017; Dottori et al., 2017) and multi-hazard assessments (Forzieri et al., 2016).

For this work, LISFLOOD was run on the Danube domain at 5km spatial resolution and daily time step. The results of this study are based on the Water Exploitation Index Plus (Wei+) indicator (Faergemann, 2012), which is a water scarce indicator. The WEI+ is determined at monthly timescale and in subregions (typically subriver-basins within a country) to avoid averaging skewed results. For uniformity, both the input and output maps presented here are area-averaged for every single subregion. More details on the model setup can be found in Burek et al. (2013).

Climate projections

The climate scenarios used in this study were produced within the EURO-CORDEX initiative (Jacob et al., 2014). Scenario simulations within EURO-CORDEX use the new Representative Concentration Pathways (RCPs) as defined in the Fifth Assessment Report of the IPCC (Moss et al., 2010). RCP scenarios are based on greenhouse gas emissions and assume pathways to different target radiative forcing at the end of the 21st century. The climate projections considered in this work are listed in Table 1 and are all based on RCP8.5 (Riahi et al., 2011). The RCP8.5 scenario represents a situation in which emissions continue to increase rapidly (worst case scenario), and typically exceed 3ºC warming before the end of the current century. From each climate projection meteorological variables were extracted for historical and future climate scenarios and used to estimate daily evapotranspiration maps with the Penman-Monteith equation. These maps together with bias-corrected temperature and precipitation (Dosio et al., 2012) were then used as input for LISFLOOD.

From LISFLOOD’s output we analysed the 30-year periods centered on the year of exceeding the global-mean temperature of 2ºC according the used Global Climate Model (GCM; Table 1) and the time window 2061-2090. To represent the present climate scenario, simulations from the period 1981-2010 are performed and analysed as well.

Table 1 EURO-CORDEX climate projections used in this study and corresponding year of exceeding 2ºC warming with the 30-year evaluation period.

	Institute	GCM	RCM	2ºC	period evaluated
1	CLMcom	CNRM-CM5	CCLM4-8-17	2044	2030-2059
2	CLMcom	EC-EARTH	CCLM4-8-17	2041	2027-2056
3	IPSL	IPSL-CM5A-MR	INERIS-WRF331F	2035	2021-2050
4	SMHI	HadGEM2-ES	RCA4	2030	2016-2045
5	SMHI	MPI-ESM-LR	RCA4	2044	2030-2059
6	SMHI	IPSL-CM5A-MR	RCA4	2035	2021-2050
7	SMHI	EC-EARTH	RCA4	2041	2027-2056
8	SMHI	CNRM-CM5	RCA4	2044	2030-2059
9	DMI	EC-EARTH	HIRHAM5	2043	2029-2058
10	KNMI	EC-EARTH	RACMO22E	2042	2028-2057
11	CLMcom	MPI-ESM-LR	CCLM4-8-17	2044	2030-2059

The DRB is approximately 802,525 km^2 large and located in Central and Southeast Europe. The ICPDR divides the DRB in 15 water management regions (Fig. 1a), mostly subbasin catchments with area ranging from approximately 13650 km^2 (Delta-Liman) to 149450 km^2 (Tisza). The results of this study will be presented based on these water management regions. The DRB explores various climate regimes due to its vast area and topographic variability and can be categorized in four climate regimes with an aridity index ranging from 0.2-0.5 (semi-arid), 0.5-0.65 (dry-subhumid), 0.65-0.80 (moderate humid), to > 0.80 (humid). The aridity index is the ratio of ensemble mean of the precipitation and potential evapotranspiration from the climate projections (Table 1). Figure 1 shows the spatial distribution of climatological aridity of both present and future climate. The derived aridity index for present climate (1981-2010) indicates that 8.6% of the total DRB area can be classified as semi-arid located in the southeastern part of the DRB surrounded by the dry-subhumid regions (22.4%) in the southeastern and middle part of the DRB with a continental climate. The moderate humid (20.2%) and humid regions (48.8%) are located in mountainous areas or in areas influenced by the Atlantic climate.

Many studies provide climate projections with temperature, precipitation and evapotranspiration trends (Stagl and Hattermann, 2015; Jacob et al., 2014; Hlásny et al., 2016; Bartholy et al., 2014; ICPDR, 2013; Laaha et al., 2016; Pieczka et al., 2011). In short, the air temperature is likely to increase in future with a gradient from northwest to southeast. Overall, small precipitation changes are to be expected as the DRB is located in a north-southern transition zone between increasing (northern part of DRB) and decreasing (southern part of DRB) future precipitation. Moreover, seasonal behavior of extreme temperature and precipitation is likely to be more pronounced with an increasing number of extreme precipitation events in winter and more dry spells in summer. These change in precipitation and potential evapotranspiration associated with warming temperatures lead to an increasing aridity of the semi-arid regions in both the 2°C warming period (+1.4%) and 2061-2090 period (+4.5%) whereby the spatial extent is growing over time towards southwest direction (Fig. 1a) on the expense of the dry-subhumid regions which decrease in spatial extent with -3.1% and -2.3% respectively (Fig. 1b). The spatial extent of both the moderate humid and humid regions are increasing with 1.0 % and 0.7% respectively between present climate and the 2°C warming period with the largest increase in the Pannonian Danube (Fig 1c,d), but the spatial extent of the humid and humid regions is decreasing again towards the end of the century (2061-2090) with respectively -0.8% and -1.3%.

From the 15 water management regions, the Austrian Danube, Morava, Vah-Hron-Ipel, Pannonian Danube, Drava, Sava and Tisza shift towards a wetter climate regime, while the Middle Danube, Great Morava, Bulgarian Danube, Romanian Danube and Siret-Prut tend to shift towards a drier climate regime under 2°C global warming. Towards the end of the century (2061-2090), some additional regions show a tendency towards a drier regime, like the Tisza and Sava. The Vah-Hron-Ipel and Pannonian Danube regions show an increase in spatial extent of the semi-arid areas, but also an increase in spatial extent of the humid regions. Only the spatial extent of the Morava region continues growing towards a wetter

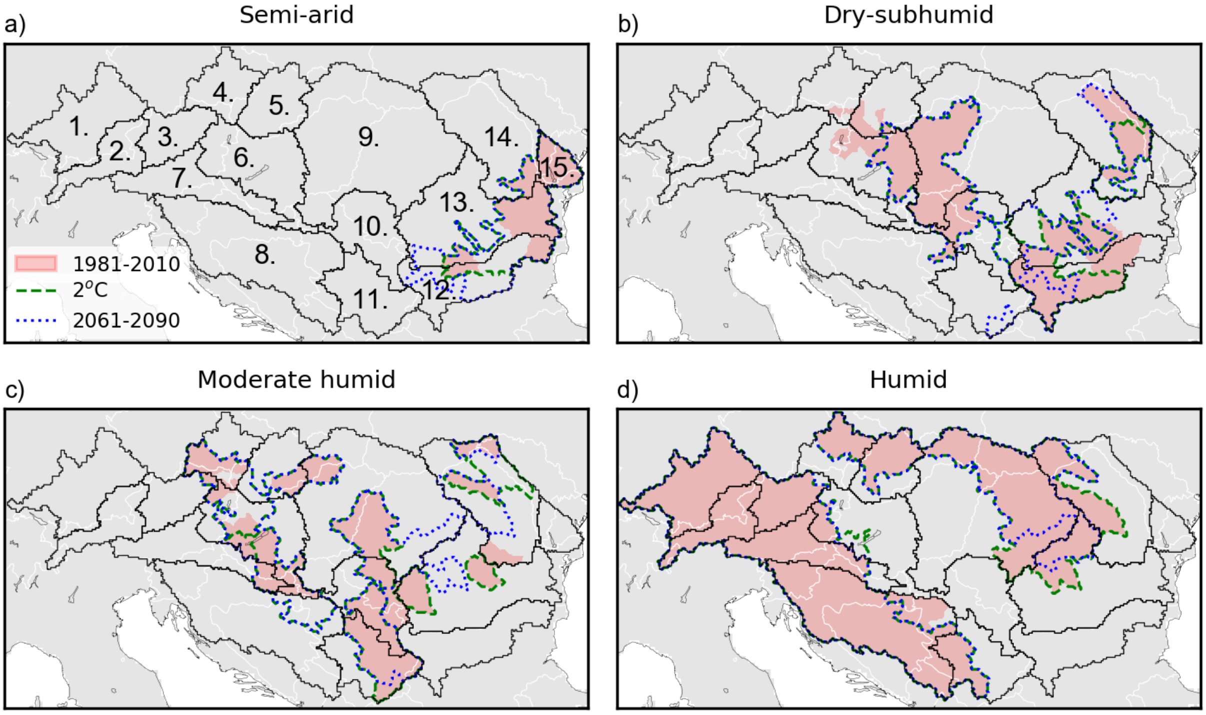

Fig 1 Spatial distribution of a) Semi-arid, b) Dry-subhumid, c) Moderate humid, and d) Humid regions for the baseline 1981-2010, 2°C and 2061-2090 warming periods based on the ratio of the ensemble mean of the precipitation and evapotranspiration. In figure 1a the 15 ICPDR water management regions are inserted: 1. Upper Danube, 2. Inn, 3. Austrian Danube, 4. Morava, 5. Vah-Hron-Ipel, 6. Pannonian Danube, 7. Drava, 8. Sava, 9. Tisza, 10. Middle Danube, 11. Great Morava, 12. Bulgarian Danube, 13. Romanian Danube, 14. Siret-Prut and 15. Delta-Liman.

climate regime. Notice that the climate regimes of the Upper Danube, Inn and Delta-Liman regions remain unchanged in time where the first two are classified as humid and the latter as semi-arid.

Land use projections

The future land use projections used in this study are modelled using the JRC LUISA territorial modelling platform (Batista e Silva et al., 2013; Lavalle et al., 2011). LUISA translates socio-economic trends and policy scenarios into processes of territorial development. Among other things, LUISA allocates (in space and time) population, economic activities and land use patterns which are constrained by biophysical suitability, policy targets, economic criteria and many other factors. Except from the constraints, LUISA incorporates historical trends, current state and future projections in order to capture the complex interactions between human activities and their determinants. The mechanisms to obtain land-use demands are described in Baranzelli et al. (2014) and Jacobs-Crisioni et al. (2017). Key outputs of the LUISA platform are fine resolution maps (100 m) of accessibility, population densities and land-use patterns covering all EU28 member states expanded with Serbia, Bosnia Herzegovina and Montenegro until 2050. CORINE land use maps (Büttner and Kosztra, 2007) are used to cover the rest of the DRB. Although LISFLOOD normally operates on a substantially coarser resolution, the details of the LUISA output will remain for a large part due to the use of sub-grid fractions in LISFLOOD as explained in the 'Hydrological model' section. For a complete description of the LUISA modelling platform and its underlying mechanics we refer to (Batista e Silva et al., 2013; Lavalle et al., 2011).

Figure 2 shows an example of projected changes of forest and urban land use classes based on the LUISA platform and used as input for LISFLOOD. In general, an increase of the forested area is projected for the DRB (3%; Fig. 2a,c) with the most increase in the upstream regions and the Bulgarian Danube. The only regions without change in forested area are the Middle Danube, Great Morava and the Delta-Liman region. On average, all the selected regions show an increase in urban land use with the most pronounced increase in the Inn catchment (24%) due to the urbanization in South Germany (Fig. 2b,d). Minor or no changes are projected for the rural areas (Fig. 2b).

Water demand projections

Water demand in LISFLOOD consist of five components from which the irrigation water demand is estimated dynamically within the model as it is driven by climate conditions. The irrigation water demand with a distinction in simulation methods for crop irrigation and paddy rice irrigation is described in Bisselink et al. (2018).

The other four external sectoral components are (manufacturing) industrial water demand, water demand for energy and cooling, livestock water demand and domestic water demand. In general, water use estimated for these four sectors are derived from mainly country-level data (EUROSTAT, AQUASTAT) with different modelling and downscaling techniques as described in Vandecasteele et al. (2014). Output of the LUISA

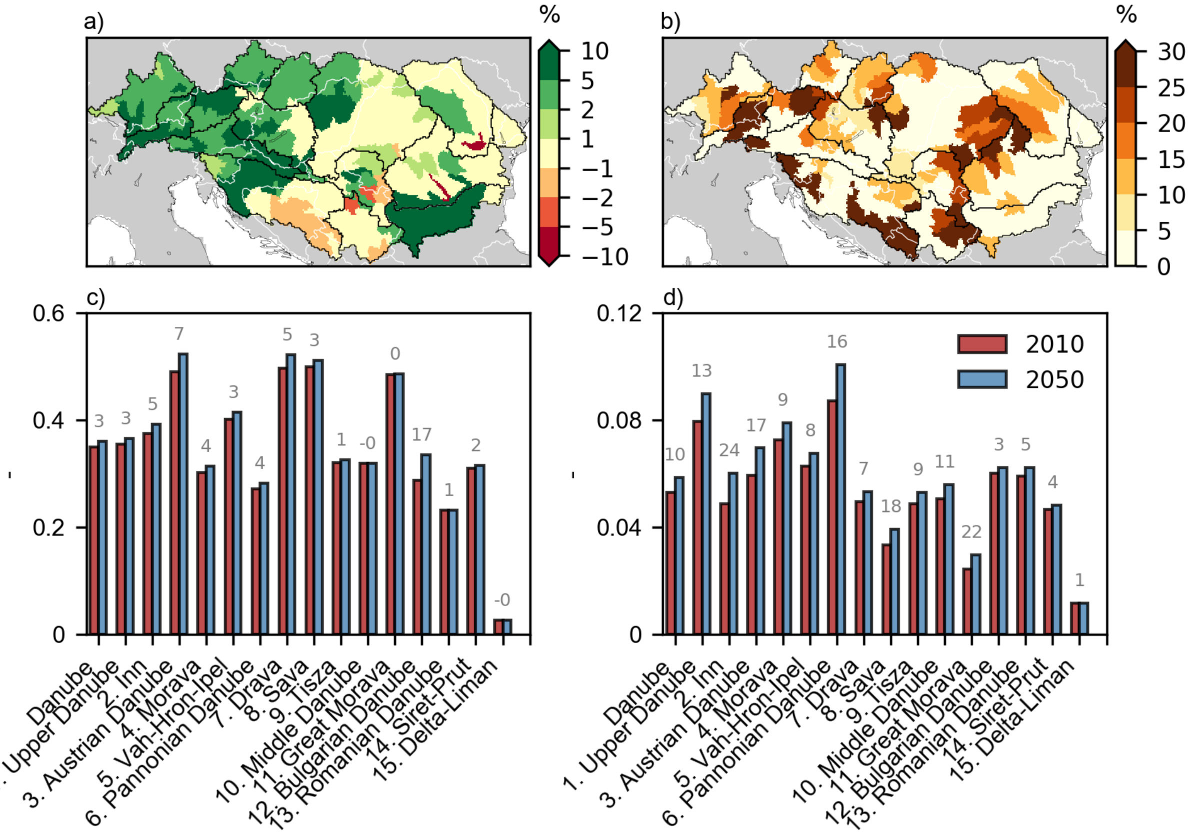

Fig 2 a) Projected change (%) in a) forest fraction, and b) urban fraction between 2010 and 2050. Barplot of area-averaged fractions (-) for c) forest and d) urban area for 2010 and 2050 for the selected regions in the DRB. The grey numbers above the bars indicate the projected change (%) between 2010 and 2050.

platform is used for the spatial downscaling of both present and future water use trends to ensure consistency between land use, population and water demand. A brief description of each sectoral component is given below. Livestock water withdrawals are estimated by combining water requirements from literature with livestock density maps for cattle, pigs, poultry, sheep and goats. The methods are described in detail by Mubareka et al. (2013).

For the energy and cooling demand, national water use statistics are downscaled to the locations of large power thermal power stations registered in the European Pollutant Release and Transfer Register data base (E-PRTR). Subsequently, the temporal trend of energy water use is simulated based on electricity consumption projections from the POLES model (Prospective Outlook on Long-term Energy Systems).

Industrial water demands are based on country-level figures from national statistics offices for the total water use by manufacturing industries, mining and construction. Future industrial water use trends are simulated based on Gross Value Added (GVA) projections from the GEM-E3 model to represent industrial activity and an efficiency factor to represent improving water efficiency due to technical developments (Bernhard et al., 2018a). Since the GEM-E3 model only provide projections for the EU28, industrial water use projections are assumed constant for countries outside EU28.

Water demands for the household sector are derived from a specific household water usage module (Bernhard et al., 2018b) which simulates water use per capita based on socio-economic, demographic and climate variables.

This model was based on collected data at NUTS-3 from 2000-2013 for all EU28 countries on household water use, water price, income, age distribution and number of dry days per year. Subsequently, regression models were fitted to quantify relationships between water use, water price and the other relevant variables for four European clusters of NUTS-3 regions with similar socio-economic and climate conditions. Socio-economic, demographic and climate projections are used to estimate future domestic water use per capita. The future projections of both the industrial and domestic water demand are calculated every 5 years until 2050. For the years in between the 5yr-window a linear growth is assumed.

Figure 3 shows a map of the projected change in total water demand between 2010 and 2050 for all water usages excluding (irrigated) agriculture. The total water demand is increasing between 2010 and 2050 in the DRB (Fig. 3a) with the largest relative change in the Romanian Danube. The largest absolute water demand change is observed in the Pannonian Danube (Fig. 3b) following the urban land use change with expanding cities like Vienna and Budapest (Fig. 2d). The water demand for energy and cooling is the largest contributor to the water demand change.

Population projections

Population projections are based on EUROSTAT and are constraints for the LUISA model (Batista e Silva et al., 2013). In Figure 4 the population change between 2010 and 2050 is presented. The population is increasing in urban areas in the northwestern part and decreasing in the more rural eastern and southeastern part of the DRB (Fig. 4a). Overall, the population in the entire DRB is decreasing with 6% with the largest relative decrease in the Bulgarian Danube (Fig. 4b). The Pannonian Danube is one of the few regions with a future population growth (14%) resulting in an increase in both urban areas (Fig. 2d) and water demand (Fig 3b).

RESULTS

Changes in water scarcity

To estimate future changes in water scarcity we used here the WEI+ indicator (Faergemann, 2012), which is defined as the ratio of the total water net consumption divided by the freshwater resources of a region, including upstream inflowing water. WEI+ values have a range between 0 and 1, with values between 0-0.1 denote “low WS”, “moderate

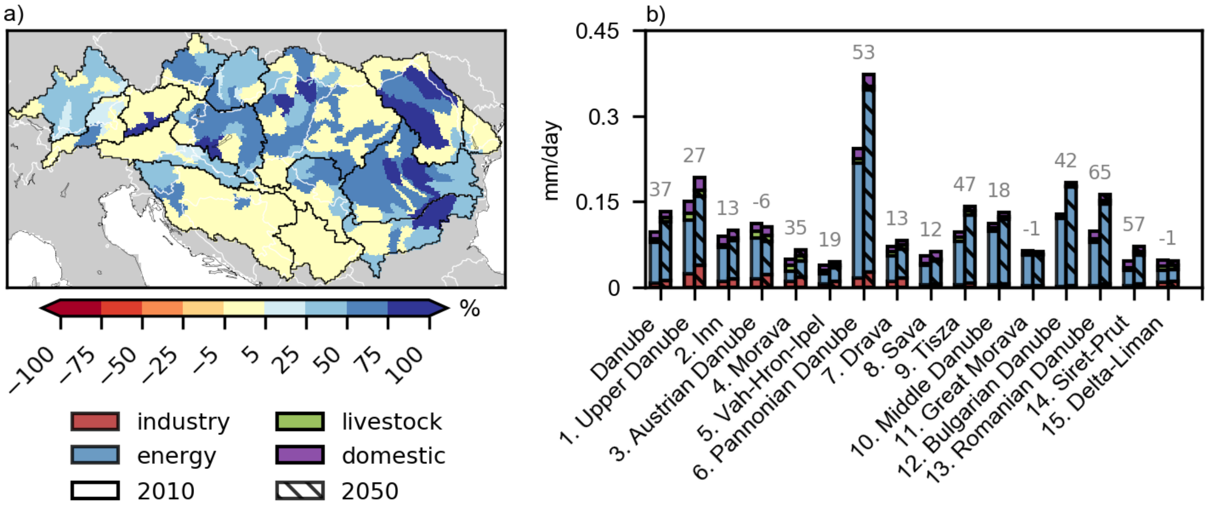

Fig 3 a) Projected change (%) of aggregated total water demand (livestock, energy production and cooling, industry, households and public sector) between 2010 and 2050, and b) barplot of area-averaged aggregated total water demand (mm/day) for 2010 and 2050 for the selected regions in the DRB. The grey numbers above the bars indicate the projected change of the aggregated total water demand (%) between 2010 and 2050.

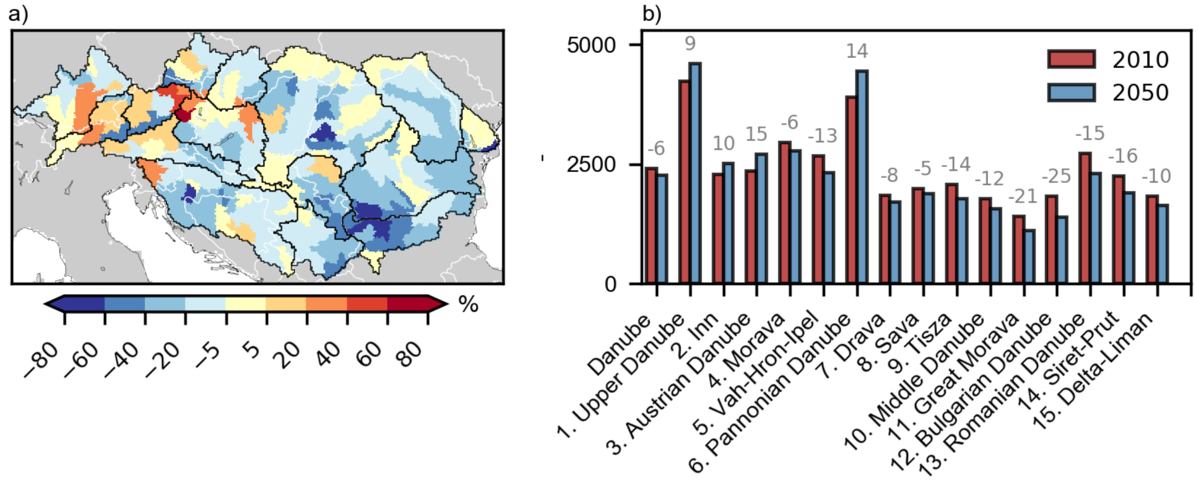

Fig 4 a) Projected change (%) in population between 2010 and 2050, and b) barplot of area-averaged population for 2010 and 2050 for the selected regions in the DRB per 25 km^2 grid. The grey numbers above the bars indicate the projected change (%) between 2010 and 2050.

WS" if the ratio lies in the range 0.1-0.2, "WS" when this ratio is in the range of 0.2-0.4, and "severe WS" if the ratio exceeds the 0.4 threshold.

First we consider the spatial pattern of the change in water scarcity days in a year for the 2°C warming period relative to present climate under RCP8.5 (Fig. 5). The DRB can be divided in three categories:

1. Regions which shift towards less water scarcity days in a year (i.e. increase in 'low WS' and decrease in 'moderate WS', 'WS' and 'severe WS') or remain unchanged: Upper Danube, Inn, Austrian Danube, Morava, Drava, Sava and Delta-Liman.
2. Regions which shift towards an increase in water scarcity days (i.e. decrease in 'low WS' and increase in 'moderate WS', 'WS' and 'severe WS'): Great Morava, Bulgarian Danube and Romanian Danube.
3. Regions including both water regions shifting towards less water scarcity days and water regions shifting towards an increase in water scarcity days (for e.g., the water region of a city): Vah-Hron-Ipel, Pannonian Danube, Tisza, Middle Danube and Siret Prut.

The most important change towards the end of the century (2061-2090) is that more regions are shifting towards an increase of water scarcity days with in the central part of the DRB (Vah-Hron-Ipel, Pannonian Danube and Sava) a shift from 'low WS' to 'moderate WS' and even a more pronounced shift in the Tisza, Middle Danube and Siret-Prut with an increase in 'WS' and 'severe WS' days. In the Great Morava, Bulgarian Danube and Romanian Danube the water scarcity days are exacerbating.

Population affected

Next, we put the water scarcity projections into a societal perspective to estimate how many people will be living in areas with 'moderate WS', 'WS' or 'severe WS' for at least 1 month within present climate, 2°C warming or 2061-2090 period. Figure 6 presents barplots of the individual regions with the number of people living for at least 1 month/30yr in 'moderate WS', 'WS' or 'severe WS' areas. The simulated 'moderate WS', 'WS' and 'severe WS' areas are overlaid with the population of the year 2010 and the projections of 2050 to quantify the contributions of solely the combined effect of land use, water demand and climate change (green dashed line) and the combined effect of land use, water demand and climate change together with population change (grey bar) respectively. The decrease or increase of the number of people living in 'moderate WS', 'WS' and 'severe WS' areas is not due to the population change if the grey bar and the green dashed line are at an equal population level. Note that, the number of people living for at least 1 month/30yr in 'low WS' areas is 100% for all regions and therefore this category is excluded. Moreover, the people living in the regions Upper Danube, Inn, Austrian Danube and Drava are never exposed to 'moderate WS', 'WS' or 'severe WS' longer than 1 month/30yr and therefore these regions are excluded.

The projections for the 2°C warming period in the DRB (Fig. 6a) show a decrease of people living in 'moderate WS', 'WS' and 'severe WS' areas compared to present climate due to the combined effect of land use, water demand and climate change together with population change. In general, the result of the DRB is also representative for the regions Vah-Hron-Ipel, Pannonian Danube, Tisza, Middle Danube, Great Morava and Siret-Prut (Figs. 6c,d,f,g,h,k). For the regions Morava, Sava and Delta-Liman (Figs 6b,e,l) the combined effect of land use, water demand and climate change is the only driver for the reduction of people living in 'moderate WS', 'WS' and 'severe WS' areas, while the decrease of the people living in 'moderate WS', 'WS' and 'severe WS' areas in the Romanian and Bulgarian Danube is almost solely due to the population change (Fig. 6i,j). Water scarcity is increasing in these regions as seen in the previous section but the people living in water scarce areas is decreasing which indicates that the areas affected by water scarcity are not growing. The areas which already experience water scarcity are projected to become more water scarce resulting in an equal or decrease in the number of people living in water scarce areas.

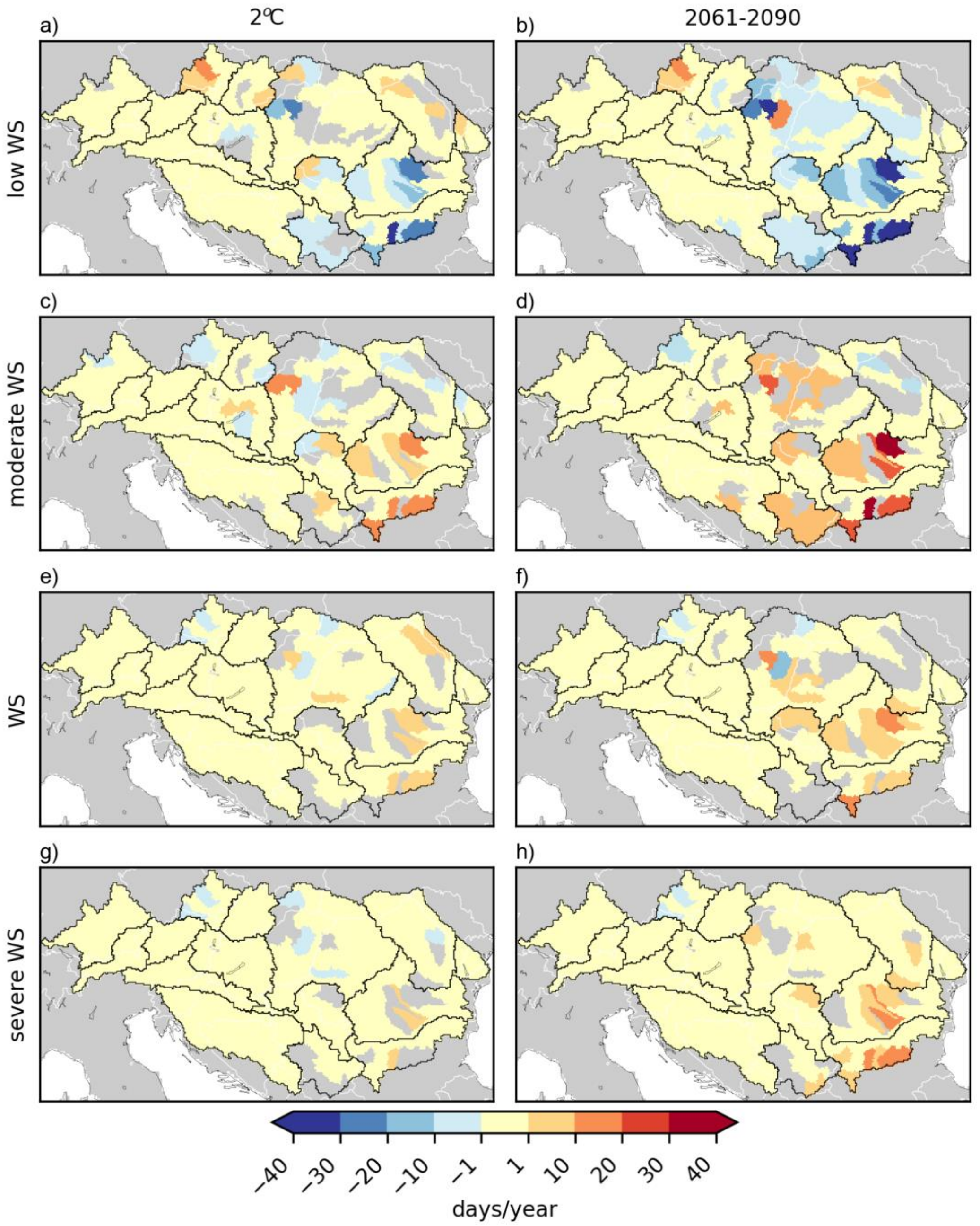

Fig 5 Projected change in days per year with ‘low WS’ (a,b), ‘moderate WS’ (c,d), ‘WS’ (e,f), and ‘severe WS’ (g,h) of the ensemble mean of the 2°C period (left panels) and 2061-2090 (right panels) relative to present climate (1981-2010). Grid cells within the DRB where not all models agree in the sign of change are greyed out. We consider the result valid if at least 7 out of 11 models agree in the sign of change (positive or negative).

For the 2061-2090 warming period, the water scarce areas in the DRB are expanding (see Fig. 5) and therefore an increase in people living in ‘moderate WS’, ‘WS’ or ‘severe WS’ areas is projected relative to the 2°C warming period (Fig. 6a). Compared to present climate, the number of people living in ‘moderate WS’, ‘WS’ or ‘severe WS’ areas are more or less equal again when only the combined effect of land use, water demand and climate change is considered but are still decreasing with the combined effect of land use, water demand and climate change together with population change (Fig. 6a). In more detail, this trend is also observed in a number of regions like: Tisza, Middle Danube, Great Morava, Bulgarian Danube, Romanian Danube and Siret-Prut (Fig. 6f,g,h,i,j,k). All these regions are projected to become just as or more water scarce in future in comparison to present climate but due to population change less people will be exposed to ‘moderate WS’, ‘WS’ and ‘severe WS’. In the Sava region (Fig. 6e) the people living in both ‘moderate WS’ and ‘WS’ areas are increasing compared to present climate and 2°C warming period due to the combined effect of land use, water demand and climate change. In the Morava, Vah-Hron-Ipel, Pannonian Danube and Delta-Liman region (Fig. 6b,c,d,l) the people living in ‘moderate WS’, ‘WS’ or ‘severe WS’ areas remain unchanged or decreases compared to present climate due to land use, water demand and climate change only (Morava and Delta-Liman) or due to land use, water demand and climate change together with population change (Vah-Hron-Ipel, Pannonian Danube).

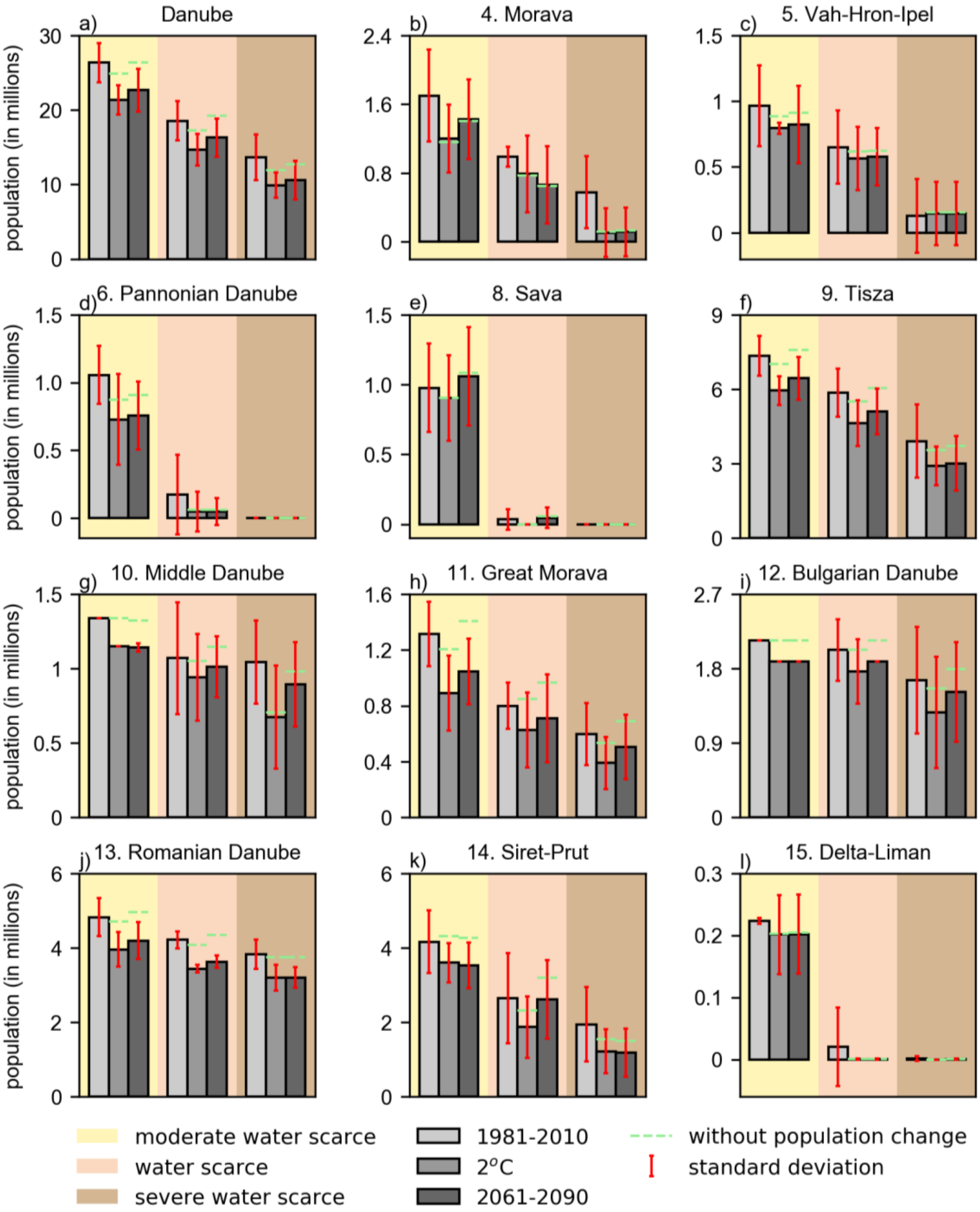

Fig 6 Barplot of population (in millions) located within water regions which have at least 1 month in the 30 year warming periods with 'moderate WS', 'WS' or 'severe WS' for the selected regions with and without taken the future population change (green dashed line) into account. Population data for 2010 is used for reference and 2050 for future projections. Error bars represent the ensemble standard deviation.

Impact of land use, water demand and climate change

The model simulations we performed in this study are an integrated assessment of land use, water demand and climate change (see section 'Methodology'). However, water resources can be considerable affected by the combined or isolated effect of land use, water demand and climate changes. Here, we attempt to quantify both the combined and isolated impact of land use, water demand and climate changes on the June-July-August (JJA) WEI+ by performing different combinations of simulations with/without land use or water demand together with climate changes. In Figure 7, the relative change between the JJA WEI+ of the ensemble mean of the 2°C warming period and present climate (1981-2010) is presented. The combined effect of land use, water demand and climate changes (Fig. 7a) on the JJA WEI+ show a decrease for water regions in the Morava, Tisza and Middle Danube, and an increase in the Great Morava, Bulgarian Danube, Romanian Danube and Siret-Prut. The most dominant impact on the JJA WEI+ change is climate change (Fig. 7b), but the land use (Fig. 7c) and water demand change (Fig. 7d) also contribute considerably in some water regions. In general, land use change has a negative effect while the water demand change has a positive effect on the JJA WEI+ change. For a more detailed illustration of

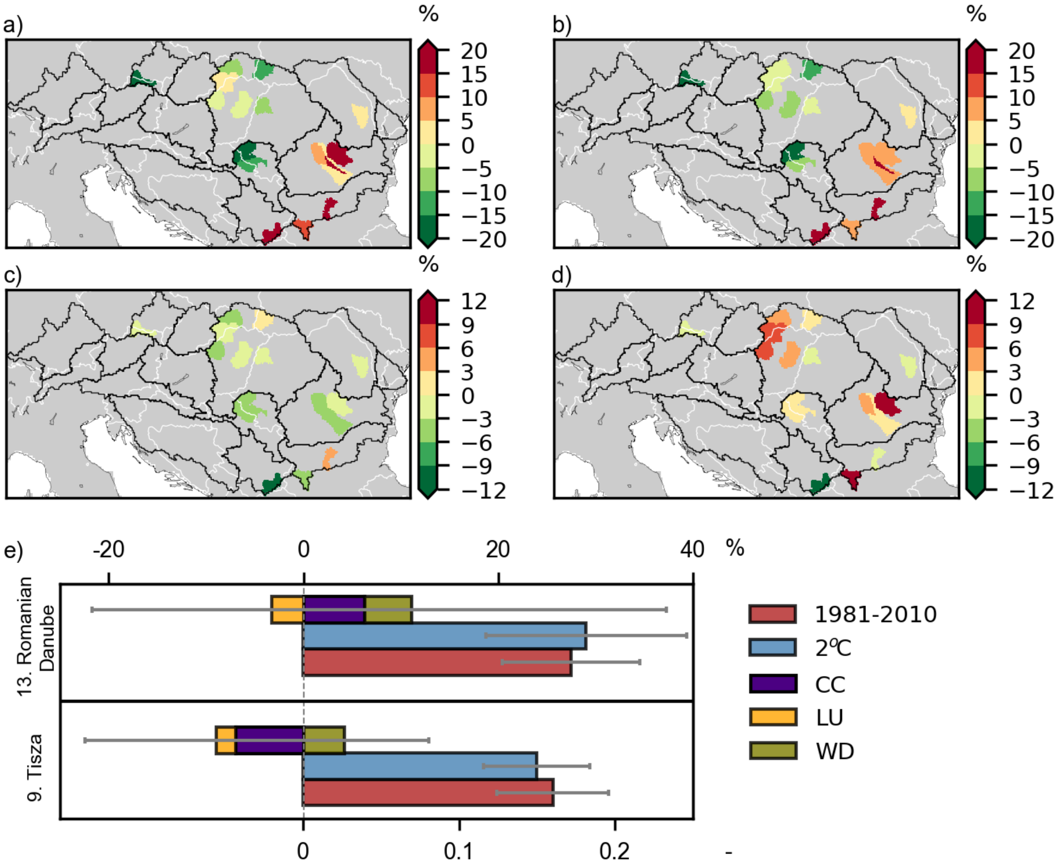

Fig 7 Projected relative change (%) between the JJA WEI+ of the ensemble mean of the 2°C warming period and present climate (1981-2010) from simulations including a) climate change, land use and water demand change, b) climate change only and the isolated effect of c) land use change and d) water demand change. Only water regions with an average WEI+ larger than 0.1 in present climate are selected e) Barplot of the contributions (%) of climate change, land use change and water demand change to the total change for present climate (1981-2010) and 2°C warming period including standard deviations for the selected regions.

this effect, the JJA WEI+ change and the isolated effect of land use, water demand and climate changes are presented in a barplot for the Tisza and the Romanian Danube (Fig. 7e). In the Romanian Danube an increase in JJA WEI+ between present climate and the 2°C warming period is observed due to climate change amplified by water demand change, while the land use change alleviates the increase of JJA WEI+. In contrast, in the situation where the JJA WEI+ is decreasing, like in the Tisza, the land use change is amplifying the decrease, while the water demand suppress this effect.

Uncertainties

Model studies with LISFLOOD, and modelling studies in general, go hand-in-hand with uncertainties. They are inextricable mainly caused by model structure or model parameterization due to for e.g. different precipitation sources (Bisselink et al., 2016). It becomes a major challenge when assessing the combined or isolated impacts of land use, water demand and climate change on water resources. The climate projections are accompanied by large uncertainties due to varying but plausible estimates of future warming. As the DRB is in a transition zone between a wetter and drier future climate, the models even disagree in the sign of change. Therefore, multiple climate projections are used to give us, at least, an estimate of the uncertainty. Unfortunately, a similar approach is not available for land use, population and water demand change. Overall, the uncertainty in land use, population, water demand and climate projections together with hydrological model parameterizations introduces considerable variability into the resulting projections of water scarcity. For this reason, the impact estimates of water scarcity and people exposed should be taken as an indication to which direction future scenarios evolves.

SYNTHESIS, DISCUSSION, AND CONCLUSION

In this study, we performed a state-of-the-art integrated model assessment including projections of land use, water demand and climate change to assess changes in water scarcity in the DRB under global warming. With the population projections we were able to estimate people exposed to low water scarcity ('low WS'), 'moderate WS', 'WS' or 'severe WS'. Moreover, different combinations of simulations with and/or without land use or water demand together with climate change allowed us to isolate the effect of land use, water demand and climate change in relation to water scarcity.

Changes in precipitation and potential evapotranspiration according to the mean of 11 climate projections reveal that semi-arid regions in both the 2°C warming period (+1.4%) and 2061-2090 period (+4.5%) are increasing in the DRB due to spatial expansion in the southeast part of the catchment. In the northwestern part we find a slight increase towards a more humid climate. These northwest to southeast gradient is in good agreement with the recently updated report of the ICPDR (ICPDR, 2018) and, in general, with the assessment of the change in water scarcity days. However, direct intercomparisons of projected water scarcity changes with other studies is not straightforward as, to our knowledge, this is the first attempt to integrate land use, water demand and climate change for future projections in the DRB.

People living in the DRB experience both increases and decreases in water scarcity in the future. Overall, this results in less people exposed to water scarcity ('moderate WS', 'WS' or 'severe WS') at the 2°C warming period, and more people towards the end of the century (2061-2090) when considering solely the combined effects of land use, water demand and climate change (i.e. population change excluded). In the 'real world' including population change even less people are getting exposed to water scarcity but not evenly distributed. The population is decreasing in the regions experiencing an increase in water scarcity while population is increasing in regions with a water scarcity decrease.

The Great Morava, Bulgarian Danube and Romanian Danube show a clear tendency towards an increase in water scarcity days between present climate and the 2°C warming period. However, this result is not reflected in the number of people exposed to water scarcity solely due to the combined effect of land use, water demand and climate change (i.e. population change excluded). So, although the combined effect of land use, water demand and climate change may not create new water scarcity areas, it may exacerbate water scarcity. Towards the end of the century (2061-2090), the combined effect of land use, water demand and climate change is creating new water scarcity areas which is reflected in the increase of population exposed to water scarcity at an equal or higher number compared to present climate again.

Opposite patterns, where the number of people exposed to water scarcity is stable or decreasing solely due to the combined effects of land use, water demand and climate change and not by population change, are observed for the Upper Danube, Inn, Austrian Danube, Morava, Drava, Sava and Delta-Liman regions for both the 2°C warming period and 2061-2090 period. In other regions, the projected water scarcity changes are very heterogeneous with areas with increasing and decreasing water scarcity in the same region. In the regions of Pannonian Danube and Vah-Hron-Ipel the change in people exposed to water scarcity is decreasing between present climate and the 2°C warming period and remains rather stable towards the end of the century. Water scarcity and the people affected in the regions Tisza, Middle Danube and Siret-Prut is decreasing due to the combined effect of land use, water demand and climate change together with population change at the 2°C warming period. At 2061-2090, the exposure to water scarcity is steeply increasing due to the combined effect of land use, water demand and climate change.

The isolated effect of land use, water demand and climate change proved that climate change is the most dominant driver for the water scarcity change. In June-July-August the water demand is also an important contributor for the change followed by the land use change. However, in other seasons the contribution of the water demand change is probably lower compared to the land use change. Anyhow, the growing water demand, mainly due to increase in energy use and subsequent cooling water usage, obviously puts pressure on the water supply resulting in amplifying water scarcity. Regions with increasing water scarcity exposure could mitigate towards renewable forms of energy production (solar) which might reduce the water needed for cooling and dampens the water scarcity increase.

Changes in hydrological cycle due to land use change are both positive and negative. Urban areas with more impervious surfaces upstream or in the water regions increase direct runoff towards the rivers, and hence the total volume of runoff in a water region resulting in tempering the water scarcity exposure, but may simultaneously decrease groundwater recharge, which is not included in the definition of the WEI+.

Although, population decrease ensures that less people are exposed to water scarcity, several sectors requiring water, such as rainfed and irrigated agriculture must adapt to reduced water availability at the risk of production loss or land degradation. These adaptation challenges are already needed in the short term for the Great Morava, Bulgarian Danube and Romanian Danube and in the long term also in the Tisza, Middle Danube and Siret-Prut.

The results obtained in this study showed that the complex interactions between land use, water demand and climate change requires an integrated model framework especially in combination with mitigation and adaptation measures involving several economic sectors. Further development in this direction is needed to tackle complex issues about water resources allocation and water scarcity problems.

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THE FEASIBILITY OF COOPERATION TO COMPLY WITH LAND USE CHANGE OBLIGATIONS IN THE MAROSSZÖG AREA OF SOUTH HUNGARY

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Abstract

In many years excess water inundations generate a major obstacle to farming in the lowland part of Hungary, including the Marosszög area. Diverting water to large distances requires an infrastructure that is costly to develop and maintain. Alternatively, low-lying local land segments could be withdrawn from cultivation and utilized to collect the surplus water. The Ecological Focus Area (EFA) requirement of the EU points to the same direction: it requires that 5% of arable land is converted to other, ecologically more beneficial uses. During the research project it was tested if it is feasible to apply a novel economic policy instrument, an auction to trade land use change obligations, to achieve the EFA requirement in a cost effective way through the cooperation of farmers, while also creating a practical solution to manage the seasonal surplus water cover on land. The research was carried out in an interdisciplinary way: a dynamically coupled fully integrated hydrological model, including surface and subsurface modules, was applied by engineers to better understand the interconnections of land use, local hydrology and the role of the water diversion infrastructure; while a pilot auction exercise was conducted by economists with the participation of farmers to understand if cost reductions can be achieved through cooperation, as opposed to individual fulfilment of EFA obligations. The analysis also revealed which segments of the water diversion network are economic to maintain. It was confirmed that it is possible to improve local water management and satisfy the EFA requirements at a reduced cost if appropriate economic incentives are applied to trigger the cooperation of farmers.

Keywords: Inland excess water, land use adaptation, agriculture, economic instruments, water management infrastructure, auction

INTRODUCTION

Seasonal water surpluses appear in the Tisza valley not only as floods, but also as temporal water coverage and water logging in low lying areas that are otherwise protected from floods (van Leuween et al., 2008). These excess water occurrences are slow but complex hydrological extremities, which affect surface and subsurface soil conditions (Szatmári and van Leuween, 2013). They frequently occur due to meteorological, morphological, land cover, pedological and hydrogeological characteristics (Pásztor et al., 2015) as well as a result of anthropogenic factors (Farkas et al., 2009; Benyhe and Kiss, 2012).

To mitigate the unfavourable agricultural and infrastructural effects of excess water, an extensive defense system of hydraulic structures - mostly pumps and weirs -, and a 42,400 km long channel network is maintained in the lowland parts of Hungary (Kozma and Koncsos, 2011). The benefits provided by water diversion are not commensurate with the otherwise rather elusive maintenance and defense costs (Pinke et al., 2018). There are several explanations for this. After 1990 land ownership and land use changed, earlier large farms that had consisted of thousands of hectares of intensively cultivated mono-culture, were replaced by medium and small sized farms, frequently with a size of only a few dozen hectares, lowering the efficiency of agricultural activities. The price signals provided by commodity, e.g. grain, markets replaced the earlier centrally set prices, introducing revenue risk to farmers. Central budget resources provided for network maintenance have been gradually lowered, reflecting fiscal difficulties as well as a shift in priorities. A shrinking resource base alone may not necessarily be problematic, fragmented land ownership, on the other hand, requires large scale cooperation, which only worked in some exceptional places, typically with the involvement of the local water management associations.

While the state slowly withdraws its resources from the field (VTOSZ, 2011), half-heartedly it continues to contribute to the maintenance of the water management system (OVF, 2016, chapter 5.5.2), thereby maintaining a false image that excess water drainage for agriculture is a public task. Practical experience, however, suggests that the systems cannot be maintained and operated on previous high levels due to the shrinking financial resources. In theory, there are two main types of solutions. 1) Farmers would have to contribute substantially to the financing of the infrastructure. They are hesitant, however, because they do not any more believe that high quality services would be provided in exchange for their payment. It is also uncertain if their increased payment would be justified by improved productivity. 2) The networks would need to be scaled back to a lower size that is easier to maintain from currently available resources. This also requires a parallel change in farming activities, as parcel characteristics would change in locations where the network is abandoned. Furthermore, the actual network modifications need to be determined, but this type of optimization requires information on the adaptation possibilities of farmers, which is not readily available to the managers of the water network.

The goal of the research was to test if the second option (shrinking the network to ensure that it is in line with reduced financial resources) can be pursued through innovative policy solutions in a way that is efficient both economically and from the perspective of altered land use. The Ecological Focus Area (EFA) requirement of the EU was picked as the driving force of change as it requires that 5% of arable land is converted to other, ecologically more beneficial uses (Viaggi and Vollaro, 2012). Farmers were involved in a pilot exercise in which they participated in a hypothetical market where they were allowed to trade the EFA obligation with each other. In other words, Farmer A could pay Farmer B so that the latter fulfils the EFA obligation of Farmer A by converting his own land. As a result, transformed land would not need to be served by the water management infrastructure any more, while it was expected that compliance with EFA would become cheaper. In addition, it was important to understand exactly which land parcels would be transformed away from intensive agriculture, to see if this shift is in harmony with local hydrological conditions. To support information on the latter, a hydrological modelling analysis was carried out for the study area.

STUDY AREA

The pilot area of the study is in the Marosszög geographical region in the South of Hungary, along the last stretch of the Maros River before it reaches the Tisza River. The geographic area under study (Fig. 1) is an approximately 120 km^2 large watershed delineated by the Maros River on the South, by the Sámson-Apátfalvy-Szárazér on the east, an irrigation channel on the north and the Makói main channel on the west. It belongs to the Great-Plain- and within that to the Alsó-Tiszavidék geographic area. Makó town also lies within the perimeters of the area. The terrain is flat, the maximum altitude difference is less than 10 meters and ranges from 75 m to 85 m above Baltic Sea Datum. However, the area has a slope towards west and south, as the receiving water body is the Maros River on the south-west of the area. The origin of the terrain is related mainly to fluvial activity, but eolian originated loess formation can also be found on the north-eastern part of the area (Deák, 2012). The Maros River played the major role in the formulation of the terrain in the Holocene, which has been ceased by the river regulations of the early 20th century. Old river-reaches and oxbows can be found on the area, which are prone to collection of runoff.

The textural types of the top soil are mainly loam, with a clay-loam intrusion from the north-west. This pattern partially stands for the deeper layers as well;

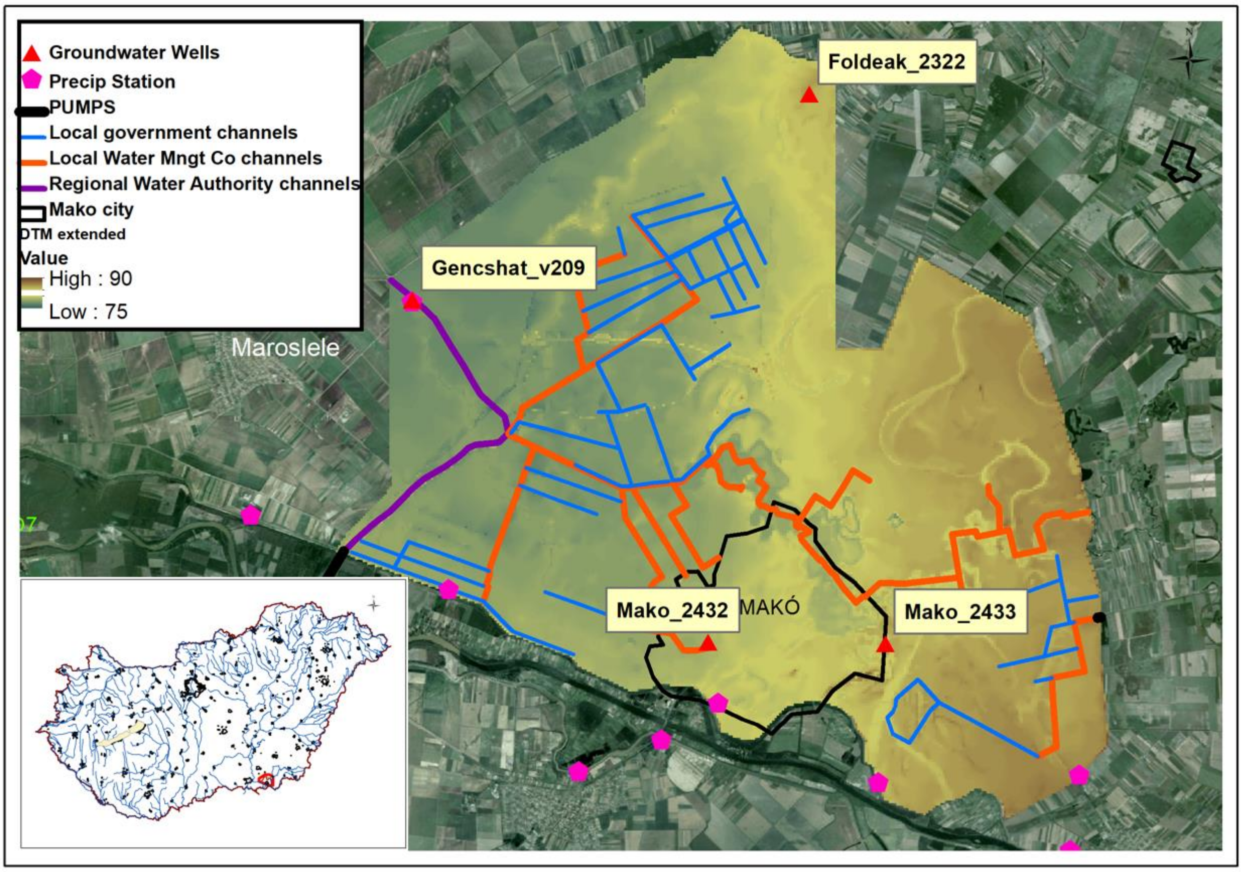

Fig. 1 Modelled pilot area with altitudes and the modelled channel network

however, in a large part of the eastern-middle part of the area the particle size distribution of deeper layers (> 3 meters depth) is dominated by the relatively larger fractions, as it is the alluvial deposition of the Maros River, generally known as coarse sand (Deák, 2012; Pásztor et al., 2015).

The area has a continental climate, with significant seasonal variations and large temperature range. The measured minimum temperature in the last century at Szeged (OMSZ) was -29.1 °C, the maximum was 39.7 °C, the coldest month is January, with an average temperature of -1.3 °C, the hottest month is July with an average temperature of 21.8 °C. The average yearly precipitation is 532.2 mm, the wettest month is June with 67.4 mm and the driest is January with 29.6 mm on average. The number of sunshine hours ranges between 1700-2400 per year. The average yearly actual evapotranspiration is 500-550 mm (VITUKI, 1972).

At present 80-83% of the study area is in agricultural use, of which 98% is used for intensive agriculture (crops and vegetables), reaching a historical peak after centuries of adaptation. The area is moderately, but regularly (every 3-5 years) affected by excess water inundation.

METHODS

The methodological concept

The research was designed as a participatory process with the involvement of farmers from the pilot area in the Marosszög. The local water management association (Tisza-Marosszög Vízgazdálkodási Társulat, TIMAVGT, www.timavgt.hu) ensured that farmers became aware of the research project and they were willing to contribute to it, thereby incorporating local knowledge and experience into the analysis.

Decision on land use/crop choice is based on a balance of productivity and the cost of maintaining necessary conditions for the production. These decisions are frequently distorted because the different subsidies together with the compensation against the losses due to external natural circumstances usually override the need for adaptation to the natural local endowments of the land. This is reasonable on the production level of individual farmers, while such an economic frame may be considered irrational by many who see the adverse effects of such policies. This contradiction supports the outsiders' view that there is no way to discuss common issues with farmers in a truly rational way.

The aim of the research was to create a situation where farmers' land use adaptation / crop choice decisions are inspected in a coherent economic frame in order to test the hypothesis that as opposed to individual, farm level optimization, the cooperation of farmers results in 1) better overall financial outcome for them and 2) a land use pattern that better suits local conditions.

This hypothesis was tested by creating a decision sphere based on a perceived "threat" from a then upcoming EU regulation. This policy process was the Common Agricultural Policy (CAP) regime to enter into force in 2014, which originally envisioned a 7% requirement for Ecological Focus Areas (EFA) as part of Pillar I green payments. Later this number was lowered to 5%, and exemptions were also provided, but within the research the 7% value was used.

From an agricultural production point of view, the EFA regulation is a forced reduction of the production intensity. Compared to the prior status quo, it generates an unavoidable burden in the form of revenue reduction for the farmers as they switch to lower revenue land use or lower value crop (The research did not deal with the net effect of the regulation including environmental gains that could be positive). The EFA regulation was applied in the research because it meant a credible future change for the farmers, therefore the possible ways to mitigate its negative effect proved to be a sensible "down to earth" question to them, offering a suitable common ground for discussions.

The economic approach was supported by hydrological simulations carried out for the pilot area, which served a better understanding of the magnitude, coverage and dynamics of the unfavourably saturated soils and surface inundations. In the absence of precise and detailed monitoring data, the simulation results of the inundations were verified by the field experience of farmers. This discussion also proved useful to create a common understanding and bonding between the researchers and the farmers. In a later stage of the research 1) the economic information that was gained from the test of the economic policy instrument and 2) the inundation frequency and coverage information of the hydrological simulation was combined to identify the financially sustainable and unsustainable elements of the channel system. Below the hydrological as well as the economic methods are described in detail.

Applied instruments – Hydrological simulation

The goal of the hydrological simulation was to understand the effect of the drainage channel network on groundwater, soil moisture conditions and surface water coverage frequency. The model calculations also helped to relate the drainage network to land use and to compare it with the judgement of farmers on which parcels are most likely to be converted from agriculture to EFA in case of external regulatory requirements. Various climate, water governance and land use scenarios were also tested to see the sensitivity of results.

The detailed spatio-temporal simulation of excess water inundation poses a number of challenges. Small relief, undrained sinks and the flow modification effect of surface water coverage prohibit the usage of methods purely based on flow hierarchy. Both surface runoff calculations and instream flow routing are necessary, as water movement can be neglected neither on terrain nor in the complex drainage network. In case of excess water, the subsurface processes are as important as the surface accumulation (Kozma et al., 2014). Finally, the above-mentioned processes occur simultaneously and influence one another. Up to date, only fully coupled/integrated hydrological models (Daniel et al., 2011; van Leeuwen et al. 2016) are 1) appropriate to deal with such complex hydrological phenomenon and 2) to analyse different water governance scenarios.

In this research the WateRisk Integrated Hydrologic Model (WR IHM) was applied, which was developed with the aim to study the hydrologic extremities (flood, excess water, drought) dominant in the low land parts of Hungary (Kozma and Koncsos, 2011; Jolánkai et al., 2012). The WR IHM is a distributed parameter, fully coupled hydrologic model. It simulates the major processes of the local-regional hydrologic cycle in parallel: precipitation processes (rainfall, interception, snow accumulation), evapotranspiration, channel and overland flow as well as unsaturated zone and shallow groundwater movement. The physical basis of the algorithm means that arbitrary climatic-land use-water governance scenarios can be set up through the adjustment of model elements (channel network, pumps, weirs), boundary conditions (e.g. precipitation, temperature time series) and model parameters (e.g. crop-specific surface roughness, leaf area index and root zone depth) (Kozma et al., 2012).

The simulations result in a temporal series of maps for all modelled components (surface water coverage, groundwater levels, stream and channel depth profiles, etc.). Furthermore, the quantitative description of flow and storage processes enables the application to calculate comprehensive volumetric water budget. This covers all surface and subsurface components and processes involved in the model system (e.g. channel discharges, pumped volumes, groundwater-channel interaction, infiltrating fluxes, evapotranspiration, surface water coverage). These features make the WateRisk application a substantial support tool for decision-making.

For the current analysis the model has been set up with a 50 by 50 meter grid (resulting in ~48000 computational cell), driven by the available digital terrain model, also 50x50m resolution (FÖMI, 2012). The channel network has been recreated in its whole extent, including the secondary channels, but not including the ditches along the agricultural plots. Approx. 125 km of channel have been included in the model. Channel cross-sections and longitudinal sections have been provided by the local water authority (Lower-Tisza-District Water Directorate - Alsó Tiszavidéki Vízügyi Igazgatóság - http://www.ativizig.hu/), including weirs, and pumping stations, with operation levels. As current roughness values were not available (only consultations with local water managers) a relatively rough Manning value of 0.05 have been used uniformly on the channel network for current conditions. This has been supported by site visit experience. The channel system drains the Szárazér channel gravitationally, and at high flow conditions the Makó pumping station lifts the collected excess water from the channel into the Maros River. Land cover was derived from the CORINE land cover maps (EEA, 2013). Precipitation data were also given by the local water authority for over 10 stations in the area for the 1998-2000 period. Precipitation, temperature and relative humidity data for the 1991-2000 period for the Szeged station was provided by the National Meteorological Service (Országos Meteorológiai Szolgálat https://www.met.hu/en/idojaras/).

Due to the complexity of the described processes and limited data availability, the formal full calibration of the model is not viable. Instead some of the key hydrological variables have been used to manually adjust the defining model parameters. Such hydrological variables are the measured groundwater levels and scattered and uncertain field observations of water coverage patches.

The state of the groundwater table plays an important role in the water cycle of the area. Water coverage extent and durations for example show high sensitivity to groundwater depth (Koncsos et al., 2011). Therefore, it is important to set the model parameters well in order to give proper groundwater table simulations. There are only two groundwater monitoring wells located in the economic auction pilot area, both being in Makó. Thus a larger area has been included in the hydrological model to include two more groundwater well time series to the calibration process. We expressed the agreement of measured and simulated groundwater level time series with common model efficiency criteria (Moriasi et al., 2007): the Pearson correlation coefficient (R^2), the root mean square error (RMSE) and the Nash-Sutcliffe model efficiency (NSME).

Scenario development

In the second phase of the project, scenario development was undertaken to generate a framework of the model simulations and to create a basis for the interpretation of the model results. We considered several alternatives for the three main affecting factors: climate, water governance scenarios and land use. Instead of setting up all the possible combinations, based on expert judgement we chose the 15 most relevant climate-water governance-land use variants.

Climatic scenarios: The IPCC SRES A2 and B2 emission scenarios (IPCC, 2000) were selected to examine the effects of possible climatic changes of the next 100 years on the water budget of the pilot area. These two scenarios have significantly different emission trends regarding the main greenhouse gases, therefore they have been selected to provide a range of possible changes, given that the uncertainty of the predictions is high. In the Marosszög pilot area the climate scenarios were implemented as simple temperature, precipitation and relative humidity time series for the 2070-2100 period. These time series were developed by different regional climate models, applied by the Prudence project (Christensen, 2005). Three such climate model results were examined and compared locally to the measured time series of the control period. These were Hadley Centre adeha, adehb, adehc data, the Sweden’s Meteorological and Hydrological Institute’s (SMHI) results and the Danish Meteorological Institute’s (DMI) data. Both annual precipitation and seasonal distribution were compared. The comparison shows that there are huge variations between the modelled climate data for either annual sums, averages or seasonal distributions. Based on this, we decided that two climate models will be used for certain hydrologic simulations. Hadley Centre adeha data was selected to drive the WR-IHM model for all of the examined scenarios, and DMI was selected to drive certain model scenarios in order to see the range of effect that the driving data can cause on the model outcome. All together six climate scenarios were set up, named as C1 – control period, C2 – IPCC A2, C3 – IPCC B2, and their combinations with the HC adeha and DMI model results.

Water governance scenarios: four Scenarios were developed for water governance. The first (WG1) is taking the assumption that the maintenance of the drainage system (Fig. 1) will be on the same level as today. The second case (WG2) assumes that there are no channels on the area, which was developed to give a reference for the effectiveness of the channel network. The third water governance scenario (WG3) was developed in order to simulate the effects of a water retention focused water governance on the whole water budget of the pilot area. For this a simple weir system was implemented on the drainage network, without any sophisticated regulation mechanism. This variant represents an extreme solution for 1) avoiding groundwater drainage and 2) implementing channel storage, even at the price that it would often cause flooding in many areas. The last scenario (WG4) was an optimistic case, assuming that there will be more funding for maintenance of the channel network in the future. In this scenario, an increased conveyance capacity of the channels was modelled by setting the Manning roughness of the channels to the typical value of well-maintained channels.

Land use scenarios: Three versions were developed regarding the land use of the pilot area. The current land use (LU1) where simplifications have been applied to the CORINE database. 18 classes were set up all together, agriculture being the largest coverage. Suburbs of Makó town also cover a significant area, while natural vegetation is small (wetlands). For future scenarios, forests were inserted to the model in places where significant water coverage durations were modelled. Under LU2 scenario 7% of the area was changed from agriculture to forest, while under LU3 scenario around 12% of the agricultural vegetation was changed to forest.

Applied instruments - Economic exercise

The economic policy instrument proposed for the Marosszög area is a market to trade land use change obligations, implemented through an auction (Weikard et. al., 2012) that can promote the common fulfilment of the EFA requirement by several farms together. It helps farmers to select the actual pieces of land for conversion, while also serving as a payment mechanism from beneficiaries (farmers whose land continues to be used for crop production) to those land owners whose land is converted. Under the concept farmers bid a portion of their land for land-use change, supplying a price tag for compensation. The farmers whose bids are accepted receive the equilibrium price from the auction for each hectare. The compensation is paid from a fund to which the owners of unconverted land have to contribute, equally after each hectare.

Initially 32 farmer interviews were carried out in order to gain an in-depth understanding of local issues and perspectives on farming and ecology, and to distribute initial information about the project. The discussion resulted in a conciliated excess water inundation map of the area that served as the basis of common understanding of the issue. Then the concept was explained in detail, followed by an auction, and finally sharing and discussing results. All of the meetings were assisted by professional facilitators to make sure farmers remained motivated through the process and they understood the presented concepts. On hypothetical examples it was illustrated that cooperating with each other can lead to an overall lower cost than if each farmer fulfilled the requirement on its own. It was explained how a farmer with good quality land and high yields can pay another farmer with low quality land to fulfil the 7% obligation for the both of them in a way that is beneficial for both parties. The farmers understood this mechanism and afterwards the economic instrument (the auction) was described.

During the exercise farmers bid a portion of their land for land-use change, supplying a price tag for compensation. The actual portion depends on the farmer. Some farmers may offer all of their land, while others may not bid at all, knowing that they would be paying someone else to change their land use instead. Farmers may bid different pieces of their land at different prices. Those farmers that did not wish to participate in the bid, did not have to, they would then carry out the required land use conversion on their own land.

From the bids a supply curve is constructed showing the marginal cost of land use change (Ungvári and Kis, 2013). This curve is used to determine the equilibrium price of converting the required number of hectares. The farmers whose bids are accepted would receive this equilibrium price for each hectare. The compensation is paid from a fund to which the owners of unconverted land have to contribute, equally after each hectare.

The owners of unconverted arable land receive a dual benefit: they pay a lower price to other farmers than the opportunity cost of conversion (= lost profit) on their own land, and the local water balance may also improve. The owners of converted land receive revenue from other farmers as part of the economic policy instrument, and fetch some land use benefits (e.g. profit from grazing; revenue from timber), possibly coupled with a payment under the Common Agricultural Policy. Before the auction, the farmers needed to be well informed about these cash flows. The owners of converted land will not any more generate revenue from intensive crop production, but – since they submit lower than average prices at the auction – this displaced revenue can be safely assumed to be lower than the average for the Marosszög. In other words, areas with low productivity are converted, while areas of higher productivity remain intensively cultivated.

22 farmers with total cultivated land of 1778 hectares participated in the exercise, a little less than 20% of the case study area. 2 farmers, with 76 hectares, decided that they would not engage in the cooperation, that is, they would rather change land use on their own plots, as they had some low quality land, and likewise, they would refrain from offering the land use change service as part of the auction exercise, even though they were aware of the potential financial benefits. Their decision was likely due to lack of trust in the smooth operation of the scheme or limited understanding of the concept.

The results of the economic exercise contributed to a simplified cost-benefit analysis in which the costs of maintaining the channels were compared to the benefits quantified as the profits generated by the agricultural activity enabled by shifting the land-use change obligation to other plots of land. Both the costs and benefits were assessed as annual values.

RESULTS

Hydrological model calibration

Main tendencies of the measured groundwater levels have been described reasonably well by the model, however some of the extreme water levels were either under-, or overestimated in different parts of the area. Table 1 highlights the model efficiency values of the three considered monitoring wells for the 1998-2000 period (note that in case of groundwater table simulations we haven't find any widely accepted guidelines for model performance in the literature). The simulation provided moderately good performance in the agricultural areas for Földeák and Gencshát wells, while inadequate for Makó well located in the settlement. In latter case, possible ignored local effects (water withdrawal and concentrated infiltration, impervious areas, etc.) can explain the bad performance. Further information about the model set up and calibration is found in Jolánkai (2013).

Table 1 Model efficiency measures of groundwater levels for the calibration period 1998-2000

Model efficiency measure	Groundwater well		
	Gencshát v209	Földeák 2322	Makó 2433
R^2	0.74	0.93	0.32
RMSE	0.78	0.49	0.79
NSME	0.45	0.41	-1.30

Figure 2 shows the observed and simulated relative changes of water level relative from the beginning of 1998. Groundwater level during the 1999 excess water flood is underestimated by the model, while the next year the simulated level follows reasonably well the trends of measured water table changes at the Földeák monitoring well.

There is no comprehensive satellite or aerial photograph based water coverage data from the area, therefore the justification of model results has been carried out in an untraditional way. Within the frame of the project, local stakeholder forums have been held to discuss future landscape management options and to assess the validity of economical tools to support future decisions with regard to management options. During these forums the local farmers were asked to evaluate the simulated maximal water coverage map. The result of this qualitative assessment is shown in Figure 3. The general opinion of the farmers about the spots of water coverage has been reaffirming. There have been spots however, where the model showed water coverage that was not confirmed by farmers. Also there have been areas, where they could not give feedback, as they did not have relevant knowledge. The farmers also indicated areas where water coverage had been experienced, but the model did not show any sign of water on the surface. The overall conclusion is that the order of magnitude of the water coverage is well estimated, while the fine spatial distribution of ponds is not so well described. Given that the soil structure of the area is rather inhomogeneous, this is not so surprising.

Hydrological simulations

As Table 2 shows, water coverage extent varies on a wide range if all the scenarios are treated together. However, if the effects of climate change, land use change and water governance change are being examined separately, a different picture emerges. Climate change has the strongest effect on the water coverage. Compared to C1, the area of water coverage in the affected areas drops to about 11 % of the total area on average in scenarios C3. Scenario C2 shows an enormous drop of water coverage (14.2 to less than 1%) according to the HC model, which may seem unrealistic. The DMI model shows a more than 50% rate of change in average water coverage in scenario C3, which is larger than the similar value for the HC similar results. It is likely that the real change would be between these values, given that the real climatic conditions are between the two regional climate model predictions with respect to the control period. The

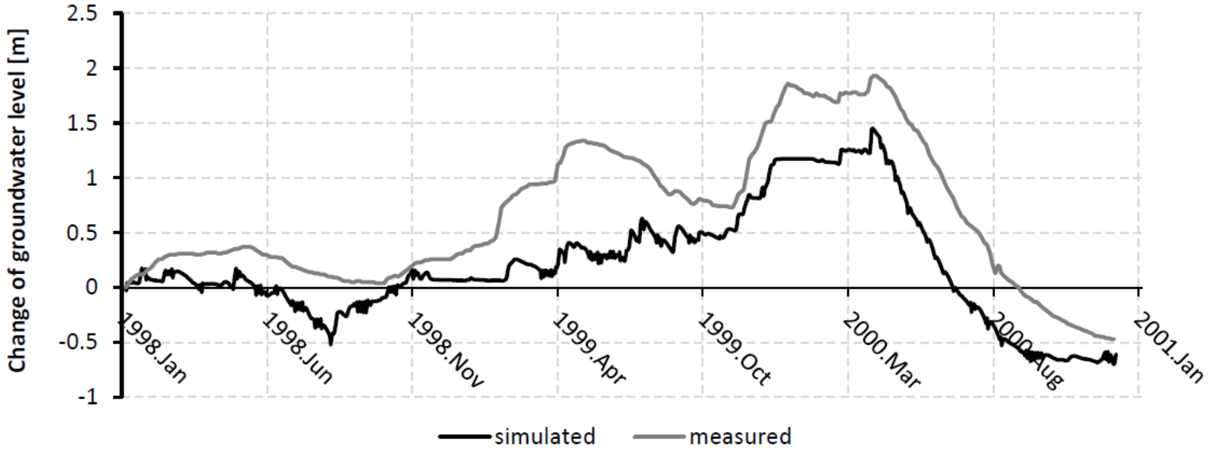

Fig. 2 Calibration results for the Földeák groundwater well – relative change of the measured and simulated water table

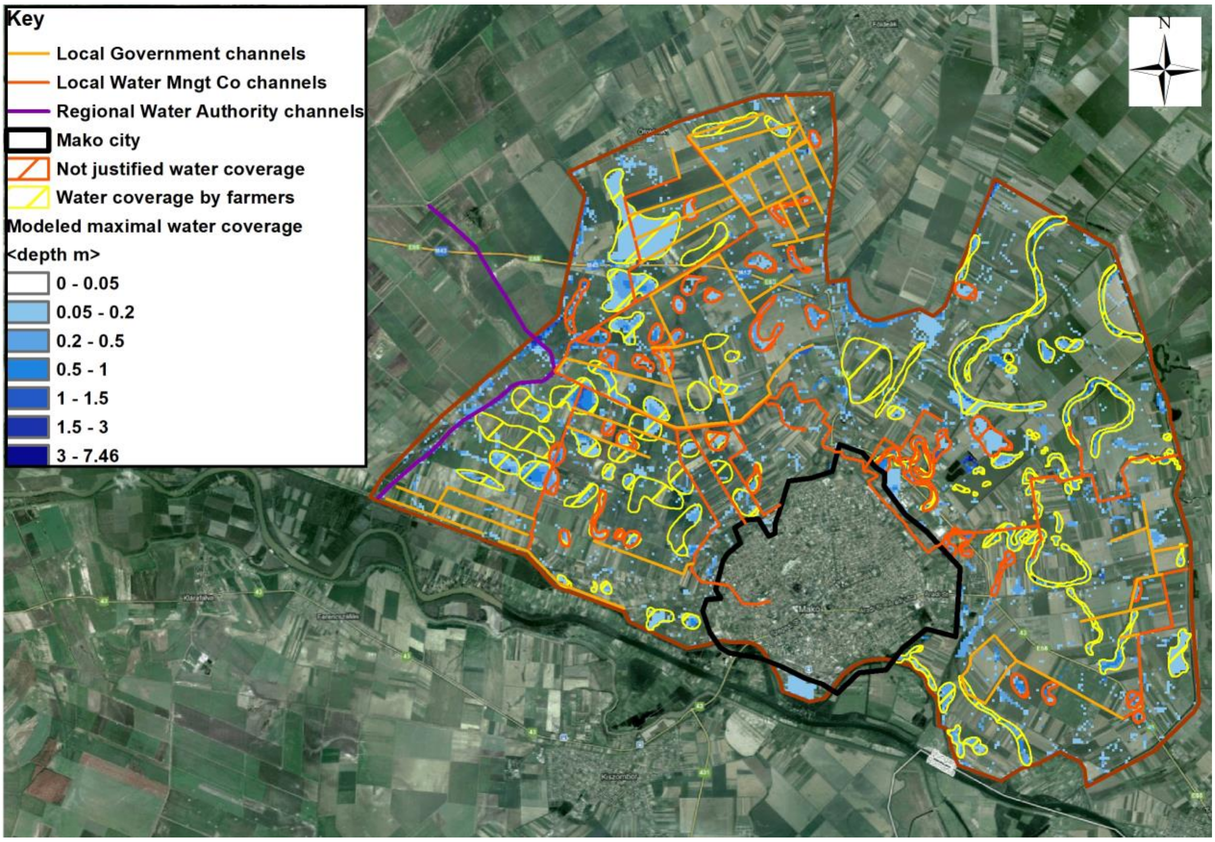

Fig. 3 Confirmed modelled maximal water coverage (1998-2000) by the local farmers in the Marosszög pilot area

Table 2 Water coverage durations (km^2) and the proportion of the coverage of the whole area (%) according to the investigated scenarios (HC: Hadley Centre adeha data, C1: control period, C2: IPCC A2, C3: IPCC B2, WG1: current water governance, LU1: current land use)

Scenarios	Duration of coverage [days]						Total [km^2]	Proportion of the whole area [%]
	0-7	7-14	14-21	21-28	28-60	60-365		
HC-C1-WG1-LU1	14.6	1.7	0.4	0.1	0.1	0.0	17.0	14.2
HC-C2-WG1-LU1	0.9	0.0	0.0	0.0	0.0	0.0	0.9	0.8
HC-C3-WG1-LU1	13.1	0.1	0.0	0.0	0.0	0.0	13.2	11.0
HC-C1-WG1-LU3	15.0	1.6	0.3	0.1	0.1	0.0	17.0	14.2
HC-C1-WG1-LU2	14.7	1.7	0.3	0.1	0.1	0.0	16.9	14.1
HC-C2-WG1-LU2	0.9	0.0	0.0	0.0	0.0	0.0	0.9	0.8
HC-C3-WG1-LU2	13.1	0.1	0.0	0.0	0.0	0.0	13.2	11.0
HC-C1-WG3-LU1	15.0	1.8	0.3	0.1	0.2	0.5	17.9	15.0
HC-C1-WG2-LU1	25.6	2.4	0.5	0.2	0.2	0.0	28.9	24.2
HC-C1-WG4-LU1	14.5	1.7	0.4	0.1	0.1	0.0	16.8	14.1
HC-C2-WG4-LU1	0.9	0.0	0.0	0.0	0.0	0.0	0.9	0.8
HC-C3-WG4-LU1	12.9	0.1	0.0	0.0	0.0	0.0	13.0	10.9
DMI-C1-WG1-LU1	14.6	1.9	1.3	1.5	2.0	2.4	23.6	19.7
DMI-C3-WG1-LU2	8.9	0.4	0.2	0.1	0.2	0.2	9.9	8.3
DMI-C3-WG1-LU1	8.7	0.4	0.2	0.2	0.3	0.3	10.0	8.4

number and duration of significant water coverage appearance on the area drops drastically in both climate scenarios (Fig. 4).

According to the model, land use change does not have a significant effect on the water coverage, as the change of water coverage in this LU scenario is only around 0.1 percent. This can be due to the fact that groundwater levels are generally deep under the surface for all scenarios. Therefore, it is not the groundwater table that is the primary reason for the occurrence of the excess water, but rather the huge amount of precipitation (or the fast snow melt) and the limited infiltration capacity of the soils (e.g. frozen soils).

The effects of water governance improvement have a similarly minor effect on water coverage durations. The improved conveyance of the channels (scenario WG4) has an effect of approximately 1 percentage point on the total water coverage compared to water retention / channel storage (WG3), while no effect compared to the baseline (WG1). As expected, the no channel scenario (WG2) has a significant effect on coverage: 70% increase of total area covered, while the number of days of duration increased by 1, which can have huge implications on plant development.

Pilot auction exercise

As it was already explained, an auction driven land-use change policy was the policy instrument that was tested with the participation of farmers from the Marosszög area. By the time the exercise took place, farmers were well aware of the project, the hydrological modelling efforts as well as the upcoming EFA requirements. During the exercise two scenarios were assessed: 1) individual compliance with the EFA requirement, i.e. all farmers have to set aside 7% of their land for EFA purposes, and discontinue traditional crop production on these parcels, 2) cooperation with each other through auction based common compliance with the 7% requirement.

20 farmers with 1702 hectares of land participated in the exercise. 7% of this area equals to 119 hectares, this is the targeted volume of land use change. Farmers made bids offering (some of) their land for land use change to others at prices specified by them in EUR/hectare/year. Some farmers differentiated their plots based on productivity, and offered different bids for different pieces of land. Altogether 55 bids were received. From the bids a supply curve was constructed, showing the price at which the cumulative quantity of land use change is offered (Ungvári and Kis, 2013). The constructed supply curve is monotonically increasing. The price at which 119 hectares of land conversion was offered happened to be 180 EUR/hectare/year. Thus, under the scheme, farmers who agreed to change their land use on behalf of others, would charge 180 EUR for each hectare per year as a service to those farmers who did not want to execute the land use change on their own parcels.

Because of the 7% criteria, every hectare of converted land enables continued crop production on 13.3 hectares of land - the 7% target implies that out of 100 hectares, 7 hectares is converted while 93 hectares stays in cultivation, thus the ratio of 93/7=13.3 results. Therefore, those farmers that choose to pay others to change land use instead of them, have to pay 13.5 EUR/year (180/13.3=13.5) for each hectare of their cultivated land in exchange for this service. Farmers thought that these results were reasonable.

Assuming that the offered bids were equal to the lost profit of the corresponding land, it was estimated that if each of the 20 farmers complied with the EFA requirement on their own, the lost profit would have been about 32,200 EUR/year for the total cultivated area – this would have been the cost of compliance. In case the farmers cooperate with each other, the total cost declines to 20,100 EUR/year – the 38% difference between the two solutions represents the economic advantage of common compliance.

There are additional, unquantified changes in costs and benefits that are partly the result of land conversion, and partly driven by the auction, as the selected regulatory instrument:

– The benefits of crop production are lost on the converted land, but benefits for other uses may appear (e.g. timber production). Since the quality of the converted plots is below average, the profitability of crop production is probably low; for some farmers cultivating these areas may even create a loss that is balanced by the CAP subisidies - the only reason for farming here. Thus, land use change in itself may improve the financial positions of farmers, if they continue to receive the CAP subsidies while they do not any more suffer a loss on their sub-prime land.

– The auction will enlarge these gains since it leads to the conversion of the worst 7% of the total case study area, while without this solution the worst 7% of each farm

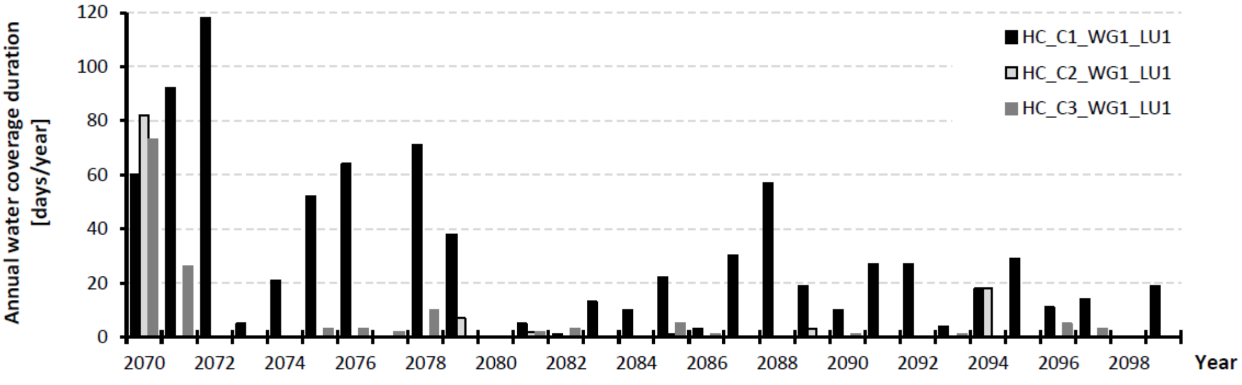

Fig. 4 Water coverage time series for the Marosszög pilot action. Effects of climate change according to the HC model

would be converted, therefore in the latter case the average productivity of the converted land would be higher.

– Once land is converted, the excess water diversion channels that used to serve the converted areas can be terminated, thereby saving some of the costs of their maintenance and operation. Also, less water needs to be pumped in case of a wet season when higher than normal precipitation coincides with relatively low temperatures and limited evaporation. The instrument, again, may make these gains more pronounced, since land gets converted in a more concentrated pattern – i.e. in a lower number of larger plots, rather than in a larger number of small plots –, making it more likely that some of the channels are not needed any more.

As far as distributional impacts are concerned, in principle everyone is better off. The voluntary nature of the policy instrument means that there are no adverse outcomes for participants - they only participate with bids that improve their position.

The state can also be better off, mainly due to avoided excess water inundation related damages, which under the current regulation are partially compensated by the government. Most of the land that is converted under the proposed scheme is subject to longer than average periods of excess water cover, therefore damage compensation following the land conversion can be substantially lower than today. On the other hand, the same locations may prove drought-resistant in dry years, which offers an economic advantage, but the current study does not address this issue.

Finally, it should be mentioned that organizing and operating the auction policy also entails costs – so called transaction costs – which should be kept low so that on balance the economic gains are not erased by the cost of implementation. Relatively low administrative requirements and large size (many farmers and lots of involved land) will help to keep transaction costs low.

A simplified cost benefit analysis

Costs and benefits were estimated and compared to determine the economic balance of the scheme. Costs are associated with channel maintenance while benefits are associated with farming activities. For the analysis it was assumed that excess water cover fully destroys the crops (generally true, but not always). Based on the team's interaction with local farmers it was concluded that the profitability of crop production falls between 170 and 600 EUR/hectare/year with a median value of 400 EUR/hectare/year. This is how much may be lost due to too much surface water.

With the help of the TIMAVGT water management association the researchers calculated the cost of maintaining and operating the channels, separately for the larger territorial networks and the local networks consisting of narrower branches. During the calculations the frequency distribution of the inundations were also considered. The maintenance costs of the territorial network channels were estimated at 30,000 EUR/year. This network, however, serves both the farms and the city of Makó, thus it makes sense to share the costs in some proportion. If all EUR 30,000 is to be covered by the farmers, then the benefits that they enjoy stay below this cost level, and it would not be rational to continue to maintain this network. However, if they are responsible to pay only 10% of the costs (in proportion to the diverted water that is of agricultural origin, while 90% originated from the city of Makó) then a net balance of EUR 24,000 results annually. Therefore, under any reasonable cost allocation between the farms and the (local) government, it is worth maintaining the territorial channels, as the benefits in most years substantially exceed the costs.

Table 3 The annual costs and benefits of maintaining the excess water drainage networks in the model area (EUR/year for the case study area, annualized)

	Benefit	Cost	Balance
Channel type	Avoided inundation loss in the agriculture	Maintenance and operating cost of the channels	
Territorial networks	27,000	30,000 / 3,000	-3,000 / 24,000
Local networks	11,000	18,000	-7,000

The local branches of the network generate net costs, i.e. a loss on average. Behind this average, however, there is notable deviation. There are plots with above average quality of soil that allow for vegetable production, a highly profitable activity. In these locations it generally makes sense to retain the local channels, but otherwise, most of the network is not worth maintaining. Therefore, decisions on maintenance should be not uniform, but case specific. Farmers are in the best position to decide if the local network segments that they use are worth maintaining at specific cost levels, or not. They will make a rational decision if they face their true share of channel maintenance and operation costs. The common compliance with the 7% EFA target also helps to determine the fate of local network segments, since the parcels without valuable crop production are revealed, and these areas do not need channels.

CONCLUSION

The proposed economic instrument, the auction for land use change obligation, offers a clear and direct economic advantage to the farmers with respect to complying with the Ecological Focus Area (EFA) requirement of the reformed Common Agricultural Policy (CAP). By cooperating with each other they can satisfy the CAP requirements at a lower cost compared to individual compliance. Once they start cooperating with each other on land use related matters, discussions of traditional agricultural practices that were abandoned during the decades of large-scale, industrialized agriculture can also take off. These discussions already started to emerge after the auction exercise, when farmers realized that the pilot scheme offers financial advantages and a more reasonable land use for the local community.

The results of the hydrologic modelling show that the concentration of the Ecological Focus Areas to the most excess water prone stretches of the landscape would not eliminate the inundation itself. The adaptation, however, decreases agricultural damage substantially, while reducing the drainage needs, therefore providing additional economic and environmental benefits. Drainage needs are also further reduced under climate change scenarios. Furthermore, increased conveyance due to improved maintenance of the channels does not reduce water coverage significantly. These results, coupled with the analysis of the auction outcome suggest that some of the local branches of the water network are not worth maintaining. The territorial network channels, on the other hand, provide benefits in excess of their cost.

The stable concentration of EFAs in the low lying areas means that EFAs end up in the sites with the highest potential ecological value. It also prevents the annual reallocation of EFAs that is allowed by the current regulation, even though this could eliminate much of the potential ecological benefits. The stable location of EFAs, including wetlands, ensures an increased level of ecosystem services in the form of pest control, pollination, nutrient reduction etc.

The farmers endorsed the auction scheme quickly and they were satisfied with the results of the experiment. But most importantly the experimental auction process produced a credible value for the conversion as a service that they can supply to each other using their least productive land segments. A discussion took place after the presentation of the results. It showed that revealing a price information through a mechanism that is understandable and acceptable to farmers initiated a constructive dialog about the local rationality of a more sophisticated land and water management. Moreover, it triggered the participants' own calculations about the possibilities they can create for themselves. This type of thinking was not experienced earlier in this context. During the discussion they raised, for example, the question of trading between other districts for realizing further gains/cost reductions.

The results also underline the importance of the EU Water Framework Directive approach that calls for the re-evaluation of the operation rationale of the water infrastructure (water services) in place and the identification of the stakeholder groups. Once water users, in this case farmers, face the true cost of the services they consume, they will be able to decide if the use of these services, and thus the maintenance of the underlying infrastructure, is indeed worth for them. These decisions will also have an impact on land use, increasing the level of ecosystem services beneficial for society.

Lastly, an important lesson from the exercise is that entrepreneurs and enterprises are absolutely open to market based solutions, even in areas where traditionally command and control regulations are applied.

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APPLICATION OF GIS FOR A CLIMATE CHANGE PREPARED DISASTER MANAGEMENT IN CSONGRÁD COUNTY, HUNGARY

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Abstract

The work of disaster management can only properly be supported by data stored in certified databases, since correct decisions can be made on the base of such data. Nowadays these data can be found in databases managed by several organisations, or only a part of the necessary data is available through GIS services. The tasks of disaster management include prevention, i.e. the preparation for potential incidents and the elaboration of related scenarios and plans taking into consideration the altering risk landscape caused by climate change. The development of modelling processes and applications based on GIS databases and the integration of the results in work processes gain ground more and more in this work phase. Geoinformatics is able to provide support for decision-making in two ways: in strategic planning and in the operative task solution. The present study demonstrates a multi-hazard multi-scale GIS tool development in Csongrád County (Hungary) in accordance with the aims of the Sendai Framework. This geoinformatic tool is applicable to support the decision-making not only of the management board but the deployed rescue units in case of an evacuation through the optimized locations of the gathering places.

Keywords: database, modelling, evacuation, information acquisition, decision support, disaster management

INTRODUCTION

Natural hazards are causing significant lives and economic losses. The amount of losses expected to increase globally thanks to the climate change as it was concluded at the findings of the 5th IPCC assessment report and also showed by the results of NatCatSERVICE and Sigma/Swiss RE global natural catastrophe loss databases of the past four decades. Direct and indirect damages are rising mainly because of socio-demographic factors such as population growth, ongoing urbanization and increasing values (IPCC, 2014; Hoeppe, 2016; Newman et al., 2017; Zuccaro and Leone, 2018). New risks were generated, because the exposure of persons and assets has increased faster than vulnerability decreased, thus indicating the need to further strengthen disaster preparedness for response (UNISDR, 2015). The number of NatCatSERVICE registered natural catastrophes were growing predominantly due to the weather-related events like storms and floods, but no relevant increase in geophysical events (e.g. earthquakes, tsunamis, and volcanic eruptions) was evident. This provides some justification to assume that climate change in particular, plays a relevant role in the ascending tendency of losses (Hoeppe, 2016).

The Sendai Framework was endorsed by the United Nations General Assembly in 2015. The framework solidifies a paradigm shift from managing disasters to managing current and future risks. It also foster resilience with an enhanced and leveraged disaster preparedness. One of the guiding principles indicate clearly that member States have the primary responsibility to prevent new and reduce existing disaster risk. Furthermore it promotes collaboration across global and regional mechanisms (e.g. climate change adaptation and sustainable development) and institutions for the implementation and coherence of instruments and tools relevant to disaster risk reduction, Sustainable Development Goals, especially goal 13 to “take urgent action to combat climate change and its impacts” including its specific target „to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries” cannot be reached without taking into consideration the impacts of natural hazards in a changing climate (UN CCS, 2017). Clear connections were already established between the three global agendas including the Paris Agreement (Fig. 1). Synergies between climate change adaptation and disaster risk reduction are also emphasized in all the main strategies and agreements at EU and regional level e.g. EU Climate Change Adaptation Strategy, the EU Cohesion policy and within the four EU macro-regional strategies including EU Strategy for the Danube Region having a priority area (PA5 - environmental risks) dedicated to both topics. Beyond the EU Civil Protection Mechanism several examples of effective transboundary collaboration exist to increase preparedness, for example, along the Upper-Rhine River the firefighting services in Strasbourg and Kehl train together and regularly exchange experiences. Here countries are operating a joint River Risk Control Training Center to train specialists from both sides of the border.

Furthermore an illustrated French-German dictionary of emergency response vocabulary has been developed. Above all the common deployment and joint cross-border management team of the 'Europa 1' firefighting vessel demonstrate the advantages of the enhanced preparedness on transboundary level (Abad et al., 2018).

For the better understanding of disaster risk, priority 1 of the Sendai Framework promotes access to and support for innovation and technology, together with the long-term, multi-hazard and solution-driven research and development in the field of disaster risk management. In addition, priority 4 urges to periodically review preparedness and contingency plans and strengthen technical and logistical capacities to ensure better response in emergencies. The framework also highlights the need towards regular exercises, including evacuation drills, training and the establishment of area-based support systems, with a view to ensure rapid and effective response to disasters and related displacement, including access to safe shelter, essential relief supplies, as appropriate to local needs (UNISDR, 2015).The support services of prevention, preparation, planning, intervention and hazard defence – i.e. the most important activities related to disaster management – can be advanced considerably by means of a GIS system. This fact has been recognised at national and local levels as well (László et al., 2014; Sik et al., 2014; Szatmári et al., 2014). Providing relevant information to the public is an important part of prevention; during preparation, measures are to be taken to protect areas exposed to critical hazards; in the case of an incidental disaster, the organisation of rescue is the most important task; and plans are to be prepared for the period of temporary operation and for the restoration of the original state.

In the phases of prevention, preparation and planning, GIS solutions that can be used in practice should be provided for the persons who take part in the management of emergency situations. Based on these solutions, the decision-makers will be able to make decisions on the rescue of human life and the protection of property, as well as on other priorities in disaster situations (Mezey, 2007; Perge, 2015).

The tasks of disaster management can be executed in practice by the use of databases of adequate quality and the applications based on them. Recognising this necessity, the Csongrád County Directorate for Disaster Management (Csongrád CDDM) started to plan GIS tools, methods and applications, and to implement their practical use.

The modelling principles developed by the Csongrád CDDM help the prevention work as well as the operative management when required. The application of the modelling processes is typical for a restricted circle of professionals, but their results can be used by the whole organisation via a web-based GIS platform. The purpose of the development of this GIS application is to manage the situations that may evolve during potential disasters and emergency situations, and to support the coordination of rescue and restoration.

The new GIS system/application can be used for the management of floods, industrial accidents and wide-ranging natural disasters that require prolonged defence.

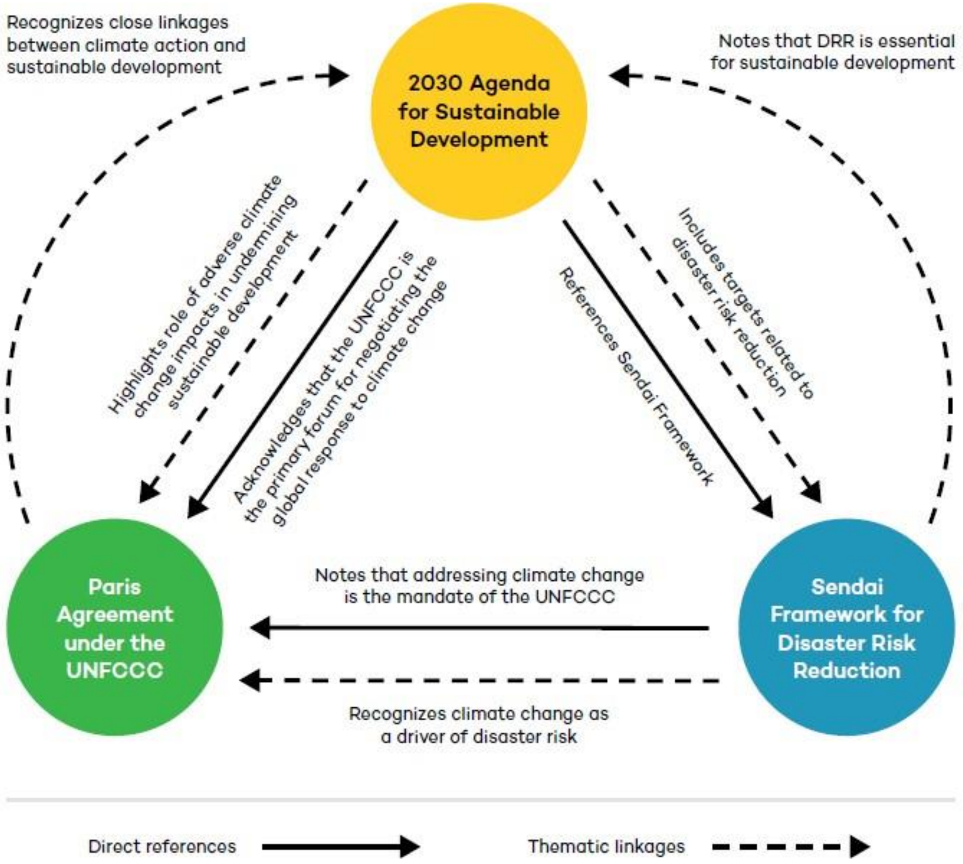


Fig. 1 Interlinkages among the global agendas (Dazé et al., 2018)

Several studies and papers have been published in connection with emergency evacuation assisting decision support systems and modelling of vulnerability (Cova and Church, 1997; Newman et al., 2017). In Northern Hungary, flash floods cause serious difficulties, and therefore the Floodlog model was developed for this environment (Ladányi and Reko, 2014).

The purpose of Csongrád CDDM was to develop and implement a GIS system in which it would be possible to make projections and to retrieve data promptly in the case of sudden incidents (first of all information about the elements – population, objects etc. – exposed to hazards).

STUDY AREA

The models and functions used in the presented GIS system were developed specifically for Csongrád County (flood areas, hydrography), in particular for the city of Szeged. Csongrád County is located in the southern border region of Hungary, and Szeged is the seat of the county. Tisza, the second largest river of Hungary, flows through the city, and has already put Szeged to great hazard several times (1879, 1967 and 2006.). According to most recent official data, the population of Szeged is around 161,000, and the administrative area of the city is 281 km^2. Due to its size, it is an ideal choice for the modelling of evacuation. It is a place with wide experience in floods, where the result of the modelling can play an important role in practice as well. Any time soon, this evacuation model can be used for other similar places that may be exposed to the hazard of floods.

DATA AND METHODOLOGY

The lack of data and information available to actors is the another challenge associated with pursuing integrated approaches to adaptation, sustainable development and disaster risk reduction (UN CCS, 2017). In the course of developing the GIS database that serves as a basis for the presented GIS system, it had to be taken into consideration that some of the data was maintained by other organisations and other data was based on own data collection.. One of the most important data sets consists of the results – derived data, for example: results of special analysis or query or select by location – of modelling and GIS operations.

Csongrád CDDM can use the databases of partner organisations either through an internet connection (public internet connection or Virtual Personal Network – through a protected network connection) or with regular updating. Most of these data consists of the data maintained by the General Directorate of Water Management, and we have been able to use these data (e.g. information about flood areas in Web Map Service).

In the case of evacuation, the most important thing is to know how many people – and in how much time – can reach the designated assembly points from a given area after they have been properly alerted. Investigations should also take into consideration the capacity and geometry of the transportation network, the current weather conditions and time of day (Cova and Church, 1997). The disaster related decision-making of individuals and societies is influenced furthermore by their attitudes during evacuation procedures. This was well illustrated in case of the Xangsane typhoon event of Vietnam where although the local population was well aware of the risks, the elderly did not want to leave their homes as it was unacceptable to die in another place (Spiekermann et al., 2015). According to the experiences, this image can be modified considerably by the fact that some of the inhabitants will always move from the endangered area on their own. The ratio of these people can be different in the various city districts, depending on the social groups that live in the given location (the basic requirement of “self-evacuation” is having a motor vehicle). According to practical experiences the ratio of “self-evacuating” people is around 70%. Evacuation compliance rates in hazardous material accidents, however, will likely be high, probably as high as 98% (Sorensen and Mileti, 1988).

During the evacuation process, special attention must be paid to older people, people with impaired mobility and other people needing attendance, which can significantly influence the evacuation time (Sorensen et al., 2002). Making accurate plans are made difficult by the fact that the storage of such data may affect personal rights, though the knowledge of them is indispensable for accurate planning, since these people must be brought along separately – so their addresses and numbers are basic input data for route planning. Now the disaster management authority is in possession of the residential addresses of people older than 70, and manages these data as a special output dataset indicated on the map as well. This result is presented in the web based GIS platform (in a browser, recommended Firefox, Chrome). The geoprocessing results are presented automatically and could be download also in excel format.

In the modelling phase, the worst case scenario should be applied, i.e. when all evacuees start to move on foot to the designated assembly point. So we have specially considered pedestrian traffic with a speed of 3 km/h (due to the movement of packages, children and family groups).

Several GIS analyses were run for planning the evacuation at the level of the city. The concept was based on the assembly points defined in legal regulations. Than three methods were used for GIS analyses (1) generation of Thiessen polygons (ESRI Thiessen), (2) allocation (use the allocation analyst of the assembly points ESRI Allocation) and (3) access time polygons (Service Area tool – ESRI Service Area) on the assumption of pedestrian traffic. In the Thiessen polygon method, the result was not that much applicable, because the border of the result polygon can’t paste to system of the settlements. The allocation analyst showed better results but the result was not polygon, only it showed, that the addresses are which assembly point belong to.

The final model was made in ArcGIS model builder for the planning of the scenarios (Fig. 2). The reason for assuming pedestrian traffic was that in a crisis situation most people leave the danger zone without observing the traffic rules, and during the evacuation, usually the people who do not possess any motor vehicle to leave their home appear at the assembly points.

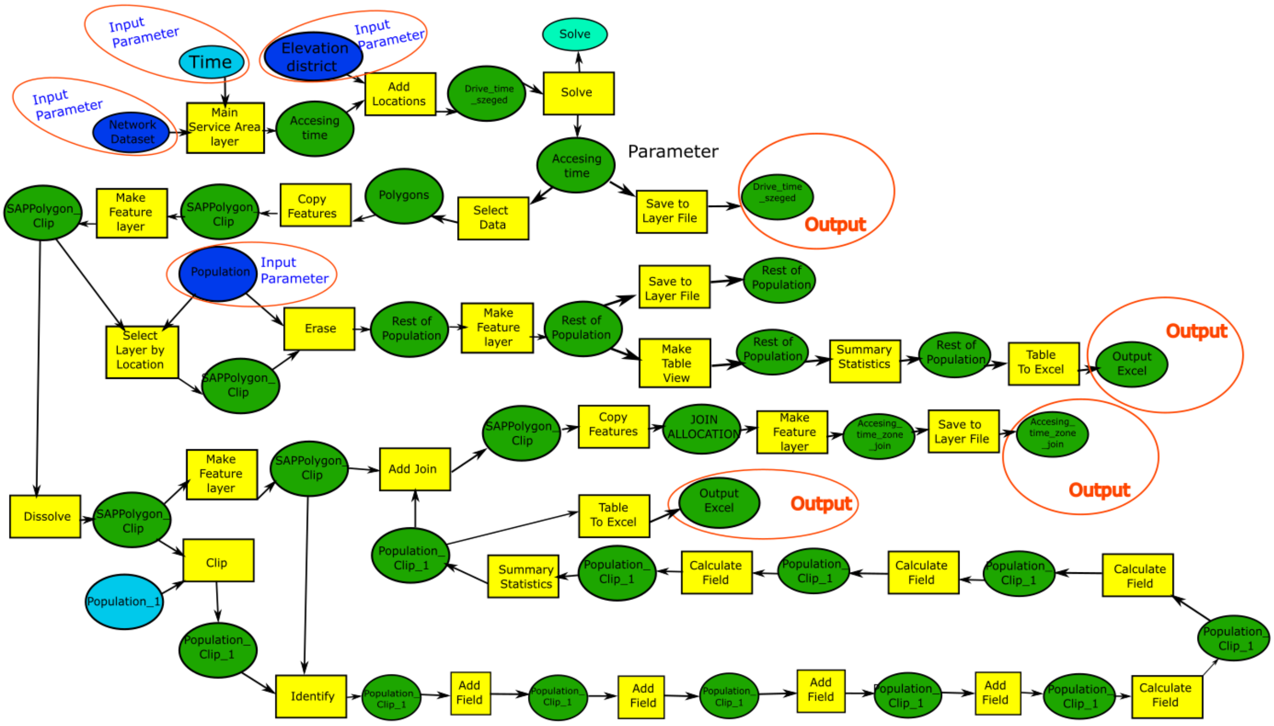


Fig. 2 Schematic diagram of the evacuation model

The best result, i.e. the tightest (there is no empty area between the coverage) coverage of the area, was achieved by mapping of the access time polygons.

The results of the evacuation model are used in the framework of stationary services in the GIS system. the format of the data publication is Web Map Service or Web Feature Service. These two types could use on client (Desktop GIS software on a PC) or in a web GIS application (in Javascript environment or older version in Flash). A special query function was developed (publicated in a geoprocess service on ArcGIS server) to give the accurate number of the people as required by the planning phase, and it makes it possible to collect the population data in an exact manner during the elaboration of the municipal emergency response plans. This facility will be integrated in the web-based system in the future (Fig. 3.).

In the case of evacuation an area based query was applied, since the affected area is maximum 0.25 – 1 km^2

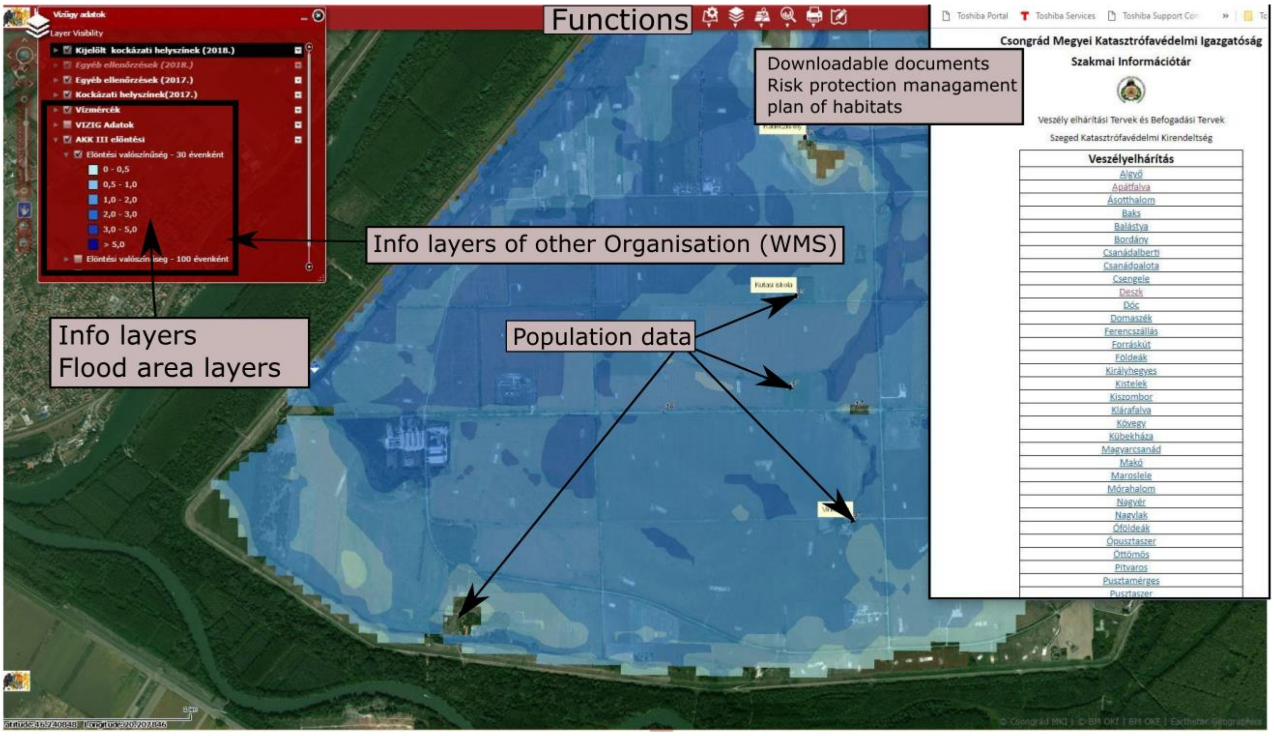


Fig. 3 The final GIS application in use: flood area with population data of residential areas (farms). All municipal emergency response plans can be download.

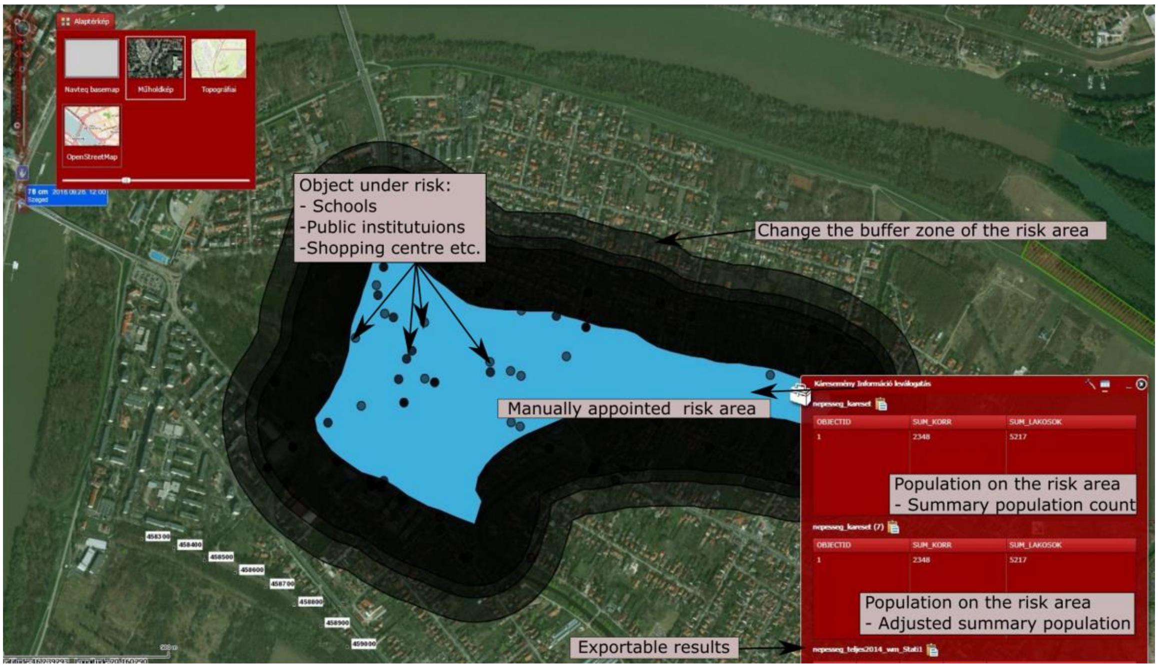
in this case (500 m distance from the source of danger), and this query is a complex operation, since the query is carried out on several separate databases at the same time. Numerous zones can be set for the query of the information about the incident locations, depending of the type of the required data. With this tool, the head of the operation is able to designate the affected area and get immediate information about the population and other objects that can be found in the given area (Fig. 4.).

RESULTS

The process of the use of the civil protection GIS system can be divided into two phases. The phase of planning is performed mainly in desktop environment, with server support. Some of the databases work in the desktop section as well, but special attention must be paid to their updating because the contact between the PC-s and the server is not constant. If somebody works without internet connect with an older version, the analysis could provide an inaccurate result, because the IT department upgraded the database meanwhile. Of course there is no problem in the web application.

A server-based GIS solution working in a protected internal network has been used for the support of operative work and other data retrieval processes. The application can be used at any location where the protected network can be accessed and does not require any special GIS knowledge from the users. The division of labour within the system is as follows: close technical cooperation with the GIS section in the planning and development phase (desktop and server administration); support of operative work from the web application exclusively for professional users.

The system has been developed on the ESRI platform, in which ArcMap 10.5 (desktop), ArcGIS for Server 10.5. The databases types are geodatabases (special ArcGIS type) and MSSQL databases (MSSQL



nepesseg_kareset

OBJECTID	SUM_KORR	SUM_LAKOSOK
1	2348	5217

nepesseg_kareset (7)

OBJECTID	SUM_KORR	SUM_LAKOSOK
1	2348	5217

nepesseg_teljes2014_wm_Stat1

Fig 4 The final GIS application in use: manually appointed risk area with queried data, for example – population, population between 8 and 16 o' clock.

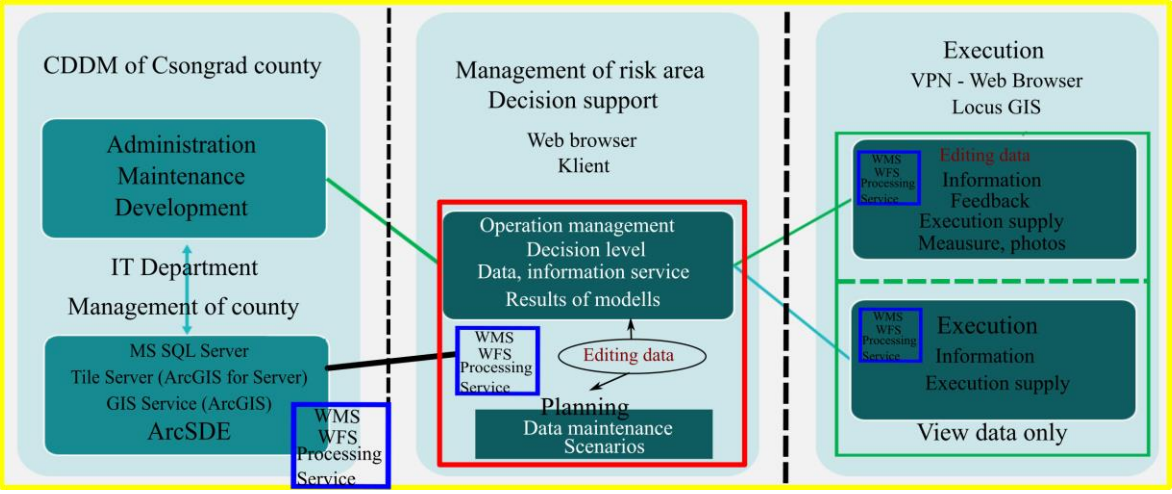


Fig 5 The structure of final GIS system with levels of operation, decision and maintenance

server). We also use the databases in combination for the services. The data is stored in separated servers. The ArcSDE facility is used for data that can be edited in web environment (Fig.5.) or in desktop environment.

At the present, official evacuation districts are assigned based on the election districts defined by law (Fig 6.). The applied model of the present study specifies new, GIS based evacuation districts. The data of the evacuation modelling, the engineering structures of flood control (defence lines, floodgates etc.) and objects exposed to hazard can be accessed simultaneously in the geoinformatics system anywhere.

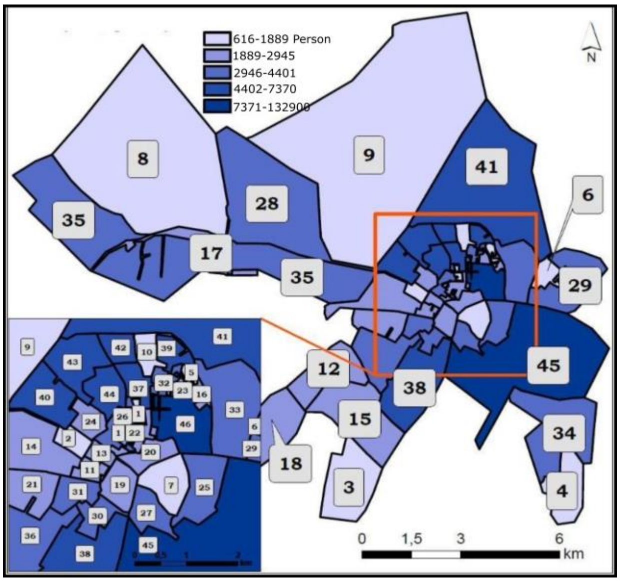


Fig. 6 The evacuation district of the city of Szeged at the present defined by law (Győri, 2015)

The available functions integrated into the systems include data retrieval and other GIS operations (query according to region or attribute, buffer zones, test of upper limit, distance measurement, coordinate query, export of GIS data etc.)

With the recently developed evacuation model, planning is not only possible with fixed input data (evacuation zones, assembly points) following the legal regulations rigidly, but a dynamic planning process can be developed as well. By changing the input parameters, it is possible to adapt to the changing circumstances, and it is not absolutely necessary to the data fixed in the municipal emergency response plans. If the situation requires the evacuation district may be changed by the spatial restructuring of the assembly points, which would be impossible in the case of a fixed plan. The model can be used to determine the areas that can be reached in intervals of 0-5, 5-15, 15-25 and 25-35 minutes. At the level of the locality, this series of intervals has ensured appropriate coverage for the existing assembly points.

The districts generated as a result of modelling are not districts adjusted to streets. In the case of Szeged, it can be seen that there is a "blind spot" even in the case of access time of 35 minutes. As for the blind spots, depending on the situation, the operative staff of disaster management may decide on the designation of new temporary assembly centres because of the 35-minute access time on foot (Fig. 7.).

In the case of evacuation zones established by modelling, the assembly points are loaded more or less uniformly. In the case of preventive planning, this spatial scheme is basically determined by the location of the objects that are essentially suitable for the role of an assembly centre. It has been one of the purposes of our modelling to analyse how the borders of the evacuation zones will change in comparison to those defined in the original legal regulations if we use the GIS approach. However, if we compare the evacuation districts established by the two methods (i.e. the election districts and the GIS analysis), considerable

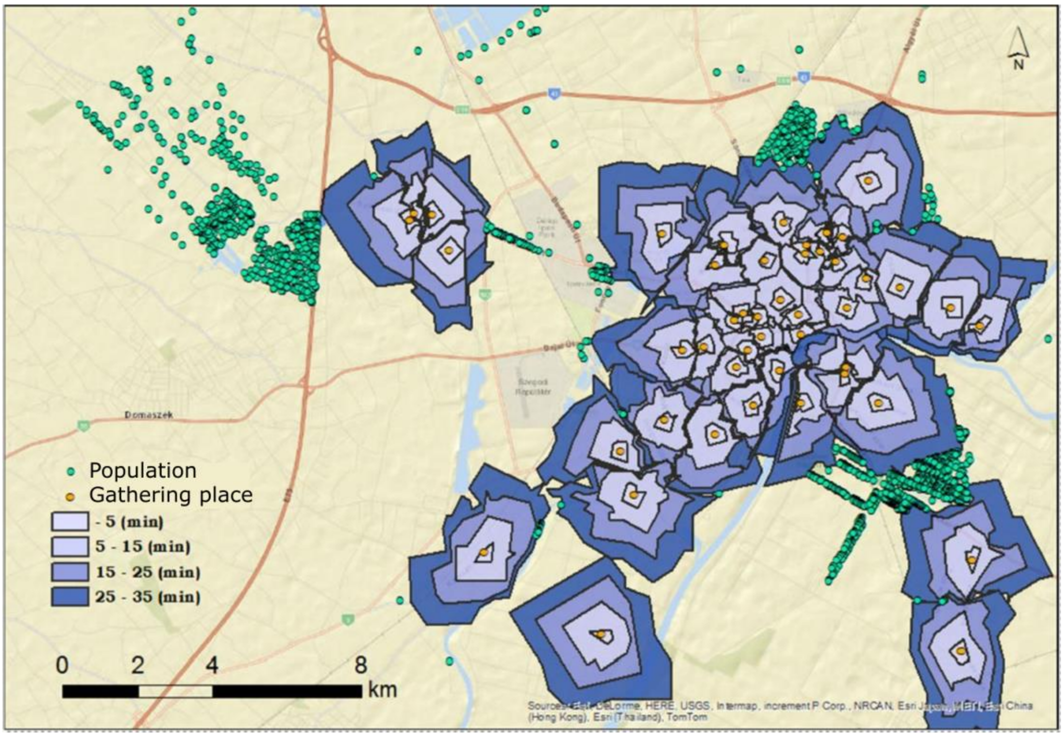


Fig. 7 Results of evacuation Model with incident locations (Győri, 2015)

differences can be found in their spatial extent and location. Due to strict legal requirements, the factors taken into account in the case of election districts are not the same as in the case of GIS analysis. Here only the population and other already existing geographical databases are needed for the modelling.

Several scenarios can been run for the final model. The variable parameter is the ratio of "self-evacuating" population. This parameter has been integrated into the model, thus the load of the individual assembly points can be calculated and the necessary further actions can be planned. The planning of the further measures related to the scenarios is continuous and depends on the actual situation. Using this system, information layers that may help the management of incidents can be displayed anywhere in a web environment (Fig. 8.).

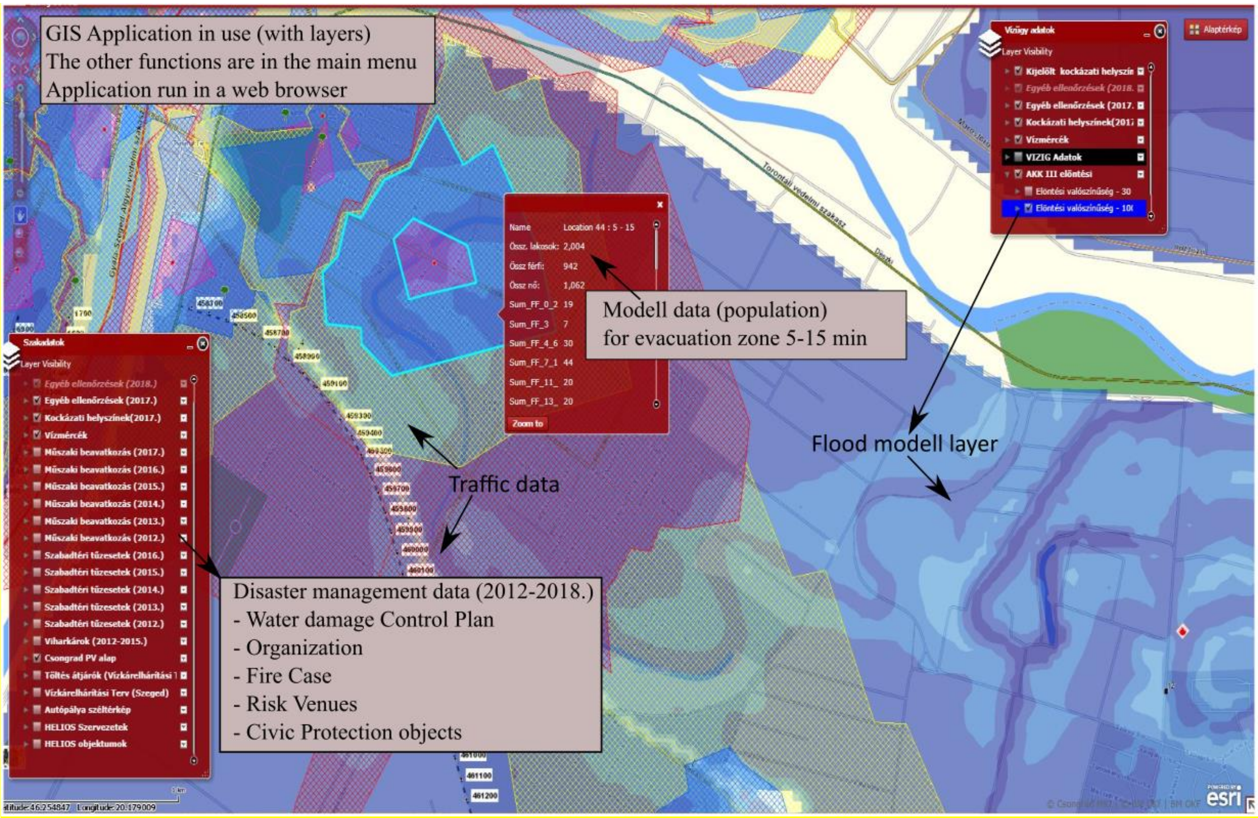
The results of queries and modelling can be exported to .kmz and .kml or .shp files, and these files can be used on-site with a suitable application on smart phones. The Csongrád CDDM favours the LOCUS GIS (www.locusmap.eu) application that has been able to operate offline on several field practices, since it is suitable for displaying the data, managing the GPS and field data recording according to pre-defined templates (in .shp format). If required, the rescue unit which is exposed to a hazard can be followed on a public website by using the Live tracking mode. The data can also be used without internet connection; furthermore, the application is suitable for recording data (e.g. the locations of drain water), which at a later moment, after recovery of the internet connection can be send to the server.

CONCLUSION

In the field of disaster management, geoinformatics started to gain ground as a decision-supporting tool/system in the last 8-10 years. However, its areas of use are restricted to operative activity (support of immediate interventions). The presented approach intends to support the field of preparation and prevention as well in line with the requirements of the Sendai Framework. The modelling work was performed for a city of the size of a typical county seat in Hungary. Henceforth the Csongrád CDDM intends to use this model for every locality exposed to flood risk in the county and to store the available data in a database. The main problem was that the evacuation plans of residential areas were defined without GIS planning. A new GIS based approach was developed for the evacuation plans. The base of the GIS application is the result of the model and the geoprocessing of the model. With this GIS application the professionals can make established decisions between the variable circumstances. At the present the analysis was tested in Szeged, but in the close future it will be applied to other settlements in Csongrád county.

The former practices and application experiences indicate clearly that this direction should be followed and may be used simultaneously with the evacuation districts defined by law. Further planned steps include the adjustment of the modelling results to the geometry of the street network, but this requires further modelling work.

Geoinformatics as a strong tool of decision-preparation and decision-support serves the preparation



GIS Application in use (with layers)
The other functions are in the main menu
Application run in a web browser

Name Location 44 : 5 - 15
Össz. lakosok: 2,004
Össz férfi: 942
Össz nő: 1,062
Sum_FF_0_2 19
Sum_FF_3 7
Sum_FF_4_6 30
Sum_FF_7_1 44
Sum_FF_11_ 20
Sum_FF_13_ 20

Modell data (population)
for evacuation zone 5-15 min

Traffic data

Flood modell layer

Disaster management data (2012-2018.)
- Water damage Control Plan
- Organization
- Fire Case
- Risk Venues
- Civic Protection objects

Fig. 8 The geographical extent of the evacuation districts in the GIS application in web browser. It can see the other relevant information layers which visible in the platform for solving problems arising within the field of duties of civil protection. In the near future, the Csongrád CDDM is intent to continuously foster the usage of geoinformatic solutions.

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Act XXXVI of 2013 on the election procedure

Decree No 61/2012 (11 Dec) of the Ministry of the Interior on the disaster management classification of localities and the modification of Decree No 62/2011 (29 Dec) BM of the Ministry of the Interior on certain rules of the defence against disasters

Government Decree No 234/2011 (10 Nov) on the execution of Act CXXVIII of 2011 on disaster management and on the modification of certain related laws (Chapters V, VI and VII)

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MODELLING OF EXTREME HYDROLOGICAL EVENTS ON A TISZA RIVER BASIN PILOT AREA, HUNGARY

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Abstract

Climate change takes more and more challenges to the water management. Future predictions show that the possibility of extreme floods and drought events are increasing, thus an additional task of the water management can be the fulfilment of the increasing water demands. These new extreme hydrological situations need to be properly handled in water management. The paper presents the first modelling results of the JOINTISZA project carried out on a selected sub-basin of the Tisza River, which is endangered by hydrological extremes. Our aim was to demonstrate the applicability of a one-dimensional hydrodynamic model to study the effects of the climate change. Future hydrological trends were introduced in the river basin and it was assessed how the results of climate models can be used for further hydrodynamic modelling. To address challenges of climate change and supply the stakeholders with an adequate amount of water, proper operation of the reservoir and the irrigation canals are needed. The use of hydrological modelling can be helpful to adequately distribute water resources.

Keywords: water quantity, drought, flood, hydrodynamic modelling, water demand, climate scenarios

INTRODUCTION

The Tisza River Basin (TRB) can be considered unique in several aspects among the river basins of Europe. In certain hydrometeorological situations, the chance of extraordinary floods is high. This was especially true at the beginning of the 2000s, when the flood waves set new record high water levels along the Hungarian section of the Tisza River (Szlávik, 2005). Over the last decades, drought has also taken more and more challenges to the experts of the local Water Directorates. The occasional extreme low water flow of the river is a problem especially in the flat areas of the Tisza River Basin. The climate change plays a major role in the emergence of these hydrometeorological situations (Lehner et al., 2006).

Regarding spatial and temporal distribution of drought in Europe, the major European droughts also impacted Hungary. Hungary has a high risk of developing a drought period, especially typical in the Great Hungarian Plain region (Tamás, 2016). The drought phenomenon can significantly increase because of the antropogenic activity and ineffective water management. It is expected that the extremely long, dry weather conditions will occur more regularly for years in Hungary (Szalai, 2009). The prevalence of the droughts has increased over the past decades, and especially the rolling drought phenomena have become critical when consecutive years of drought multiply the adverse effects of previous years (Pálfai, 1992). Regarding to the final report of the Danube River Basin Climate Adaptation Study from Mauser et al. (2018) the possibility of more intense and more harmful droughts are expected in the Middle Tisza region.The water demand is also expected to increase in the Great Hungarian Plain which causes new challenges in water management (Somlyódy, 2011). The local Water Directorate is responsible to provide adequate amount of water (NWS, 2017) to satisfy the water needs. This requires river basin planning, and proper water management.

In the JOINTISZA project a pilot area was selected in the Middle Tisza which is endangered by both extreme situations, such as floods and droughts. Our main goal was to investigate the impacts of climate change induced drought and flood issues on a smaller region within the TRB. This paper introduces the first modelling results which are the possible impacts of a long-lasting period with water scarcity in this pilot area.

We applied the forecasts of climate models produced by the Joint Research Centre. The data sets they generated – according to the predicted hydrological, meteorological, economic, and social conditions – were used in modelling as a boundary condition (Bisselink et al., 2018). With the help of these time-series, we aimed to explore possible medium and long-term conflict situations in water resources and to make recommendations for possible measures, thereby helping the water management planning of river basins with similar problems.

PILOT AREA

Characteristics of the pilot area

The selected pilot area is located in the flat region of the TRB in the middle of the Hungarian Great Plain (Fig. 1). The pilot area gets water from the Lake Tisza, which water intake is controlled by the local Water Directorate. This pilot area is selected because only a proper water management work could satisfy the water demands.

The size of the pilot area is 2884.6 km^2. It is bordered by the Tisza River from the west, and by the Lake Tisza from the north. The eastern border is the Hortobágy-Berettyó River and the Tiszafüredi main irrigation canal, and the southern border of the area is the Hármas-Körös River. The area is characterized by a very low elevation (79-100 mBf).

In the Tisza sub-basin the lofty sedimentary rocks dominates in the top 10 m caprock formations. Most of the soils are typically well-productive, so a significant part of the pilot area is suitable for agricultural activity. The typical genetic soil type in the region is the Chernozem. Large areas are covered with meadow and alluvial soils, which are common in the floodplains. The proportion of alkaline soils is exceptionally high in the Hortobágy-Berettyó region.

The size of the agricultural land is the largest in Hungary in the Tisza sub-basin, but from agro-ecological point of view this land use is considered to be the most unfavourable structure. Large area is arable land and they have low proportion of intensive cultures (vegetables, fruits). A significant part of the agricultural area consists of arable land (73 %), while the share of the garden, fruit and grapes represent less than 0.5%. The peculiarities of this river basin are the relative importance of fish ponds. The proportion of forest areas does not reach 5%.

Hungary's water network is basically determined by the fact that the country is located in the middle of the Carpathian Basin. In the country, about three-quarter of the water resources is transported by the Danube and the Drava Rivers, while almost only a quarter of the available water resources is transported by the Tisza River.

The Tisza is the second most significant river in Hungary. The Tisza's full gradient is 30 m (5 cm/km) in Hungary. The minimum measured water flow was 56 m^3/s, and the maximum measured value was 2950 m^3/s at Kisköre. The average flow value is 507 m^3/s at this Tisza river section.

The Lake Tisza is the biggest artificial surface water in Hungary. The lake was artificially created when the Kisköre Barrage was constructed. The lake is operated as a reservoir, so it has two different operating water levels for summer and winter seasons. The summer water level usually lasts from the middle of March to the end of October, and it is 88.57±0.05 m. The surface of the Lake Tisza is 127 km^2, with a volume of 253 million cubic meters; more than 130 million m^3 can be utilized. Lake Tisza can be considered as a multi-purpose water management facility; its main utilizations are: water supply, hydropower (at the Kisköre Barrage), fishing and nature.

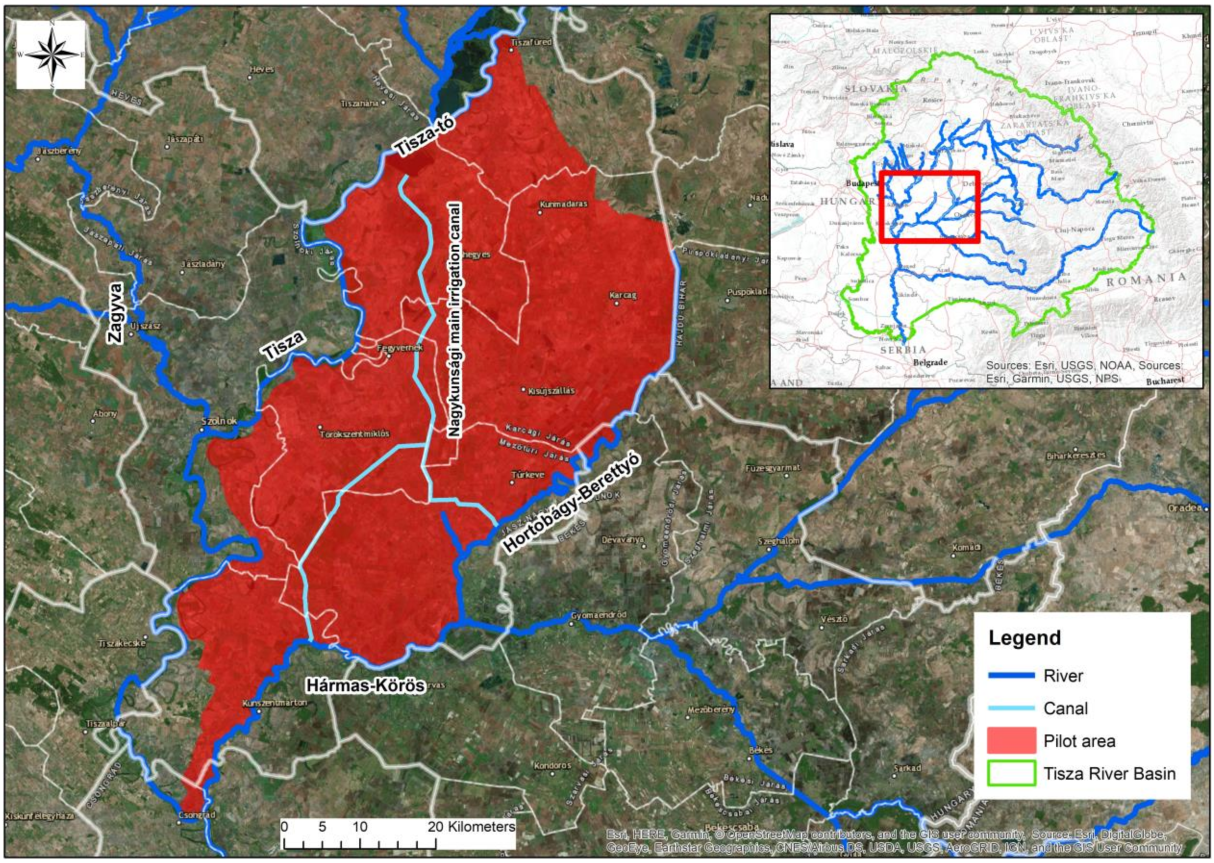


Fig. 1 Location of the selected pilot area located in the Tisza River Basin, Hungary

The area has a dry continental climate, and it has the driest climate in Hungary. The annual average temperature is between 10-11°C, and the monthly average temperature in July is around 21°C. The mean annual temperature fluctuation is 23.0-24.5°C. The annual amount of sunshine hours in the Hungarian Great Plain is over 2000 hours. Based on the measured data of the Middle Tisza District Water Directorate, the annual precipitation is about 520 mm in this area, which is the lowest annual average precipitation in the country. The territorial and temporal distribution of the precipitation is also extreme. The annual rainfall also varies within wide limits. Some years (e.g. the year of 2010 when the annual precipitation was 820 mm) had a lot of precipitation and it caused floods and inland excess waters. In the last some decades that even in the same year after a wet period a dry and warm period occurred with heavy drought.

Climate change can play a major role in the emergence of extreme conditions. Future predictions suggest that even more extreme drought periods may also occur more and more often (Mauser et al., 2018). Because of these extreme situations a well performed and appropriate water resource management planning and regulations are important. The pilot study intended to contribute to a better planning process that takes into account the climate change induced impacts on surface water quantity.

The pilot area has some particular characters that were taken into account when it was selected. The required amount of water by the stakeholders in the pilot area can be ensured only by the proper water management of the District Water Directorate (NWS, 2017). The water demand is satisfied by a dense canal network of the area from the Tisza River. In a dry period, the Lake Tisza can provide sufficient water for the region, but the water flow is exclusively managed by District Water Directorate into the pilot area. The special features described above have determined which model type could fit most to assist the water quantity management.

Nagykunsági irrigation system

The most significant irrigation system of the pilot area is the Nagykunsági irrigation system. Based on the water usage data of the Middle Tisza District Water Directorate, the annual volume of water supply of the area is around 15-20 million m^3 on average, but can reach 25 million m^3 in a drier period. The main irrigation canal in the irrigation system is the Nagykunság main canal. This canal gets water from the Lake Tisza through a water intake structure controlled by the local Water Directorate and passes the water to the Hármas-Körös and the Hortobágy-Berettyó Rivers. The water inflow is around 20-35 m^3/s in irrigation season (from April to September). The canal is split into two branches near Örményes. The overall length of the main canal is 74.5 km (including the western branch). The eastern branch of the canal is 18.07 km long. The Nagykunsági main irrigation canal flow out from the 403.000 fluvial km section of the Tisza and reaches the Hármas-Körös River at the 35.600 fluvial km section. The Eastern branch of the Nagykunsági main irrigation canal flow out from the Nagykunsági main canal, reaches the Hortobágy-Berettyó River at the 16.630 fluvial km section.

The water from the Nagykunsági main irrigation canal is distributed to various irrigation sections to reach the user (Fig. 2). The most important irrigation sections of the Nagykunsági irrigation system are the following: NK III, NK IV, NK V-1, NK V-2, NK VII-1, NK X, NK XII. Figure 2 shows the main parts of these irrigation sections; the water can be drained to the other part of the pilot area. The irrigation canals have several hydraulic structures to properly drain the water through the Nagykunsági irrigation system. The Nagykunsági main irrigation canal has 7 inline structure (Fig. 2). The main aim of these structures to ensure water retention, and to provide proper water distribution.

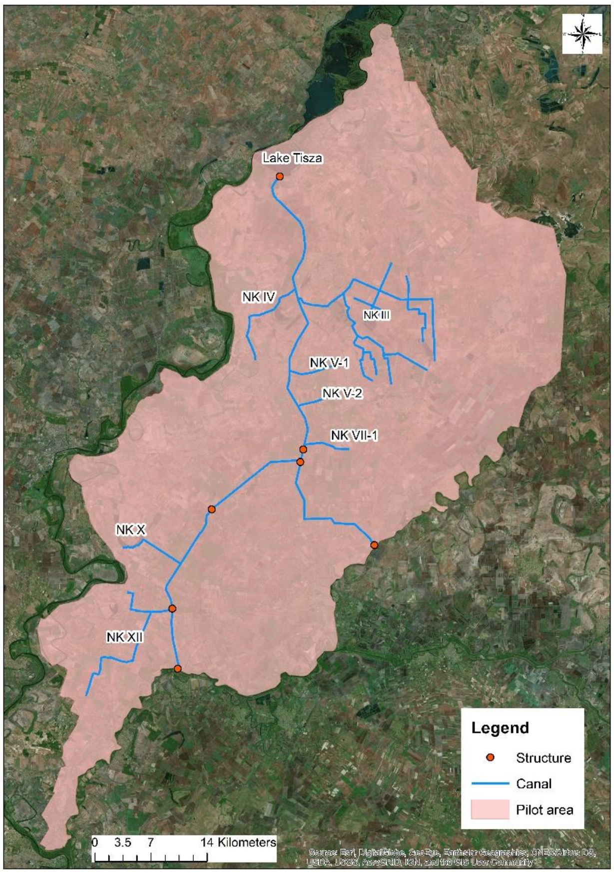


Fig. 2 Irrigation sections of the Nagykunsági irrigation system

METHODS

One dimensional hydrodynamic model

HEC-RAS is capable of performing one-dimensional water surface profile calculations for steady varied flow in natural or constructed channels. It is the basic equation and numerical model of free-surface, one-dimensional, continuously variable non-permanent water movement. The most important conditions are: one dimensionality, graduality, free-surface, and non-permanent character. Of these, the first two are the hardest to follow; these are the most important constraints. In our case, when we model a non-permanent hydraulic phenomenon in a complex cross-section of a meandering watercourse network, the validity of these conditions has a decisive influence on usability (US Army Corps of Engineers, 2016).

In its current structure, the database of the model includes the 600 km long river section between Tiszabecs and Szeged from the Tisza. The model also contains the canals of the pilot area. The total length of streams involved into calculations exceeds 2 000 km. We installed 102 bridges and 19 inline structures into the model. The model contains the Nagykunsági irrigation canal, which is the most important irrigation canal of the pilot area.

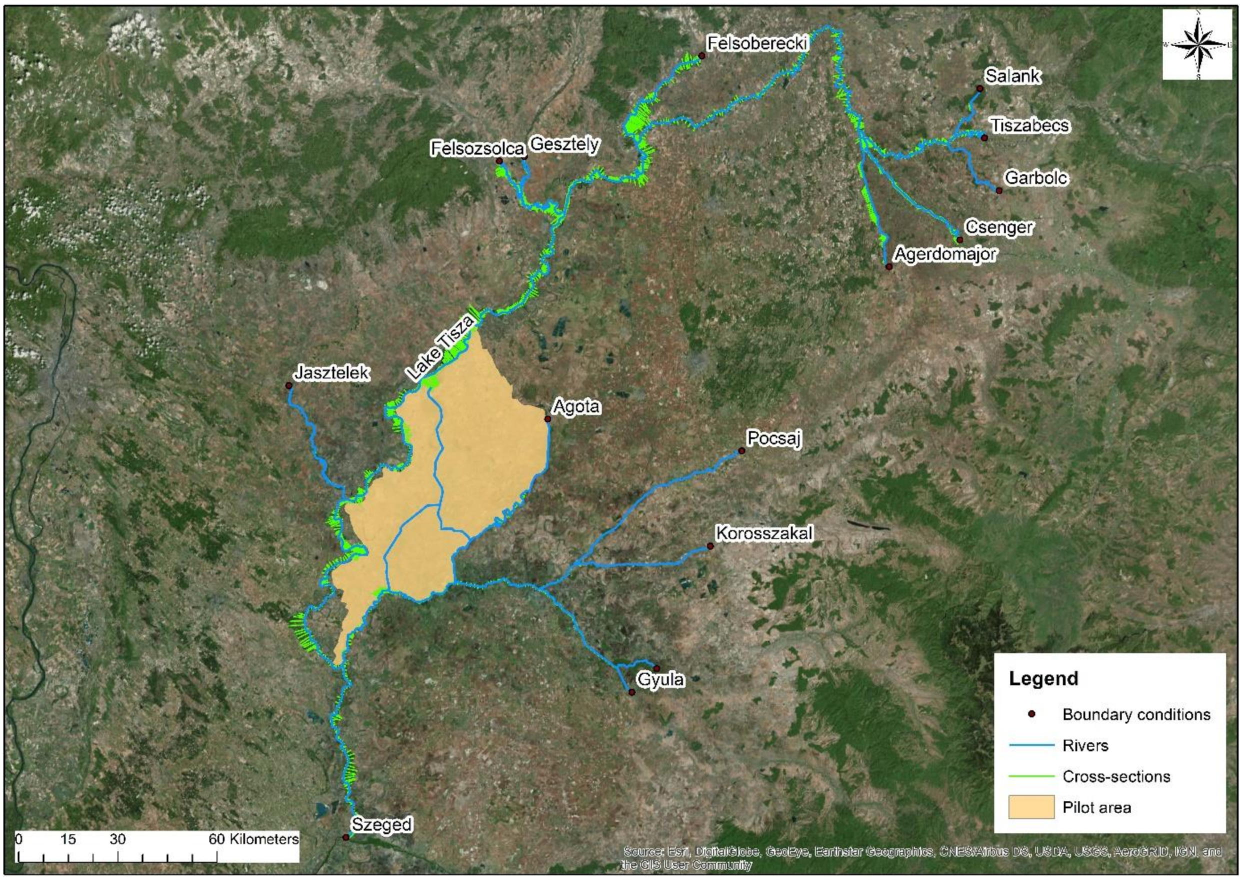
The complete hydrodynamic model includes the following river sections (Fig. 3):

- Tisza, from Tiszabecs to Szeged (600 km),
- Szamos, from Csenger to outfall (50 km),
- Kraszna, from Ágerdőmajor to outfall (45 km),
- Bodrog, from Felsőberecki to outfall (50 km),
- Hernád, from Gesztely to outfall (23 km),
- Sajó, from Felsőzsolca to outfall (50 km),
- Zagyva, from Jásztelek to outfall (55 km),
- Berettyó, from Pocsaj to outfall (68 km),
- Sebes-Körös, from Körösszakál to Köröstladány (54 km),
- Fehér-Körös, from Gyula to outfall (9 km),
- Fekete-Körös, from Ant to Remete (16 km),
- Hármas-Körös, from Gyoma to outfall (90 km),
- Hortobágy-Berettyó, from Ágota to outfall (80 km),
- Nagykunsági irrigation canal (with the eastern and western branches), from Abádszalók to Mezőtúr/Öcsöd (110 km).

We have advanced the stream system of the model by more than 2 000 cross sections. The cross sections are the basis of the one-dimensional models. The calibration and the roughness coefficient are only party compensate the possible inaccuracies of the cross-sections. The model stability is greatly improving if the cross sections are as dense as possible. Based on previous modelling experiences, the optimal distance between cross sections - from model point of view - is 400 - 800 m for the Tisza, and 200 - 400 m for the tributaries of the Tisza. For the irrigation canals, the optimal distance is 200 - 400 m.

The hydrodynamic model has 14 upstream, and 1 downstream boundary condition. The boundary conditions of the rivers are located on the Hungarian border sections. We have chosen these points to minimize the impact of the boundary conditions on modelling results in the pilot area. At each point there are flow data available for input data.

The applied HEC-RAS model gives detailed description of the entire river system and provides an opportunity for taking into consideration the hydraulic engineering structures, as well as bridges, barrages, culverts, overflow weirs, floodgates, bottom stages, bottom sills, side overflows and gates, static reservoirs, pump head stations and water intakes (US Army Corps of Engineers, 2016). The model includes 102 bridges, and 16 inland structures, and it also contains water intakes. We took into the model every irrigation section of the Nagykunsági irrigation system as a point like water intakes. The model also contains every directly water use along the Nagykunsági main irrigation canal, so water consumption can be tested as a simple drainage. We used



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Fig. 3 The layout and the boundary conditions of the model the possible water demand values for input data which are based on the survey of the Hungarian Chamber of Agriculture (NWS, 2017).

For calculation of the water discharge capacity of the main river bed of Tisza as well as for taking the flood plain vegetation into consideration we used the roughness (smoothness) factors given in the Table 1 in the course of calibration of the model. We determined the vegetation on the flood plain by aerial photographs, i.e. by ortho-photographs, as well as by the results of on-site inspections. The roughness factor was changed crosswise according to flood plain vegetation. The roughness (smoothness) factor assigned to these was determined on the base of the prescriptions of the Hungarian standard, as well as on the base of values applied also by HEC-RAS and proposed by Chow (1959).

Table 1 Roughness / smoothness coefficients

No.	Type	n (s/m$^{1/3}$)		k (m$^{1/3}$/s)	
		Min	Max	Min	Max
0	River/canal channel	0.060	0.017	16.67	58.8
1	Pasture	0.050	0.025	20.00	40.0
2	Plough-land	0.050	0.020	20.00	50.0
3	Sparse shrub	0.080	0.035	12.5	28.6
4	Dense shrub	0.160	0.040	6.25	25.0
5	Forest without undergrowth	0.120	0.030	8.33	33.3
6	Forest with undergrowth	0.200	0.080	5.00	12.5

The calibration of the model was accomplished gradually, starting with the shorter sections. We assembled together the individual section and then performed the river sections.

The calibration of Tisza and its tributaries was made for the low-water period of the year 2012. On the river section between Tiszabecs and Szeged, the difference between the calculated water level and the observed was between 0 and 10 cm in absolute values, which can be considered as a very good result. The pilot area's canal network calibrated separately. We used data from the year of 2013 to calibrate the irrigation canals. The difference between the calculated water level, and that of observed was between 0 and 10 cm, like the river network. After the calibration was made, the separate water streams were connected.

Climate scenarios of the Joint Research Centre

The Joint Research Centre (JRC) studied the effects of changing climate, land use, and water demand on water resources in the Danube River Basin using climate induced runoff modelling technique (Bisselink et al., 2018). The water resources calculations were done with the LISFLOOD 2.0 model which is a GIS-based spatially-distributed hydrological rainfall-runoff-routing model (De Roo et al., 2000, Van der Knijff et al., 2010; Burek et al., 2013). As a result of the runoff modelling, water flow data were made available for our work for the rivers of the Tisza River Basin.

In the JRC analysis, 11 different European EURO-CORDEX climate scenarios have been used (Table 2). The Coordinated Downscaling Experiment over Europe (EURO-CORDEX, Jacob et al. 2014) is an international climate downscaling initiative that aims to provide high-resolution climate projections up to 2100 (Bisselink et al., 2018).

Flow time-series were made available for our work for every boundary condition calculated from the JRC runoff model. Time-series were from 2011 to 2099 for each 11 climate projections. In addition to the boundary

Table 2 EURO-CORDEX climate projections (Bisselink et al., 2018)

No.	Climate scenario	Institute	Global climate model	Reg. climate model	Exceeding 2°C warming
1	CLMcom-CCLM4-8-17_BC_CNRM-CERFACS-CNRM-CM5_rcp85	CLMcom	CNRM-CM5	CCLM4-8-17	2044
2	CLMcom-CCLM4-8-17_BC_ICHEC-EC-EARTH_rcp85	CLMcom	EC-EARTH	CCLM4-8-17	2041
3	CLMcom-CCLM4-8-17_BC_MPI-M-MPI-ESM-LR_rcp85	CLMcom	MPI-ESM-LR	CCLM4-8-17	2044
4	DMI-HIRHAM5-ICHEC-EC-EARTH_BC_rcp85	DMI	EC-EARTH	HIRHAM5	2043
5	IPSL-INERIS-WRF331F_BC_rcp85	IPSL	IPSL-CM5A-MR	INERIS-WRF331F	2035
6	KNMI-RACMO22E-ICHEC-EC-EARTH_BC_rcp85	KNMI	EC-EARTH	RACMO22E	2042
7	SMHI-RCA4_BC_CNRM-CERFACS-CNRM-CM5_rcp85	SMHI	CNRM-CM5	RCA4	2035
8	SMHI-RCA4_BC_ICHEC-EC-EARTH_rcp85	SMHI	EC-EARTH	RCA4	2041
9	SMHI-RCA4_BC_IPSL-IPSL-CM5A-MR_rcp85	SMHI	IPSL-CM5A-MR	RCA4	2044
10	SMHI-RCA4_BC_MOHC-HadGEM2-ES_rcp85	SMHI	HadGEM2-ES	RCA4	2030
11	SMHI-RCA4_BC_MPI-M-MPI-ESM-LR_rcp85	SMHI	MPI-ESM-LR	RCA4	2044

conditions, discharge data were also available for an internal river section of the Tisza, which was the inflow section of the river into Lake Tisza. This point was an important control point in the Middle Tisza from water management point of view. Using the data of this control section it was possible to examine how much water flows into the Lake Tisza from the Tisza River. If the flow of this river section decreases below 105 m^3/s water shortage can be considered, and when discharge falls below 60 m^3/s, water restrictions may be needed (MTDWD, 2013).

RESULTS

Hydrological changes of the Middle Tisza

Analysis has been made for the 11 flow time-series which refers to the inflow section of Lake Tisza, which can be used to quantify future trends in the Middle Tisza hydrology.

In the months of September and October will have the highest probability when the flow will decrease below 60 m^3/s at the river section near Tiszafüred. The return time for extreme low-water periods is 3-4 years in all 11 climate projections. Based on the data released by the JRC, the occurrence of more and more long-lasting low-water periods are also predicted for the second half of the century. The most extreme "SMHI-RCA4_BC_ICHEC-EC-EARTH_rcp85" run occurred a 128-day period below 60 m^3/s. with a 24.5 m^3/s minimum discharge.

In addition to the extreme low-water conditions, some climate scenarios have also generated extraordinary flood waves. In the case of two projections (CLMcom-CCLM4-8-17_BC_CNRM-CERFACS-CNRM-CM5_ rcp85, IPSL-INERIS-WRF331F_BC_rcp85), the maximum flow is above 4500 m^3/s, which would pose a serious flood risk to the Middle Tisza in the future, with special regard to the Kisköre barrage.

It is based on the analysis to define which climate scenario should be used as the boundary condition of the hydrodynamic model. According to the analysis, the "SMHI-RCA4_BC_ICHEC-EC-EARTH_rcp85" is selected to study low-water periods.

Water demand changes of the study area

It was necessary to determine the future water demand of the pilot area for the study of water resources. The Hungarian Chamber of Agriculture conducted a nationwide water demand survey (GWDM, 2018).

Based on the survey it can be stated that the water demand is well above the amount of water currently used in Hungary. The annual water demand of the pilot area exceeds 55 million m^3, which is expected to increase in the future. 80 % of this value refers to the Nagykunsági irrigation system. It can be stated, that the Nagykunsági irrigation system satisfies the large part of the water needs. Part of the water demand can be assured directly from the Nagykunsági main irrigation canal, and the other parts of water needs are distributed through the irrigation sections (Fig. 4). These water demands have become the part of the hydraulic model as water abstractions.

According to the survey, there are 6474 locations for water uses. 3914 are new request for using water from this number. These new demands account 23 million m^3 quantity of water in a year, almost half of the total annual water needs in the pilot area.

Results of the hydraulic modelling

The modelling scenario is a long-lasting low-water period, whereby the water flow to the area is lower than the sum of water flowing to the tail-water at Kisköre barrage and of into the irrigation canals from the Lake Tisza.

The boundary conditions are selected based on the statistical analysis of the water flow datasets produced by the JRC. In this scenario, there are several periods with water scarcity. The year of 2085 of the time series includes an extreme low-water period, which data sets of the year have been used as the boundary conditions of the model at every upstream river sections. At the river section of the Tisza near Tiszafüred, for more than 3 months, the flow of the river is below 105 m^3, which is a period with water scarcity.The boundary condition of the model for the Tisza is shown in Figure 5.

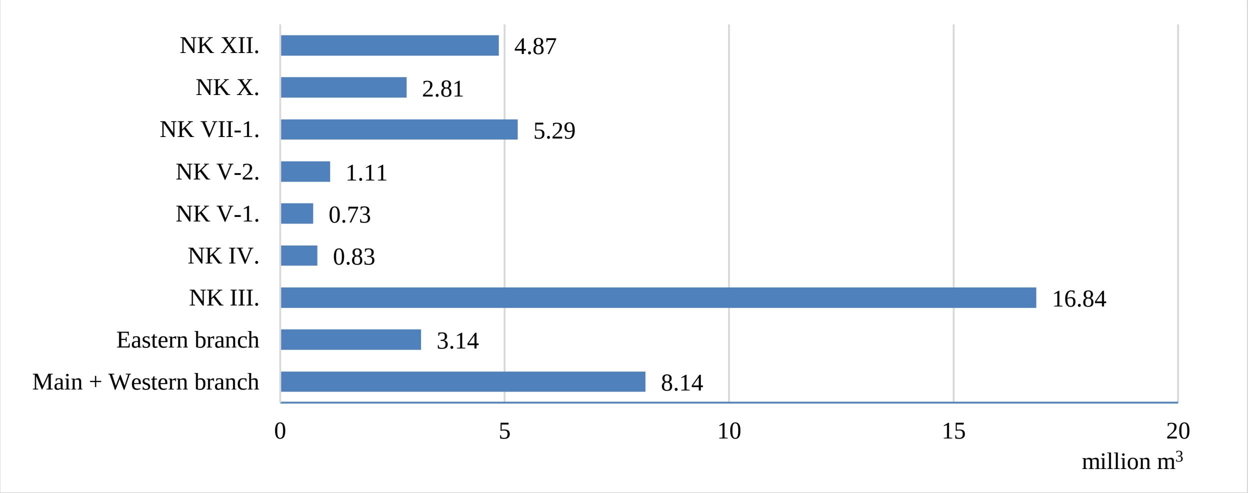


Fig.4 The distribution of future water demand in the Nagykunsági irrigation system

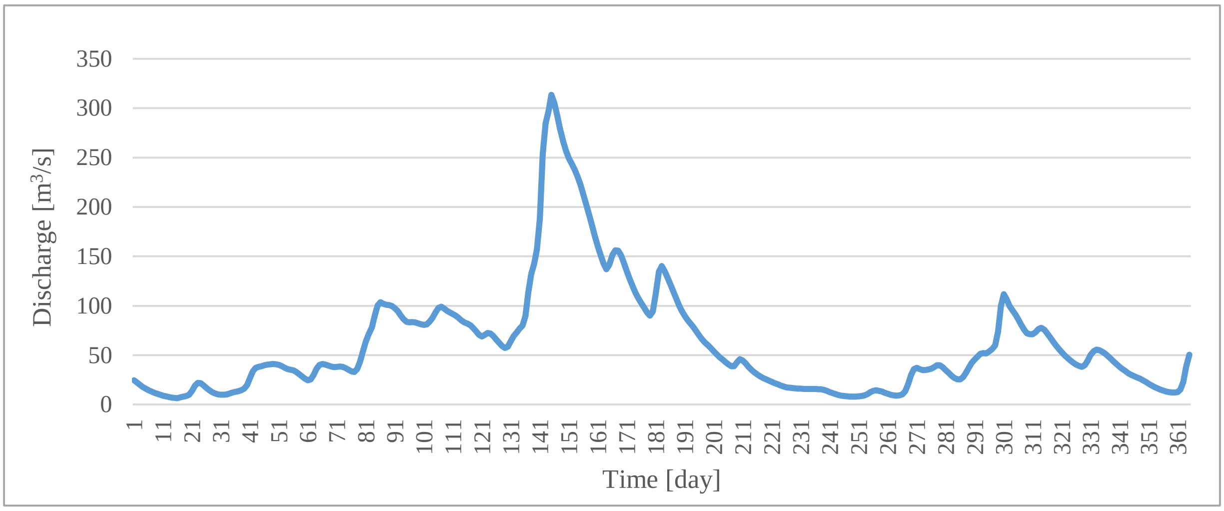


Fig. 5 Boundary condition of the hydrodynamic model for the Tisza River in the modelling scenario

In the modelling scenario - when the river's flow falls below 100 m^3/s - the water level of the Lake Tisza gradually began to decrease. The trend continues for two months when the discharge at the upper section of the river increase above 100 m^3/s. During the critical period, the amount of water which is drained from the Lake Tisza to the Nagykunsági main irrigation canal is continuously ensured and corresponding to the water demands (Fig. 6). We studied how quickly the stored water of Lake Tisza would be consumed.

Figure 7 shows the development of water flow and water level at Kisköre barrage in the modelled year. In the first half of the year there is enough water flow to the river to maintain the operating water level (88.67 ± 0.05 m) of the reservoir. Then in the summer months, the river flow gradually decreases until it reaches the critical 60 m^3/s value. This low water condition lasts for one and a half months when the water level of the reservoir is reduced by 2.96 m. This level of water is reducing in order to meet the water demands in the pilot area without any problems and to ensure the minimum 60 m^3/s to the Kisköre barrage tail-water. This minimum flow of water is needed in addition to the ecological goals, it is also necessary for the water supply of Szolnok.

In addition to provide sufficient quantity of water at the river section downstream of Kisköre, enough water is also drained into the irrigation canals. In the Middle Tisza there is a Water Restraint Plan which determines the cases when the amount of water taking from the Lake Tisza to the irrigation canals should be limited. According to the regulations 14.4 m^3/s flowrate must be secured from the eastern branch of Nagykunsági main irrigation canal to the Hortobágy-Berettyó, as well as 1,6 m^3/s from the western branch of Nagykunsági main irrigation canal to the Hármas-Körös (MTDWD, 2013). The main goal with these minimum flows is

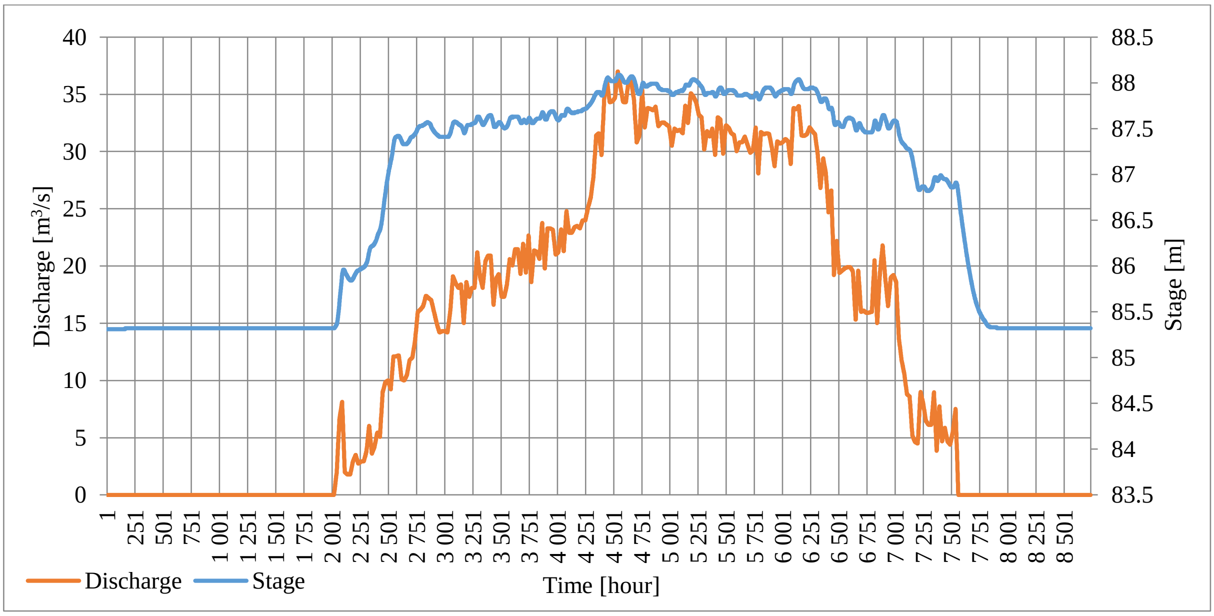


Fig. 6 Discharge and stage at the inlet point of the Nagykunsági main irrigation canal

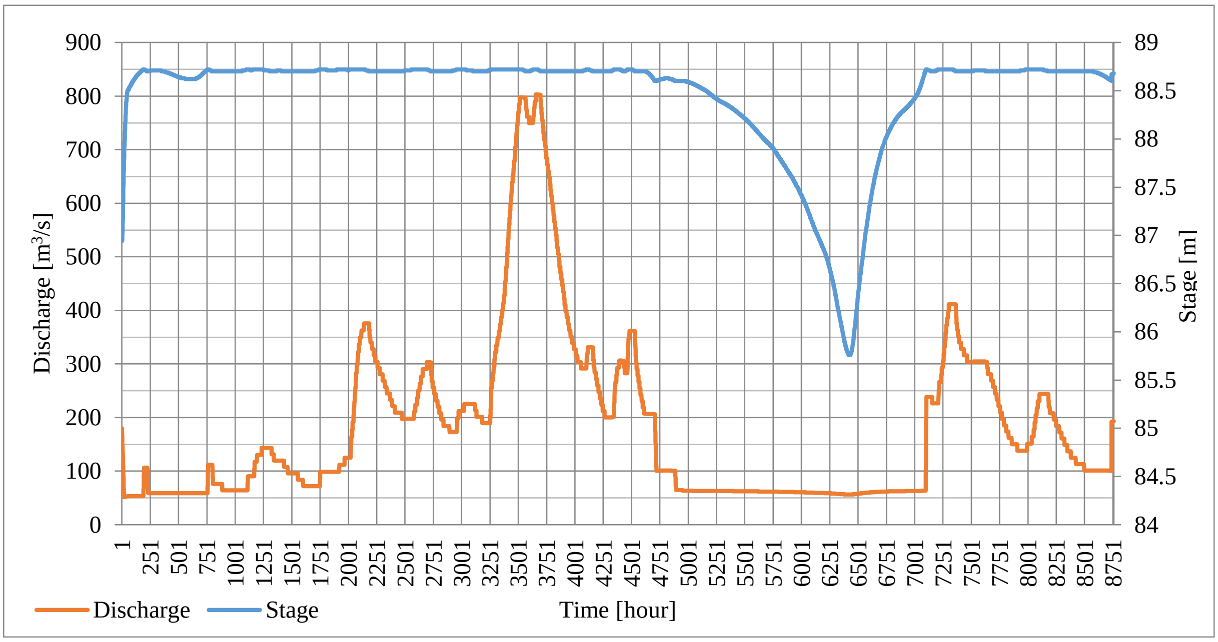


Fig. 7 Discharge and stage at the headwater of Kisköre barrage

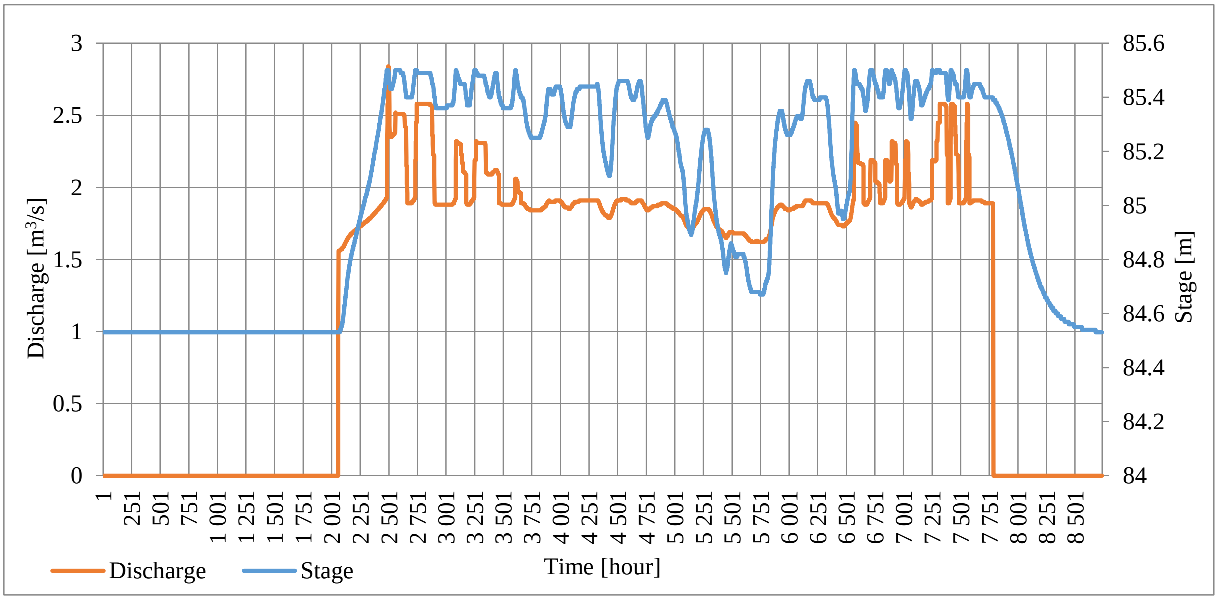


Fig. 8 Discharge and stage at the outflow section of the Nagykunsági main irrigation canal (with the western branch)

to provide water for the Körös Valley. However, when the discharge of the Tisza falls to a critical level (below 60 m^3/s), the amount of water passed through the Nagykunsági main irrigation canal may need to be reduced. In the first scenario of modelling, this regulation was not considered. In the model scenario the minimum flowrate was guaranteed at the outflow sections of the Nagykunsági main irrigation canal. Figure 8 shows the development of the water flow and stage at the outflow section of the western branch. 1.62 m^3/s is the minimum flow during the summer period, which is almost the same as the value in the operating rule.

Figure 9 shows the development of water flow and water level at outflow section of the Eastern branch of the Nagykunsági main irrigation canal in the modelled year. The time series shows that the water flow is between wide limits during the entire irrigation period. This is caused by the operation order of the inline structure at the outflow section. The gate is set to maintain a certain water level at the headwater, which is 84.55±0.05 m. The average discharge is 14.9 m^3/s during the irrigation period.

The results of the model show what is happening with the water resources of the Lake Tisza in an extreme low-water situation. The model runs show that the Lake Tisza is able to supply the area with water during a period with water scarcity, but in extreme cases the water level may become critically low. The water restrictions are not in the model scenario and it was assumed that the water level of Lake Tisza would not reach critically low level. These steps were not included in this model version because the main goal was to investigate at what condition the pilot area can be supplied with enough water.

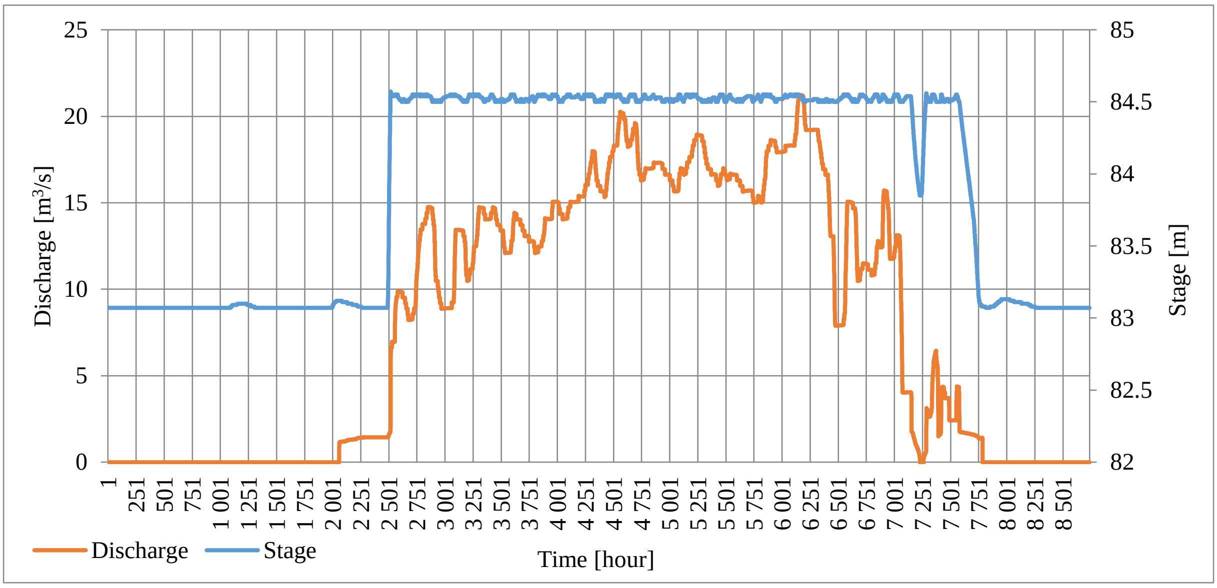


Fig. 9 Discharge and stage at the outflow section of the Nagykunsági main irrigation canal (with the eastern branch)

CONCLUSIONS

The climate change can have serious impact on the selected pilot area, which pose also challenges to the water management of the area. Lake Tisza has the highest value among water resources in the Middle Tisza region, which can provide great help in overcoming these challenges. Supplying the stakeholders with an adequate amount of water proper operation of the reservoir (Lake Tisza) and the irrigation canals are needed. It can be helpful to use hydrological modelling to distribute water resources in a proper way, which means that enough water has to be available.

As demonstrated in the modelling results, the necessary water could be provided in the pilot area without the introduction of water restriction measures. In case of long-lasting drought period the water users of the area could have enough water, but in exchange that the water resources of the Lake Tisza would be reduced to a dangerous low level. This could cause serious ecological, economic and social conflict.

Based on the experiences of this model results, the further researches could include water restriction measures. It will also help to assess how the water level of the Lake Tisza can be maintained within the regulation range, while at the same time limiting the use of water in the area according to the water restriction plans in consensus with the stakeholders.

Acknowledgement

The JOINTISZA project is co-funded by the European Union ERDF and IPA funds focuses on interactions of two key aspects, the river basin management (RBM) and flood protection, taking into account the views of relevant stakeholders who have pivotal role in the Tisza RBM planning process.

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TOOL FOR DROUGHT MONITORING IN THE DANUBE REGION – METHODS AND PRELIMINARY DEVELOPMENTS

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Abstract

Drought is a naturally recurring phenomenon of the climate system that affects virtually all regions of the world. During the past decades extreme droughts with extensive negative effects on ecosystems became evident also in the Danube region. At the moment regional capacity to monitor drought is still very diverse and not synchronised among different countries. In this is paper, we present a recently developed drought monitoring tool – the Drought User Service (DUS) for the Danube region using remote-sensing products which aims at offering a more accurate and in near-real-time monitoring via different drought indices. The DUS was created as the monitoring tool of the risk-based paradigm, which seeks to give information in near real-time about the location and severity of droughts throughout the Danube region. Satellite remote sensing products meet the requirements for operational monitoring because they are able to offer continuous and consistent measurements of variables, which can be used to assess the severity, spatial extent and impacts of drought. In the DUS three different variables – vegetation, soil moisture and precipitation – are monitored with earth observation products. The condition of vegetation and soil moisture is tracked with two simple indicators computed as long-term anomalies of the NDVI and SWI products made available through EU's Copernicus Global Land Service. The importance of DUS and of the developed methods for faster detection of drought onset as useful foundation for establishing a better pro-active drought management in order to mitigate the negative effects of drought in the region is discussed.

Keywords: drought monitoring, drought impacts, drought management, satellite data, Drought User Service

INTRODUCTION

Drought has been a recurrent phenomenon in the Danube region and its characteristics in the last decades are changing. It has become more intense and is developing more frequently. According to recent findings related to climate change, drought is likely to become more frequent and severe in the 21st century in many regions of the world, especially in water-scarce and already vulnerable areas that include parts of Europe (IPCC, 2014). In the current climate, summer water scarcity is already a problem in the Danube basin but its duration and magnitude are projected to increase especially in the southern and eastern part of the Danube basin (Bisselink et al., 2018; van Lanen and Vogt, 2018). Despite the impacts on the economy and welfare of people caused by drought in the last decades, drought is still not considered an issue of high priority, people remain reactive in their actions and any measures are carried out only when drought has already developed. In the last years, there have been important efforts both in the scientific and technical field in relation to drought. Unfortunately, a universal definition of drought is difficult to formulate due to the range of drivers and impacts that a drought event may have (Sepulrce-Canto et al., 2012). Drought projects increase the knowledge on drought in different research areas and regions, providing additional monitoring tools and management experiences for policy-makers and water related managers in the EU i.e. DROUGHT-R&SPI (Drought - R&SPI, 2015), DEWFORA (Dewfora project, 2013), PESETA (Watkiss et.al., 2009) and regional cooperation programmes such as EUROCLIMA (European Commission, 2018), as well as several national initiatives. Findings from the projects have advanced the knowledge base with better access to information, guidelines and services on (van Lanen et al., 2017): drought monitoring, prediction and early warning, drought impacts and links with the hazard, drought risk assessment, risk reduction and drought response and policy, and planning for drought preparedness and mitigation across sectors.

As a result, a range of indicators is used to detect and monitor agricultural drought, which are typically based on meteorological observations and estimates from remote sensing and modelling. The status of drought monitoring in the Danube region is still in its early stages, characterised by cross-border inconsistency with products that are often not delivered on time. Furthermore, methodologies for drought risk assessment and drought impact assessment are not harmonised across the region. Drought management in the region is reactive, dealing mainly with losses and damages, cooperation among key actors is missing and formal legislation considers drought only partially and insufficiently. Aiming at overcoming these weaknesses was the main motivation for launching of the project DriDanube – Drought Risk in the Danube Region (DriDanube, 2018). The paper presents some of its results, focusing on a new monitoring tool – the Drought User Service (DUS) that makes use of the earth observation operational products from the EU's Copernicus Global Land Service: the Soil Water Index (SWI) and the Normalized Difference Vegetation Index (NDVI). SWI and NDVI long-term anomalies can be used as indicators for operational drought monitoring and early warning across 10 countries in Danube basin. The DUS presents to the public near-real-time information on drought via an online portal: www.droughtwatch.eu. Timely, relevant and reliable drought information will be vital for detection and alert systems at the core of response activities in the Danube region.

RESEARCH AREA

To provide context for the consideration of drought detection, an overview of the regional climate is given. The research area covers almost the entire catchment area of the Danube River and includes the territories of 10 countries: Czech Republic, Slovakia, Austria, Hungary, Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and Romania (Fig. 1). Generally, most of the Danube basin is dominated by a continental climate, only the western parts of the upper basin and its southwestern part are influenced by the Atlantic climate or by the Mediterranean climate, respectively. Annual precipitation depends mainly on orographic features and ranges from less than 200 mm per year to over 2000 mm per year. The rivers fed by water and moisture from the wet mountains help to balance evapotranspiration deficits, typical for the Pannonian plain and the delta, in the dry lowlands (Danube Regional project, 2012). Eight extreme drought events that have occurred across various parts of the Danube region since 2000 have caused extensive damage to natural ecosystems and diminution of agricultural production and in many countries also disturbance of surface and groundwater supplies.

REMOTE SENSING DATA AND DROUGHT INDICATORS

Recently developed platform called Drought User Service (DUS) is an innovative web-based tool for the viewing and analyses of the drought related spatial datasets. The purpose of the tool is to upgrade the systems for monitoring of the drought in the Danube region with the goals of mitigating the effects of drought and preparing potential users for timely reaction. The development was followed a pre-set plan, roughly composed of three consecutive phases. First, we were interested in the ideas and demands of potential users. We collected these with a web-based questionnaire comprising of 35 questions related to the basic information about the user, information about their experience in working with Earth Observation data, and questions concerning the components of the planned system, its tools, and data usage (analyses). We have sent the questionnaires to all project partners and other potential users, including national hydrological and meteorological services,

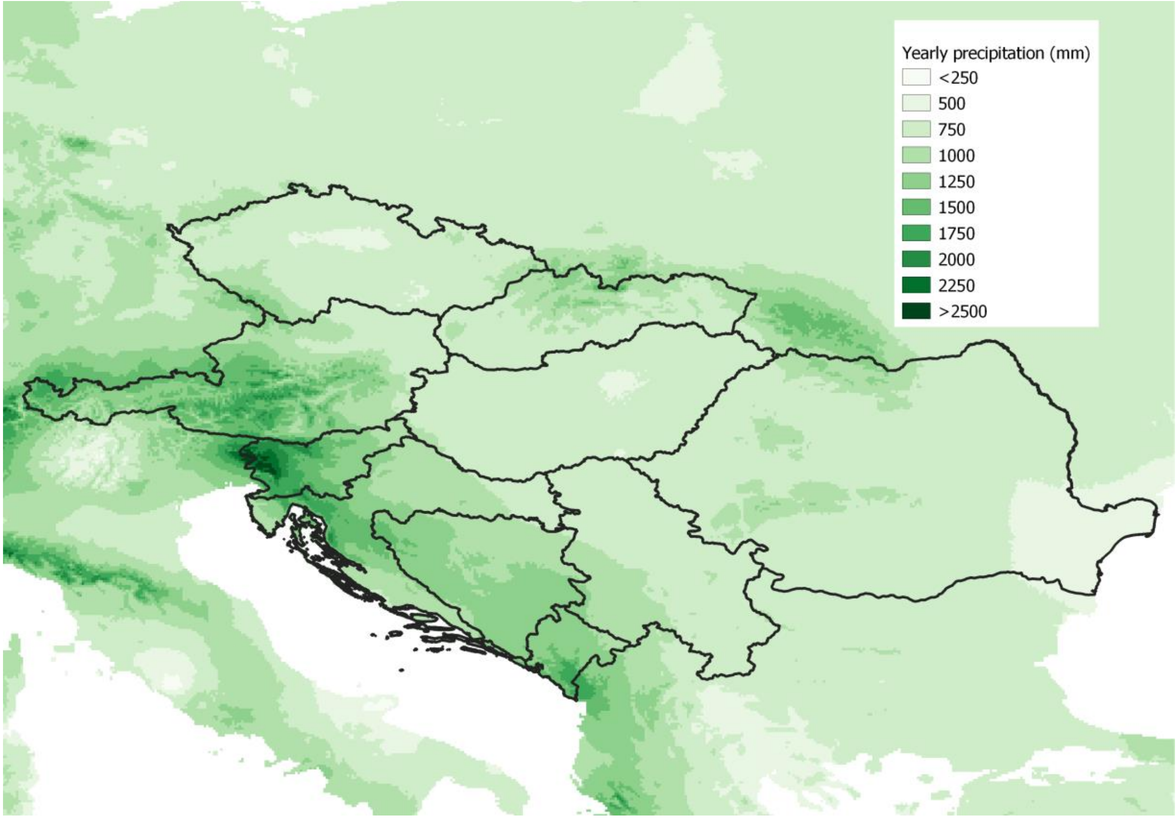

Fig. 1 Annual precipitation map (shades; average for period 1971-2000) and political boundaries (black line) of the region and countries, participating in preparation of Drought User Service (Source of precipitation data: worldclim.org; Fick and Hijmans, 2017)

environmental agencies, other governmental agencies, international and non-governmental organizations, and research institutions. 47 institutions from 10 European countries responded. The analysed results were translated into the priority scale of the requirements, based on the MoSCoW method, in which the requisites are divided into four categories: must-have, should-have, could-have and will-not-have requirements (Bittner and Spence, 2004).

DUS offers near real-time information about drought conditions with two remotely sensed indices: the Soil Water Index (SWI) and the Normalized Difference Vegetation Index (NDVI). This section describes these indices, their usefulness and implementation for drought monitoring in the Danube region. The data source for both SWI and NDVI products are made available through the Copernicus Global Land Service (GLS).

Soil Water Index (SWI) anomalies for soil moisture monitoring in drought conditions

Soil moisture (SM) is an important element in the Earth's system. Its key role in the hydrological, carbon and energy cycles and their interaction led to its recognition as an Essential Climate Variable in 2010 by the Global Climate Observing System (e.g. Leghates et al., 2011; Seneviratne et al., 2010). Furthermore, soil moisture is one of the indicators used to monitor, forecast and characterise drought. Operational online drought monitoring tools around the world incorporate information on soil water content from modelled and/or remote-sensing-based estimates: e.g. the US Drought Monitor, the European Drought Observatory (Vogt et al., 2011), the African Flood and Drought Monitor.

SM estimates are available from in-situ measurements, atmospheric and hydrological models, and satellite imagery and are characterised by method-specific advantages and limitations (e.g. Leghates et al., 2011; Nghiem et al., 2012; Petropoulos et al., 2015). The satellite-based SM products are most commonly retrieved from microwave activate and passive sensors (e.g. SMOS – Kerr et al., 2010; SMAP – Entekhabi et al., 2010; AMSR-E – e.g. Njoku et al., 2003; ERS and ASCAT– e.g. Wagner, 1998) and offer the advantage of continuous temporal and spatial measurements (in contrast to e.g. point-measurements from in-situ networks which are not representative over an area due to the high spatial variability of soil moisture).

The Copernicus SWI product provides global daily information on moisture conditions at different soil depths at a spatial resolution of 0.1 degrees (Paulik, 2017). The SWI data used to calculate the SWI anomalies displayed in DUS uses as input the ASCAT-25km surface soil moisture (SSM), a remote-sensing product (Bartalis et al., 2008) provided operationally in near real-time by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). The ASCAT scatterometer on board the Metop satellites (Metop-A and Metop-B) is a real aperture radar that operates at 5.255 GHz (C-band) and uses six vertically polarised antennas for transmission and reception of long pulses that after several specific steps (as described in e.g. EUMETSAT, 2015; Wagner et al., 2013) become backscatter coefficients (σ^0) given in units of decibels (dB). Exploring the underlying high sensitivity of microwaves to the water content in the most upper layer of the soil (1-2 cm) these backscatter measurements are then transformed into surface soil moisture estimates with the TU Wien method by Wagner et al. (1999a,b,c) originally developed for the ERS-1/2 AMI instruments and further improved by Bartalis (2006, 2007) and Naeimi et al. (2009a,b). However, besides soil moisture, the microwaves are sensitive also to other factors such as the surface roughness and vegetation cover; the TU Wien's SSM retrieval model is a change-detection model which minimises these effects by interpreting changes in backscatter (σ^0) over time as detailed in Wagner et al. (2013).

SWI gives information on the moisture conditions available to plants in their root-zone which has proved to be useful for characterising agricultural drought (e.g. Gouveia et al., 2009). Based on the method proposed by Wagner (1999b), the SWI algorithm uses an infiltration model that describes as a function of time the relation between the soil moisture observed at surface and the profile soil moisture. Thus, using a two-layer water balance model, the SSM observations are transformed into SWI with Eq. (1).

$$\mathrm{SWI}_{(\mathrm{t_n})} = \frac{\sum_{\mathrm{i}}^{\mathrm{n}} \mathrm{SSM}_{(\mathrm{t_i})} e^{\frac{\mathrm{t_n}-\mathrm{t_i}}{\mathrm{T}}}}{\sum_{\mathrm{i}}^{\mathrm{n}} e^{-\frac{\mathrm{t_n}-\mathrm{t_i}}{\mathrm{T}}}} \text{ , for } \mathrm{t_i} \leq \mathrm{t_n} \qquad (1)$$

where t_n is the observation time of the current measurement and t_i are the observation times (in Julian days) of the previous measurements; all SSM observations made before t_n are summed up and exponentially weighted. The factor T determines the weights (e.g. for T = 5 the weight is equal to 0.135; where 10 is the number of days SSM was taken before t_n) and how much SSM observations taken in the past influence the current SWI value.

For near real-time operations, the SWI can be calculated with a recursive formulation (Eq. 2) (Albergel et al., 2008, Paulik, 2017):

$$\mathrm{SWI_T(t_n)} = \mathrm{SWI_T(t_{n-1})} + \mathrm{gain_T(t_n)(SWI(t_n)} - \mathrm{SWI_T(t_{n-1}))} \qquad (2)$$

where t_n and t_(n-1) are the observation times of the current and previous SSM measurements, respectively.

Agricultural drought follows the meteorological drought and is characterised by drying of soil which results in a reduction in vegetation growth and in crop and biomass production (Mishra and Singh, 2010; Van Lanen et al., 2017). In DUS, long-term anomalies of SWI are used as indicator of drought. The long-term anomalies are used, rather than current absolute values as they reflect better the positive and negative variations in soil water content in a historical context, and thus of drought conditions. These are computed daily (Eq. 3) as the difference between the SWI (T=10) value for a certain day (e.g. 1 March 2018) and the long-term average for the same day over values since 2007 up to the last full year (e.g. for a value in 2018 the period considered is 2007-2017; Copernicus SWI product is available only since

2007). Before anomaly computation the data is masked for frozen soil and temporary water on the surface using the Surface States Flags (SSF) as described in Paulik (2017).

$$\mathrm{SWIanomaly_t} = \mathrm{SWI_t} - \overline{\mathrm{SWI}} \tag{3}$$

where $\mathrm{SWI_t}$ is the SWI value of day t of the current year, and $\overline{\mathrm{SWI}}$ is the long-term average of SWI. According to the definition of the SWI, the SWI Anomaly represents values expressed as units of degree of saturation. In the DriDanube's Drought User Service the SWI Anomaly values are displayed as daily maps. The maps depict with brown shades the SWI anomalies as percentage up to -25% less than long-term average and with blue shades up to 25% more than the long-term average; zero represents no change in soil moisture conditions from the long-term mean.

The SWI product has certain limitations, which have to be considered for the interpretation of SWI anomaly indicator presented here. These are related to the model definition of the SWI; e.g. soil texture that defines the relationship between value *T* and soil depth is not taken into account, and therefore the availability of values which allows the user to select and compare the best data. Also, evapotranspiration is not considered by the SWI algorithm which can lead to false high values when precipitation and satellite observation times coincide and the rainfall evaporates rather than infiltrate into the deeper layers of the soil. Furthermore, as already mentioned at the beginning, vegetation has a strong influence on the radar signal of which the annual cycle in the base product – the ASCAT SSM – is considered to be the same for each year; however, if this deviates significantly form the average the retrieval of SSM becomes biased.

The SWI product, as well as its underlying ASCAT SSM product, has been extensively validated in numerous studies against external data sets including in-situ soil moisture measurements in Paulik et al. (2017 and all other studies therein referenced). The products show good correlations with both modelled and ground measurements, except arid areas and for the northern latitudes. The accuracy of the product was reached for 75% of the sites when the target was set to 0.1 m^3/m^3, while a target of 0.2 m^3/m^3 was obtained for 98% of sites (Paulik, 2017). Furthermore, the SWI product has a good temporal consistency that reflects well the seasonal cycle with the exception of very dry conditions. The spatial consistency is also good, however, SWI estimates are not reliable over high altitudes, dense forest and desert areas; and cannot be estimated for frozen conditions.

Normalized Difference Vegetation Index (NDVI) anomalies for vegetation drought monitoring

NDVI is the most straightforward way of detecting and monitoring vegetation from satellite measurements (Anyamba and Tucker, 2012) and represents the starting point of satellite-based indicators for drought monitoring. This simple metric has been present since the 1980s and was first formulated for AVHRR imagery by Tucker et al. (1979). Given its early development almost 40 years ago, this indicator has been widely studied for its utility in various applications: e.g. land cover classification, agricultural monitoring, biomass estimation or is included as input in land-surface or biophysical models (Anyamba and Tucker, 2012); or combined with other variables into more advanced indices (e.g. the Vegetation Condition Index by Kogan and Sullivan, 1993). NDVI has also proven to be valuable for detecting drought-induced stress to vegetation and therefore included in the Handbook of Drought Indicators and Indices– a general guide on commonly used drought indicators for identifying the spatial extend, onset, duration and severity of droughts meant for practitioners who deal with drought management (WMO and GWP, 2016).

NDVI, an index without physical units, is calculated from measurements of the spectral reflectances in the red spectrum (RED) and near-infrared (NIR) regions of the electromagnetic spectrum (Eq. 4) (Brown et al., 2013). Theoretically, the NDVI values range between -1.0 and +1.0, where an increased NDVI is a sign of biomass abundance, while a low NDVI marks the lack of vegetation or decrease of photosynthetic activity.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \tag{4}$$

The Copernicus Normalized Difference Vegetation Index (NDVI) product (Smets et al., 2018) are generated based on the SPOT/VEGETATION C3 and the PROBA-V C1 data separately. The NDVI values are provided for every 10-day period at a spatial resolution of 1/112 degrees (~ 1km), and represent the best measurement selected from 10 consecutive days based on the criteria detailed in Swinnen et al. (2017).

The usual way of using NDVI for drought detection and monitoring is to compute NDVI anomalies (Anyamba and Tucker, 2012). In DUS, the NDVI Anomaly indicator is based on the difference from the long-term mean which shows the current drought severity in a historical context. It is produced for every 10-day period and is calculated as the difference between a certain 10-day NDVI value (e.g. first decade of July 2017) and the long-term average (Eq. 5) over values since 1998 (Copernicus NDVI product available since 1998) up to the last full year (e.g. for a value in 2018 the period considered is 1998-2017). Before anomaly computation, the data is masked for cloud and cloud shadow, snow or ice and water using the Quality Flags as described in Smets et al. (2018).

$$\mathrm{NDVIanomaly_t} = \mathrm{NDVI_t} - \overline{\mathrm{NDVI}} \tag{5}$$

In Eq. 5 $\mathrm{NDVI_t}$ represents the 10-day NDVI value of the current year, and $\overline{\mathrm{NDVI}}$ is the long-term average of NDVI. Negative NDVI anomalies represent lower than average NDVI values and are an indicator for vegetation stress and lower than average photosynthetic activity. In DUS, the anomalies are displayed as maps for every 10-day period (decade). The maps depict with brown shades the NDVI anomalies as percentage up to -25% less than long-term average and with green shades up to 25% more than the long-term average; zero represents no change of vegetation conditions from the long-term mean.

Similar to the SWI product, the NDVI product is not free of shortcomings which are sensor dependent – the well-known inability of optical sensors to penetrate through clouds; additional factors such as – variations in solar zenith and viewing angles, surface reflectance bidirectional effects, atmospheric conditions, topography, data dropouts in cold regions – also influence the NDVI values. A full description of how are these addressed is available in Smets et al. (2018). The overall performance of the product is rated as "good" based on validation studies carried out against similar products e.g. the NDVI from MODIS /Terra - NASA and from AVHRR/Metop – EUMETSAT (CGLS, 2018).

RESULTS AND DISCUSSION

The drought monitoring tool DUS (Fig. 2), being developed within DriDanube project, increases the amount of new data and improves accessibility of existing data used in predicting and managing drought and its effects. The combination of data, new tools and previous research (e.g. Ceglar et al., 2012) enables the planning of more efficient control mechanisms, spatial interventions and management practices in the Danube basin. On the other hand, DUS serves the end users, such as various ministries, agencies, and farmers, to make decisions and take action on the ground. Most of the service data covers the entire Danube region and, due to their nature (mostly satellite data), they have great potential for further development and geographic expansion. This opens the possibility for the competent departments of different countries to engage at a higher level of cooperation between the integrated regions of one of the major river basins in Europe.

18 requirements were created from the user survey. Four of these are general, related to the availability of the service and user support. Six requirements relate to the data, their quality, temporal and spatial resolutions, availability basic cartographic data and auxiliary data. The respondents requested eight usability requirements, referring to the interaction of the user with the service (Hasenauer et al., 2017). When the initial user requirements were met, the project consortium followed up with the user trainings where the service has been reviewed. The collected feedback was later reviewed, categorized and implemented.

The results of the survey were the basis for the design of the technical solution. The Drought User Service is implemented with a combination of modern tools and technologies for web application development. The graphical user interface is composed with the HTML5 markup language and CSS3 cascading style sheets. The service is written in the JavaScript programming language and the developed in Aurelia framework. The use of online maps is enabled through the OpenLayers 4.6.4 library, and MapServer 7.0.7 platform is used to display the drought-related data provided through our own Web Map Service (WMS). The technologies used facilitate potential service extensions and long-term compatibility with other web tools. They are also available without licencing fees, have a wide range of users, and are actively developed and updated in line with modern trends.

The web interface displays three types of data. The first type includes the basic cartographic layers: Google Maps (obtained 2018), OpenStreet Map (OSM, 2018) and the Satellite Image Mosaic, based on Sentinel-2 data and

Fig. 2 Appearance of the Drought User Service portal

provided by EOX GmbH (EOX, 2017). The second type includes the various vector layers of administrative boundaries at different NUTS levels for the area of the Danube River basin (Eurostat, 2018). The last type are raster data layers for the study of drought at a range of temporal and spatial resolutions, provided by various institutions. These form the core of the planned upgrade of the system, which will include the analysis of drought and its impact, and provide a drought early warning system.

Additional data will therefore include information layers developed during the project. These will show the state of drought and related phenomena. The system is designed modularly and enables quick and easy integration of new data; either in the application itself or through online services for displaying and transmitting geographic information, e.g. WMS, Web Coverage Service (WCS), Web Feature Service (WFS).

In the DUS first observational year drought index SWI and vegetation index NDVI showed good spatial matching. In Figure 3. we see long-term anomalies of SWI index from May to September 2018 with 1-month intervals and in Figure 4. long-term anomalies of NDVI index for the same time frame as SWI index. In May 2018 SWI showed that areas with a level of soil moisture saturation lower than long-term average were scattered across Danube area. In same time period vegetation index NDVI showed higher values than long-time average across Danube region which are mainly caused by the earlier development of green mass due to higher temperatures in spring in this area. In June SWI index increased in almost all investigated areas and especially in north and west became positive or higher than the long-term average. NDVI index in June lowered and in some areas in the north, central and east region became negative and showed good correlation with SWI index. In July and August situation changed and SWI index in the north part of the region become negative, especially deep in the Czech Republic. At the same time index rises in south and east areas and became much higher than the long-term average in Romania, Bulgaria and Serbia. NDVI index in July and August stay in negative zone in northern parts of the region and slowly worsened and spread in the west and central parts. At the same time in the south and east parts index became positive which correlate with SWI index. In September SWI index slightly improved in almost all investigated areas with exception of the areas along East Adriatic coast and central Danube region, while NDVI index showed more negative anomalies in the north and central parts and less positive in east and south parts of the region.

The goal of development is to take a step further from the creation of a web browser. The DUS therefore enables the user to analyse and compare the displayed data. It is possible to overlay multiple layers, modify their transparency, and remove the selected layer to display underlying layers. The user can query the values of individual pixels or display and export a timeline graph for the selected pixel. Users can also download data to a desktop computer and analyse them in a Geographic Information System. When selecting a vector layer object, the records in the attributes table of this object are displayed. Individual data layers are provided with the basic descriptive information while descriptions that are more detailed are accessible from the application in the form of fact sheets. These describe the purpose, usability, the production method, technical information and product quality of an individual data layer.

The DriDanube project's objective is to create a framework for relevant stakeholders in the Danube region to increase their capacity to prepare better in case of drought events; in other words, moving from the traditional post-event crisis management to a pro-active risk-based management of droughts which includes several actions such as: preparedness, monitoring, risk-mitigation and response. As presented in this paper the

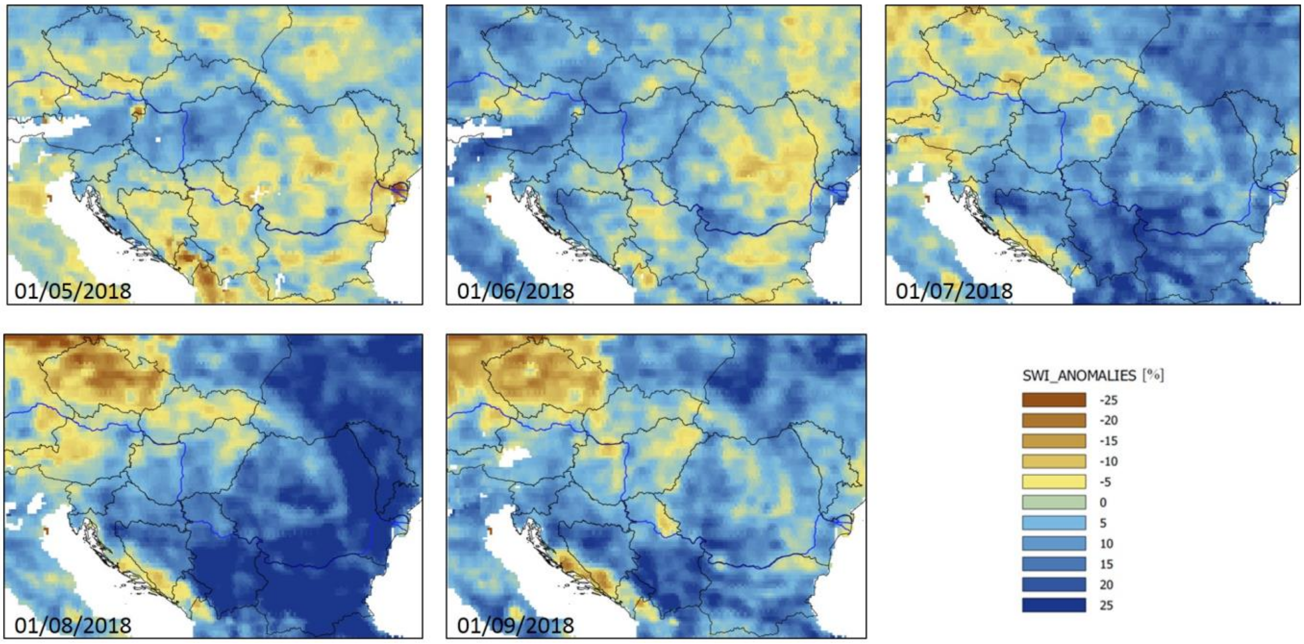

Fig. 3 SWI long-term anomalies on 1st of: May, June, July, August and September 2018 over the Danube region: brown shades represent lower than average soil moisture conditions and blue shades represent higher than average soil moisture conditions.

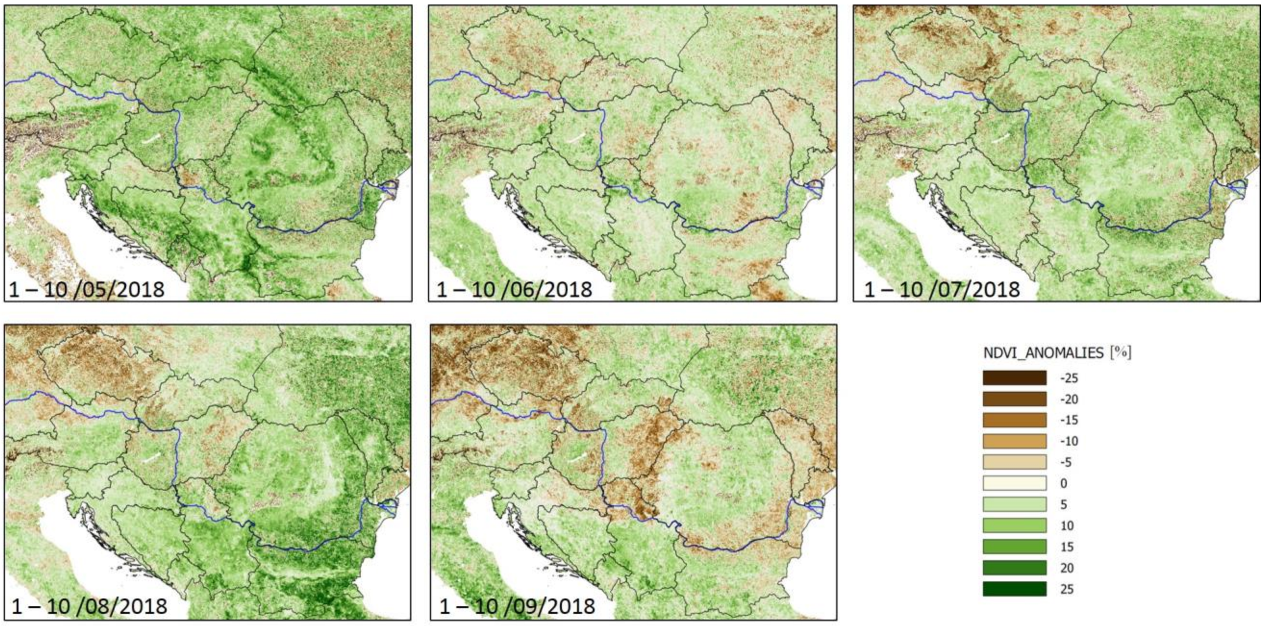

Fig. 4 NDVI long term anomalies for the 1st decade (1-10) of months: May, June, July, August and September 2018 over the Danube region: brown shades represent lower than average vegetation conditions and green shades represent higher than average vegetation conditions.

two indices were selected based on their well-known potential to characterised droughts. However, beside the limitations determined by their production (associated with sensor type, algorithm etc.), it is recognised that no one indicator or index can fully capture the complexity of droughts (e.g., Hayes et al., 2012). Additionally, in the DUS only long-term anomalies are available at the moment, however different other reference periods could be considered (10-days, weekly, monthly) and further investigated for their ability to monitor drought effects for example in relation to land cover types (e.g., crop types). Also, although the whole period available is considered for the calculation of NDVI and SWI anomalies, 19 and 11 year, respectively, it might still not be representative for drought events in the region. Considering different T values (at the moment $T = 10$ is used) for calculating anomalies could also be explored over different areas and land-cover types within the Danube region. Furthermore, one needs to take into account limitations of the earth observation products. For ASCAT surface soil moisture, the input of SWI, long-term positive trends have been observed over Europe especially located close to large cities. These positive trends in soil moisture, and thus backscatter, are likely caused by expansion of urban areas, where multiple scattering increases backscatter, and possibly Radio Frequency Interference. Currently, TU Wien is further investigating the source of these trends and how to correct for them.

In recent years, an increased demand for information at finer spatial resolution (field size) has emerged as in the case of agriculture monitoring. In the DUS, we have also presented for the first time SWI anomalies at 1 km spatial resolution which is based on the original SWI Anomaly indicator downscaled with parameters calculated from Sentinel-1. This approach combines the advantages of the Sentinel-1 high spatial resolution and that of the ASCAT high temporal revisit time and show promising results as described in Bauer-Marschallinger et al. (2018); the product is currently being prepared for operational dissemination through the Copernicus GLS (2018).

CONCLUSION

No single source of information is authoritative and comprehensive to identify potential drought area alone, especially given the climatological heterogeneity within the Danube basin. The DUS brings to the drought practitioners in the region indicators based on earth observation products that offer information on the current status of drought and enables them to compare current situation to past drought episodes. In addition to the near real-time monitoring, the portal also makes available the results of the impact and risks assessments carried out within the scope of the project. Conclusions on the drought situations are most confidently when many or all factors indicate a similar situation of dryness in a region. Any reduction of ambiguity associated with data and information used by DUS contributes to an improved linkage between early warning and early response. The drought monitoring approach improved by DUS through the integration of satellite data and developed impact databases can form the basis for decision support systems at a national level for producing reliable and useful information that is regional in scope and relevant for local decision-making.

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