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Spatial assessment of the inland excess water presence on subsurface drained areas in the Körös Interfluve (Hungary)

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Abstract

Due to extreme meteorological and soil hydrological situations the agricultural production security is highly unpredictable. To release the extent and duration of inland excess water (IEW) inundations or two-phase soil conditions during the period intended for cultivation, subsurface drainage (SD) has been used as a best practice in several countries. SD interventions took place between 1960's and 1990 in Hungary. After 1989, land ownership conditions changed, thus professional operation and the necessary maintenance of the SD networks designed as a complex system became insignificant. In this paper, our aim was to present the IEW hazard in one of the most equipped areas by SD in Hungary. The occurrence frequency of IEW inundations in drained and non-drained (control) areas in different time intervals were compared. According to our results, we could state that the frequency of IEW on the subsurface drained areas was moderately lower in only a few periods compared to the control areas. IEW hazard of the arable areas at the Körös Interfluve was classified as non-hazarded in 52.7% of the area. Another 38.2% were moderately hazarded, 8.26% of the lands were meanly hazarded and less than 1% were highly hazarded area by IEW.

Keywords: drainage*,* subsurface water management, IEW, GIS

Introduction

Following the regulation of the River Tisza and its tributaries, the agricultural cultivation of the periodically flooded deep floodplain areas has begun. These areas "did not forget" their previous hydrological conditions. The undrained (excess / surplus) water could not leave local depressions and unfavourably structured soil patches. Excess water is a temporary water inundation that occurs in flat lands due to extreme precipitation, sudden snow melting and emerging groundwater level (BOZÁN et al., 2017). This IEW is mainly detrimental to agriculture (RAKONCZAI et al., 2011).

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IEW formation is influenced by natural and anthropogenic factors that are constant over time (determining the conditions for the formation of IEW, e.g. geology, relief, soil etc.) and changes over time (causing IEW inundation, e.g. hydrometeorology, groundwater) (LABORCZI et al., 2020a; BARTA et al., 2013). BARTA et al. (2016) have shown that infrastructural elements and linear facilities (road and railway network, canals, embankments, etc.) established in former agricultural areas block the free movement of the excess water from precipitation etc. So the formation of IEW in the surrounding areas must be expected. IEW inundations occur in the lowland areas of Hungary, with an average area of 150.000 hectares (maximum 300.000–500.000 ha). In the absence of drainage, IEW can cause very high yield losses both directly (damage to the crop) and indirectly (the number of cultivable days is reduced) during the growing season. There are three main formation modes of the IEW: (1) In situ, (2) confluence, including congested water in canals, and (3) water uprush by confined groundwater (BOZÁN et al., 2017). NAGY et al. (2019) observed that the IEW is mostly generated in Serbia from rainfall origin, but also highlight the importance of the rise in groundwater levels after snow melting. As water systems are typically designed and operated as a set of interconnected elements, if there is a shortage of capacity in any element of the drainage route, the water system will malfunction from that point. The water system collects the water but the water is not transmitted to the main recipient. Due to the fact that the system is being forced to store the water on the surface as a form of inundation (KOZÁK, 2020). MEZŐSI et al. (2014) mentioned that IEW returns every 2–4 years in the lowland areas of the Carpathian Basin. In the lower part of River Tisza, e.g. Vojvodina (Serbia), the average extent of the IEW inundation alone approaches the average volume of IEW inundated areas in Hungary (NAĐ et al., 2018). The appearance of IEW is not only specific to Europe. This hydrological phenomenon practically may occur in all lowland areas with poor runoff and unfavourable water management properties of soils (LABORCZI et al., 2020a). Many approaches have been published to describe IEW which are very diverse: (1) the in situ mapping of IEW (VAN LEEUWEN et al., 2013), (2) the determination of the extent and probability of IEW hazard (BOZÁN et al., 2018; LABORCZI et al., 2020a; LABORCZI et al., 2020b), and the modeling of its movement phenomena (KONCSOS, 2011) are the most studied topics to researchers. NAĐ et al. (2018) adapted the SEERISK methodology to assess the risk of IEW appearance. IEW vulnerability was assessed in the following different land use categories: vegetable, orchard, crop, vineyard, grassland, and forest. Their result map was categorized into four risk level zones “Low”, “Medium”, “High” and “Very high”. Other researchers have tried to take into account the effects of environmental and anthropogenic factors influencing IEW hazard based on different methodologies (BAUKÓ et al., 1981; PÁSZTOR et al., 2015). Since 2001, MATE ÖVKI (and its predecessors) have made significant improvements in the mapping of IEW hazards. In 2019, the Complex Nature-Based Inland Excess Water Hazard Map was prepared (BOZÁN et al., 2019). LABORCZI et al. (2020a) stated that the IEW inundation maps currently generated by the Water Directorates (field surveys) should not serve as an absolute reference for more accurate investigations due to their spatial uncertainty. The delimitation of the extent of IEW patches can be determined most accurately by processing remotely sensed data. With such methods, it is possible to separate soil surfaces that do not have an open water surface but are completely saturated with water (two-phased state). From a methodological point of view, the validation of field measurements using aerial and space imagery has been a significant step forward (RAKONCZAI et al., 2003). VAN LEEUWEN et al. (2020) used Sentinel 1 and Sentinel 2 surveys for their research. They managed to delineate IEW patches from 65.5% to 94.5% efficiency by GIS classification.

Properly operated SD networks can affect the IEW hazard of a cultivated area, among other factors. According to the literature, the extent of the areas affected by subsurface drainage in Hungary is 150.000 hectares (BABICS, 1989), but HORNYIK's (1984) study, based on soil data analysis, mentions that nearly 1.3 million hectares of arable land required subsurface drainage. For almost 40 years, a written database or cadastre on the national location of tile drained areas has not been implemented since PRIMÁS et al.'s (1983) work. Regarding the soil conditions, JÁRÁNYI (1989) highlights that during the construction of the subsurface drains carried out in the FAO Tisza II project, it soon became apparent that the classical Dutch methods developed for the relatively uniform natural and soil conditions, could not be applied schematically. The reason for this is the extremely changing climatic, soil hydrological and economic conditions in Hungary. It was especially necessary to adapt the contemporary drainage scaling formulas to the conditions of the area to be treated, but in many cases this adaptations was overridden by economic interests (JÁRÁNYI, 1989). Accordingly, permanent (Donnan, Ernst, Hooghoudt, Kirkham methods) and non-permanent (Glover-Dumm, Tapp-Moody methods) scaling methods were used in Hungary (SZINAY, 1982). In addition to their subsurface water management objectives, the tile drained areas were highlighted as crop production experimental areas. In these areas, the scaling issues of subsurface groundwater management, the yield-improving effect, the role of salt and nutrient movement, and the possibilities and limitations of double operation of the subsurface drains, so in general the effectiveness of the SD interventions, were mostly studied. The researchers emphasized that the comparative assessment of the conditions of the subsurface drained areas before and after the interventions could be achieved by continuous data collection and data provision in accordance with full professional criteria (BUKOVINSZKY, 1983). However, it was often reported that monitoring the required parameters (e.g. local groundwater level) was not always consecutive (KATONA and SZŰCS, 1982). Currently an exact GIS-based cadastre of tile drained areas is not available about their location and other attributes. We also know very little about the current technical condition of existing SD networks. TÚRI et al. (2021) used complex field investigation methods to study tile drained agricultural plots for 30 years. According to their results, the limitations of the operation of the tile drains are (1) the blockage of the drainage pipe outlets, (2) the inadequate operation and environmental condition of the recipient channels, and (3) the lack of appropriate agrotechnics applied on the land parcel. Decades of inadequate maintenance of tile drains are also a problem in several European countries (TLAPÁKOVÁ, 2017; MATICIC and STEINMAN, 2007). According to DJUROVIĆ and STRIČEVIĆ (2004), the function of an improperly treated tile drained area may significantly decrease even after

10 years. An important question, then, is whether drains that have not been used for decades may still have features that could reduce the frequency of IEW appearance. In this study, we present the development of the impact of drainage investments on IEW hazard in a study area. We also examine the efficiency of previous SD based on the appearance of IEW on the blocks, for which we processed six decades of IEW inundations data.

In the course of our research, we conducted a survey to answer the following questions:

- Which areas are subsurface drained at the Körös Interfluve?
- How can the IEW hazard be characterized at the Körös Interfluve?
- Examining different periods, how did the actual IEW inundations appear in the Körös Interfluve? Is there a difference in the inundation frequency of IEW at the drained and undrained (control) areas with favourable and unfavourable water management properties of soils?

Materials and methods

Study area

The investigated area (119,960 ha; *Figure 1*) is situated within 116,600 ha in Békés County and 3,360 ha in Hajdú-Bihar County in the lowland of the Great Hungarian Plain. It is supervised by the Körös Valley District Water Directorate.

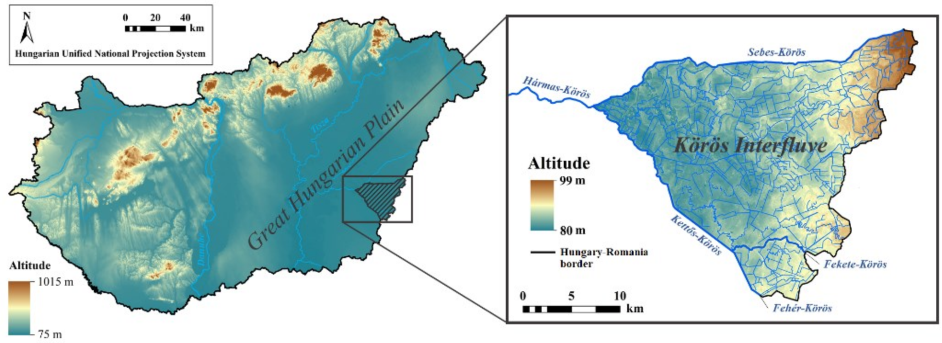


Figure 1
Overview of the relief map of Körös Interfluve

Motivations for selection of the studied area were as follows:

- – the area was significantly affected by subsurface drainage interventions before 1990;
- – more than 70% of the area has been hazarded due to IEW inundations;
- – half of the area has heavy textured soils with limited infiltration and low permeability conditions;

- a significant part of the Körös Interfluve has been under agricultural cultivation where IEW can cause the greatest material damage;
- there are various data series available in the necessary length and quality for the analyses.

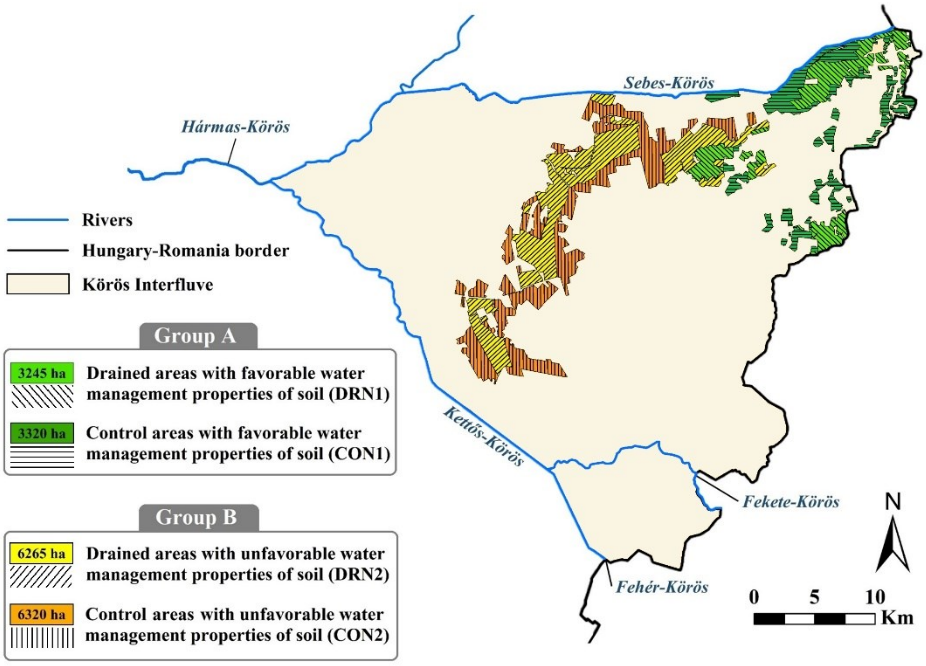


Figure 2
Map of the examined subsurface drained and the control blocks at the Körös Interfluve

The area called Körös Interfluve, is near the border of Hungary and Romania and it is surrounded by the Sebes-Körös, Kettős-Körös and the Fehér-Körös Rivers. The area has a very diverse geomorphology, characterized by the former dead riverbeds of the Körös River and its tributaries. These depressions are the most affected by the IEW inundations. The annual precipitation is 500–550 mm, but its distribution is very hectic. In addition to the frequent droughts, IEW can also cause damages within the same year. Depth of groundwater varies, generally 0.5–4.5 m with seasonal fluctuation. Land use is characterized by a high proportion of agricultural land (88%), and within it is a very high proportion of arable land (67.8%), well above the national average. Grassland (11.9%) and forest (8.14%) are also highly represented.

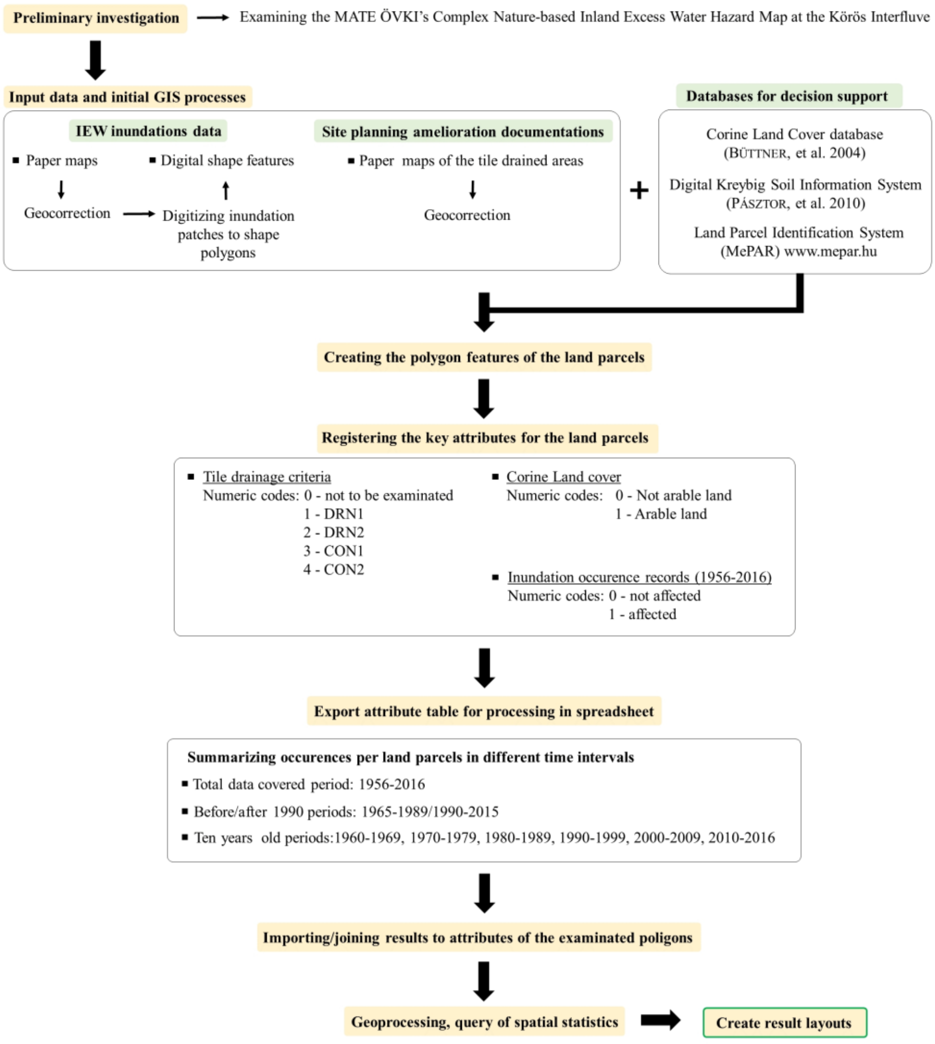


Figure 3
The flowchart of the applied databases and methods

At the Körös Interfluve, the delineated tile drained areas and the control areas closely to same territorial extent were determined (*Figure 2*). Based on the soil water management categorization of the Digital Kreybig Soil Information System (DKSIS) database (PÁSZTOR et al., 2010), SD areas with favourable soil water management properties (DRN1) were selected in conjunction with Control (CON1) areas (later: Group A). It was the same in the case of drained areas with unfavourable soil water management properties (DRN2) paired with CON2 (later: Group B). In the long run, the size of agricultural blocks has changed significantly during land amelioration interventions, and currently, cultivation methods and parcel allocation can vary within a block. Thus, we needed territorial units that have a permanent area and boundaries. The basic unit of the Agricultural Parcel Identification System (MePAR) is the physical block. Within the physical blocks, agricultural parcels / plots are marked. A physical block is a plot of agricultural land that is contiguous in terms of cultivation and has been identifiable with the same outline for several years (*71/2015. (XI. 3.) Decree of the Ministry of Agriculture). Based on the MePAR physical blocks, we created the polygons of the Körös Interfluve to be examined in a GIS environment. In addition to delineating physical blocks, we used the Corine Land Cover (CLC) database (BÜTTNER, 2004) to specify the attribute of cultivated areas. From the land cover database, 2 categories were highlighted as attributes arable land (codes: 211,212) and non-arable land. Several versions of the CLC database are available. According to SZABÓ (2010), we compared the versions released in different years. We found that in terms of arable land, the category boundaries of the different versions had the same extent and boundaries. The reference datasets and databases used for the investigation as well as the methods used are shown in *Figure 3*.

MATE ÖVKI Complex Nature-based Excess Water Hazard Map

The two elements of the digital mapping methodology we have applied (BOZÁN et al., 2019; LABORCZI et al., 2020a):

1. Environmental co-variables that are causally (physically, determining their formation, etc.) or indicatively related to the variable to be mapped and provide full spatial coverage for the area to be mapped (the variables used for the analysis were treated as equal and grouped into factors for better sortability). The six main factor groups we determined are hydrometeorology, topography, soil, geology, groundwater and land use. Random Forest (RF) method was used for modeling. The applied maps cannot be considered the same as the field reality (each map is the result of some spatial estimation), so the sampling and subsequent modeling are performed in several implementations, which can be up to 100 or even more hundreds. Taking each set of points as a reference data set, we perform the spatial modeling, i.e. the correlation analysis consisting of the hybrid data mining and geostatistical elements, which models the relationship between the variable to be mapped and the auxiliary variables used. Based on the model built in the given realization, the spatial extension takes place. The result is an estimation of the spatial distribution of the variable to be mapped. The same process is repeated for all generated random point sets. In IEW hazard mapping, the RF method is used to generate the synthesis map, in which the deterministic part is estimated by RF, supplemented by Ordinary Kriging (OK) for the spatial extension of residues. The method combines predictions given by multiple decision trees. The result is a combination of multiple runs and does not tend to cut off extreme values as in case of Regression Kriging (BOZÁN et al., 2018). The RF method contains the useful properties of classification trees and regression trees but is more accurate and less sensitive to over-parameterization compared to them. The synthesis map categorizes IEW

hazards according to the probability of IEW inundation: not hazarded (0–20%), moderately hazarded (20–40%), meanly hazarded (40–60%), highly hazarded (60–80%) and extremely hazarded (80–100%).

2. Reference data for the variable was mapped (normalized IEW inundation frequency map edited from formal IEW map documentations). The reference data can be available from two origins: point measurements and map (spatial) data.

Table 1
The total area of IEW inundations in each affected year at the Körös Interfluve

Year of IEW event	Total IEW inundated areas at the Körös Interfluve (ha)
1956	20915
1962	1084
1963	1356
1966	13776
1967	108
1977	10255
1978	4725
1979	9184
1981	10033
1986	3681
1987	3368
1989	7947
1996	2558
1997	5297
1998	1626
1999–2000	13859
2003	3304
2006	5058
2010	1441
2013	3512
2016	5713

To determine and evaluate IEW inundation frequency values (data provided by Körös Valley Water Management Directorate), descriptive statistics were used. The years of the IEW events, and the total inundated areas are shown in *Table 1*. The formal database of the IEW inundations of the Körös Interfluve had the appropriate resolution to determine the annual impact of each block. Polygons of IEW inundations are registered at their maximum extent by the Water Management Directorates. The data to be compared under the statistical analysis are originated from GIS spatial statistical processing. In the attribute table of shape polygons (created in ArcGIS environment) we registered the occurrences of the IEW (Code 1) in the affected years, which attribute data were aggregated for the total and split time periods. The differences in IEW inundation occurrence were determined based on the difference maps generated with the zero point of the year 1990 in case of total periods.

The relative inundation frequency (RIF) of IEW inundations was determined according to the following equation:

$$\mathrm{RIF} = (\sum n) / (\mathrm{IEW} * y)$$

where, RIF = relative inundation frequency; n = time interval in years; IEW = inland excess water inundation per physical block; y = number of events

During the processing, the available IEW inundation maps were merged. For each temporal study period, the spatial extent of the blocks with the same inundation frequency was determined and then the result to the percentage of the total area was compared. In the first round of the investigation, the number of IEW inundation frequencies in the period covered by the full data source (1956–2016) was examined. The period before 1990 (1965–1989) and the period after 1990 (1990–2015) and their differences were also studied. This time split was applied because large-scale land reclamation investments were carried out in 1990, and the ownership structure and land structure also changed at that time. Although larger-scale construction began in 1980 in the Körös Interfluve, the main SD interventions were more typical in the second half of the decade. According to our hypothesizing, due to the operation of the subsurface drains, IEW was less present in the tile drained areas before 1990 and in the next few years thereafter. To verify our hypothesis, the time series of the available IEW inundation database at 10-year intervals (1960–1969, 1970–1979, 1980–1989, 1990–1999, 2000–2009, 2010–2016) was also examined, and the RIF was compared in case of both Groups (A,B).

Results

IEW hazard in the study area

The probability of IEW hazard based on natural influential factors (MATE ÖVKI Complex Nature-based Excess Water Hazard Map generated using RF-based digital mapping methodology) was on average 21% in the blocks of the Körös Interfluve. This area ratio was 5.43% higher than the average IEW hazard of arable lands in Hungary. IEW hazard of the arable blocks of Körös Interfluve was classified as non-hazarded in 52.7% of the area (42,906.5 ha). Another 38.2% (31,074.5 ha) were moderately hazarded, 8.26% (6,724 ha) of the lands were meanly hazarded and less than 1% were highly hazarded by IEW. The maximum probability of IEW appearance in the study area reached 71.38%, which could be categorized into the highly hazarded category. These extremities were typical of less than 2% of the cultivated areas. The clip of excess water hazard synthesis map actualized on the tile drained and control areas are illustrated in *Figure 4*. The areas of Group A were mostly characterized by a 10–20% probability of IEW occurrence, which according to our IEW hazard classification was not considered hazarded (*Figure 4*). Based on the maximum probability of IEW occurrence of 41.29% in the study area, the IEW hazard reaches the meanly level. Most of the areas in Group B were moderately hazarded by IEW (the probability ranges from 20–30%). A probability of more than 70% only occurred in CON2 areas (*Figure 5*).

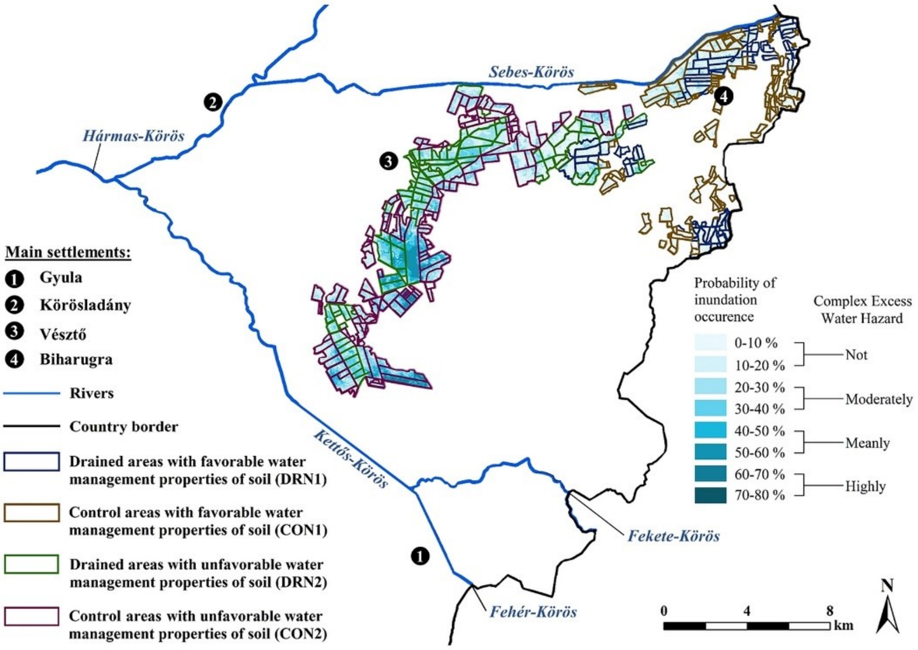
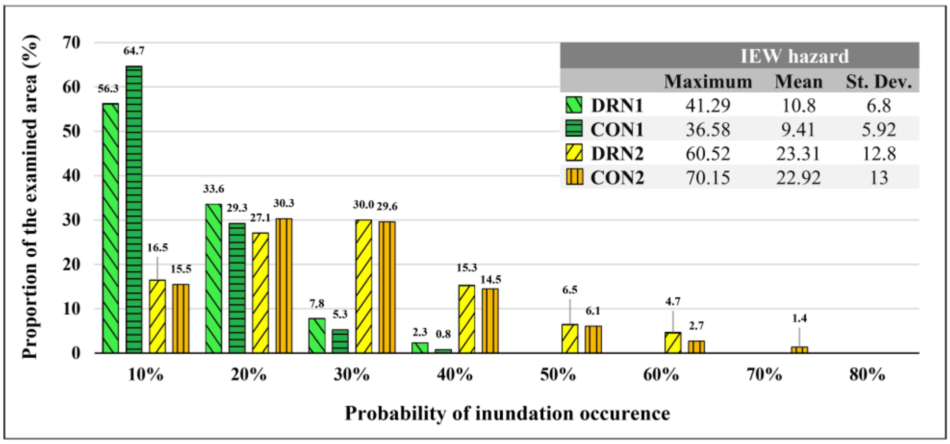


Figure 4
Map of the IEW hazard at the Körös Interfluve based on the MATE ÖVKI Complex Nature-based Excess Water Hazard Map generated using RF-based digital mapping methodology

Changes in IEW inundation frequency

In terms of relative inundation frequency (RIF), the most affected land plots were identified 15–16 times within 60 years, representing IEW inundations every 4 years (*Figure 6*). IEW inundation events occurred in 22 of the investigated 60 years, affecting an average of 25% of the total arable area. IEW inundations data from the years 1999 and 2000 were available together, considering that extreme hydrological conditions were present without interruption during this period. It could be observed that after the extreme numbers of IEW events of 1999–2000, the proportion of areas affected by IEW inundations was almost the same year by year (*Figure 7*).



	IEW hazard		
	Maximum	Mean	St. Dev.
▧ DRN1	41.29	10.8	6.8
▤ CON1	36.58	9.41	5.92
▨ DRN2	60.52	23.31	12.8
▥ CON2	70.15	22.92	13

Figure 5
The probability of the inundation occurrence compared to the percentage of the examined DRN1, DRN2, CON1, and CON2 areas

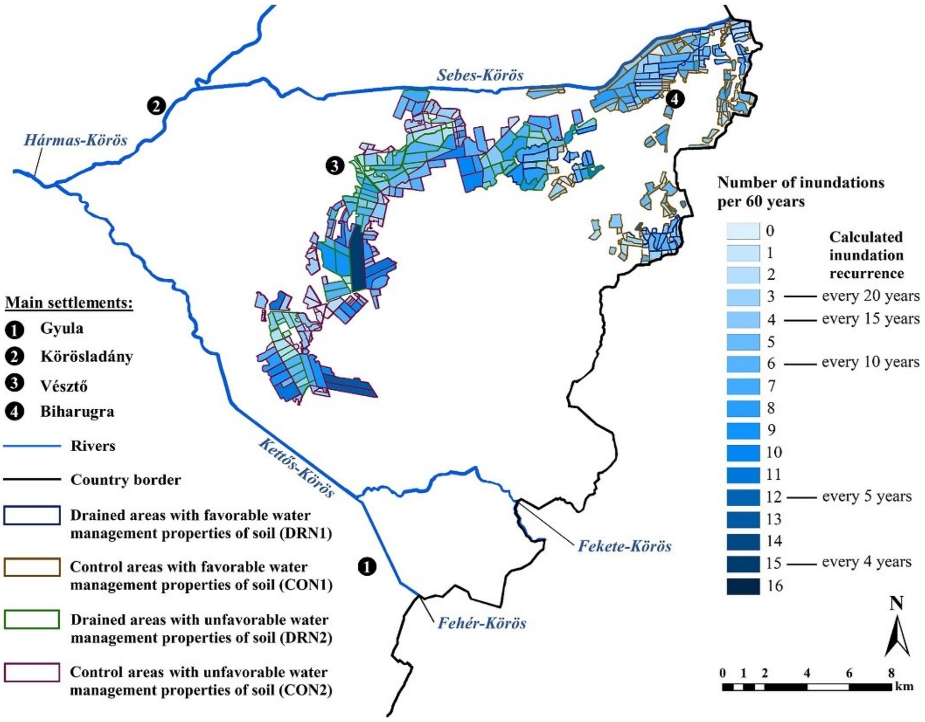


Figure 6
The total IEW inundation numbers on the arable blocks within 60 years

IEW hazard of the 1956–2016 (total) period

Figure 8 illustrates that in Group A, blocks in the control areas were less affected by IEW inundations than in drained areas. In the case of the areas of Group B, the IEW inundation averages of the DRN2 and CON2 were approaching each other, and even almost equal to the inundation average of the drained areas of Group A. Blocks in Group A were inundated up to 9 times during the examined period. In Group B, 10–15 inundations also occurred on some blocks within the 60 years. The proportion of areas not affected by IEW inundations was higher in CON1 areas than in DRN1 areas within Group A. For Group B, the proportion of areas not inundated by IEW was higher in the drained areas than in the control areas.

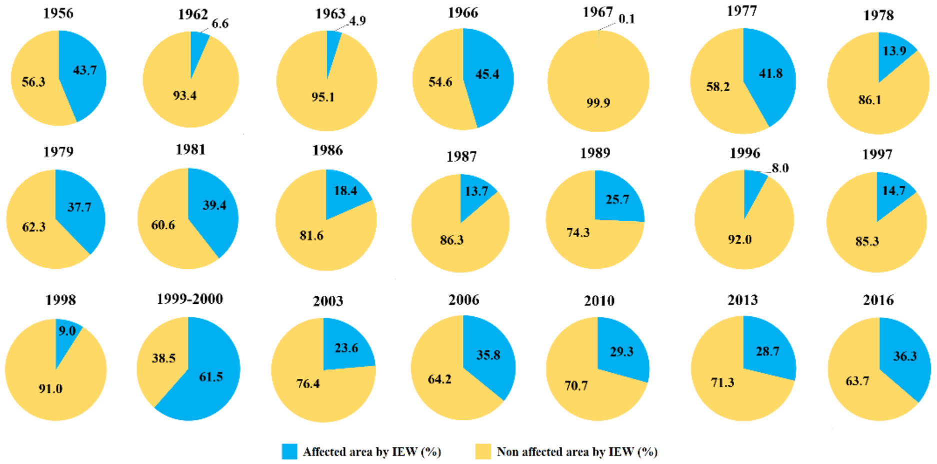


Figure 7
Percentage of the affected and non-affected areas by IEW inundations at the arable lands of the Körös Interfluve

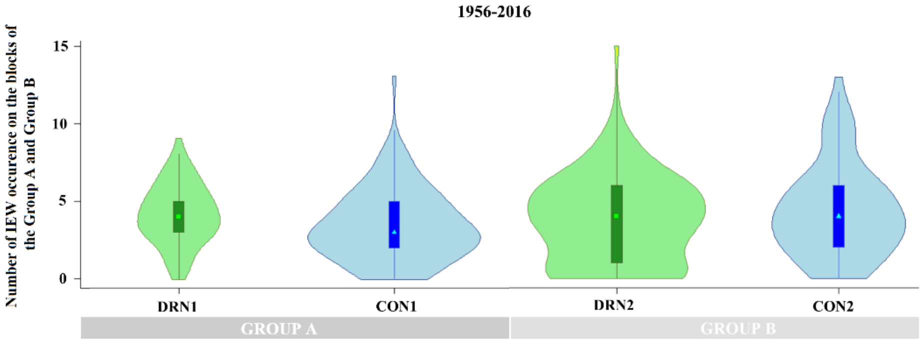


Figure 8
The number of IEW occurrences between 1956–2016 on arable blocks of the examined groups

IEW occurrence comparison of the time split 1965–1989 / 1990–2015

The number of the blocks affected by IEW inundations belonging to each group illustrates in *Figure 9*. The IEW inundation numbers of the Group A showed that after 1990, the exposure of the drained areas to IEW increased significantly compared to the previous period. Meanwhile, before 1990 the IEW exposure was the same in DRN1 and CON1 areas. After 1990 there were some fewer inundations in control areas than in the drained ones. In Group B, after 1990, the drained and control areas were equally affected by IEW inundations. Before 1990, Group B control areas were inundated twice as often as drained areas.

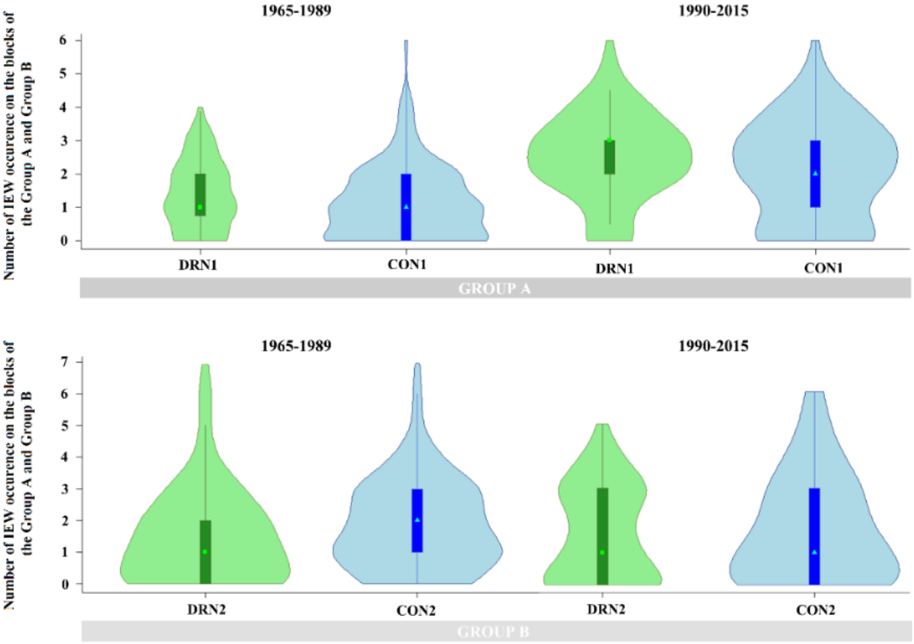


Figure 9
The number of IEW occurrences between 1965–1989 and 1990–2015 on arable blocks of the examined DRN1, CON1, DRN2 and CON2 areas

Inundation occurrence differences of the time split 1965–1989 / 1990–2015

In the periods before and after 1990, not only was the change in the averages within the Groups analysed, but also the extent to which the number of inundations in the blocks belonging to each Group changed in a positive or negative direction. In addition the blocks, where there was no change in the number of IEW inundations, were also examined (*Figure 10*). Our basic presumption was that IEW occurrence in drained areas would be reduced by functioning SD networks. Examining the change in IEW inundation occurrence in the DRN1 areas, it could be observed that in 17.5% of the areas there was no change in the number of inundations. At the CON1 area, blocks approached a similar value (16.7%). Examining the changes in IEW inundations in the DRN2 areas, it could be observed that the proportion of the areas where there was no change in the number of inundations was the same as in the DRN1 areas. Considering all the Groups, it could be determined that the potential for reducing the frequency of IEW inundations could be found in areas with poor soil water management properties.

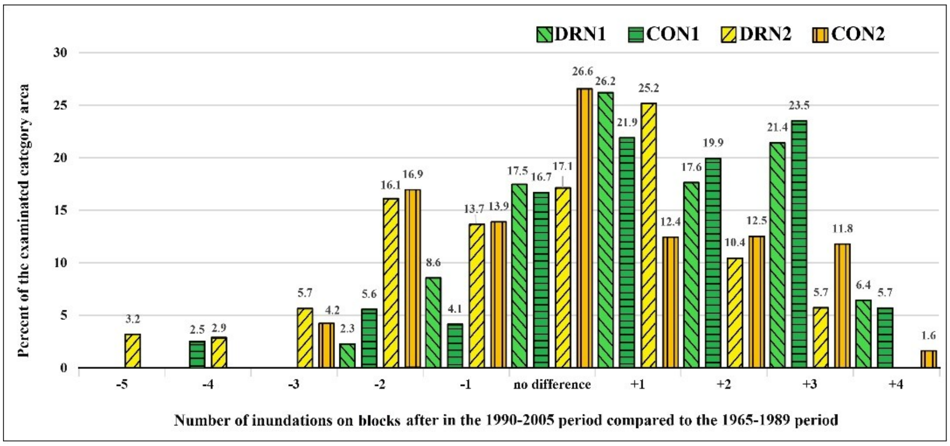


Figure 10
The change in the number of the inundations on blocks after 1990 compared to the percentage of the examined DRN1, DRN2, CON1, and CON2 areas

Group A in 10 years of periods

In ten-year splits, inundations occurrence in the drained areas (DRN1) compared to the control areas (CON1) were examined (*Table 2*). Our assumption that SD interventions resulted in less exposure of drained areas to IEW than in control areas was confirmed in two periods (1960–1969 and 1980–1989). Thus, even before the interventions, there might have been hydrological situations where the involvement of the later drained areas did not reach the level of the control areas. An interesting question about the reasons for the lower IEW exposure in the post-2010 period could be raised namely, in Group A areas an almost 8% positive difference was observed. For the studied periods, it could be determined that the examined blocks had a maximum of three inundations in all 10 years periods.

Group B in 10 years of periods

The 10-year survey of drained (DRN2) and control areas (CON2) with unfavourable soil water management properties was examined (*Table 3*). The exposure of the SD areas to IEW was lower in only three time periods than in the control areas: 1960–1969, 1980–1989 and 2010–2016. The period of 1960–1969 could not be connected to the drainage interventions in this case. In the 10-year periods studied, the IEW inundation appearance on the blocks was a maximum of three events, except for the period between 1980–1989, where four IEW inundation events also occurred on the blocks.

Table 2
The proportion of areas affected by IEW on DRN1 compared to the CON1 areas

Examined period	Proportion of areas affected by IEW compared to the control area	Inundation frequency on land parcels in 10 years	Percentage of the affected areas (DRN1)	Percentage of the affected areas (CON1)
1960–1969	↓ 6.5%	1	28.9	35.5
1970–1979	↑ 27.0%	1	49.1	20.9
		2	7.4	8.6
1980–1989	↓ 3.6%	1	40.2	47.3
		2	12.5	9.0
		3	1.3	1.2
1990–1999	↑ 6.8%	1	52.4	56.7
		2	30.7	11.5
		3	8.0	16.2
2000–2009	↑ 8.3%	1	48.8	54.4
		2	40.4	26.0
		3	0.0	0.5
2010–2016	↑ 7.9%	1	41.9	28.0
		2	15.0	20.5
		3	0.0	0.5

Table 3
Proportion of areas affected by IEW on DRN2 compared to the CON2 areas

Examined period	Proportion of areas affected by IEW compared to the control area	Inundation frequency on land parcels in 10 years	Percentage of the affected areas (DRN2)	Percentage of the affected areas (CON2)
1960–1969	↓ 1.6%	1	42.0	48.7
		2	8.5	3.3
1970–1979	↑ 8.2%	1	46.5	36.7
		2	23.3	19.2
		3	0.9	6.6
1980–1989	↓ 8.1%	1	30.5	44.6
		2	12.4	17.1
		3	6.8	4.6
		4	12.7	4.3
1990–1999	↑ 12.0%	1	50.3	30.1
		2	15.3	19.6
		3	2.4	6.3
2000–2009	↑ 1.3%	1	53.8	32.9
		2	20.7	31.7
		3	0.0	8.5
2010–2016	↓ 5.7%	1	53.8	32.9
		2	20.7	31.7
		3	0.0	8.5

Discussion

According to our results we found that IEW inundation events occurred 22 times of the investigated 60 years, affecting an average of 25% of the total area. The proportion of areas not affected by IEW inundations was higher in control areas than in drained areas. The number of IEW inundations on the drained and control areas with favourable soil water management showed that after 1990, the exposure of the drained areas to IEW increased significantly compared to the previous period. Meanwhile, before 1990, the IEW exposure was the similar in control and drained areas as well. After 1990 there were fewer inundations in control areas than in the drained ones. In the case of the drained and control areas with unfavourable soil water management, after 1990, the drained and control areas were equally affected by IEW inundations. Before 1990, control areas were inundated twice as often of drained areas. Concerning the drained areas regardless of soil properties, the IEW hazard was slightly higher (<1.4%) than in the control areas in both Groups examined, confirming the subsurface drainage interventions were eligible. According to our results, the long-term relative inundation frequency (RIF) was less than 2–4 years, as determined by MEZŐSI et al., (2014). The blocks inundated in every 4 years were only represented by 1.17% of the arable lands. In 60% of the study area, the relative inundation frequency was 10 years or more per 60 years. Drained areas with favourable soil water management had an average of 4.16 inundation events, meaning the occurrence frequency of IEW inundations was 15 years, and control areas have an average of 3.42 inundation events per 60 years, which means the occurrence frequency of IEW inundations was 17.5 years. Drained areas with unfavourable soil water management areas had average inundation events (3.75), i.e. the occurrence frequency of IEW inundations was 16 years. Control areas with unfavourable soil water management areas had an average of 4.38 inundations, suggesting the frequency was 13 years. A comparison of the period before and after 1990 showed that the efficiency of drains established in neither the areas of favourable nor unfavourable soil water management properties could be demonstrated. This was supported by the studies of DJUROVIĆ and STRIČEVIĆ (2004) that the neglect of tile-drained areas had eliminated the positive effect of drains on water management after only a few years. Nonetheless, based on the available IEW inundation data, it can be stated that inundation maps from previous ”in situ” recordings do not provide adequate information, as LABORCZI et al. (2020a) findings also confirmed. These databases can be refined with remote sensing data, as described by VAN LEEUWEN et al. (2020), although the availability of remotely sensed data for the period before the 1990s is quite questionable.

Conclusion

Subsurface drainage has not become a widespread practice in Hungary, but clarifying its future usability is an important task. Locations of the tile drained areas were mostly unidentified and no data was provided about their location, condition and functionality. The Körös Interfluve was a highlighted area for lowland amelioration interventions, intensively in the period of 1980–1990. 6.3% of the nationwide subsurface drained area is located here. For this reason, we hypothesized that the decrease of the high IEW inundation frequency was supported by the subsurface drainage interventions. From the point of view of our results, it is questionable which influential factors, local IEW inundations or other kinds of water–related damage events, or (perhaps) the direct financial support for the former agricultural collective farms could have justified the subsurface drainage interventions in the past. Furthermore, it is also questionable to what extent of design, and scaling schemes were applied during the design of subsurface drainage networks (e.g. the Dutch method), which may not have resulted an efficient subsurface water management in some areas with various soil properties. The currently available IEW inundation databases did not have sufficient accuracy for precise spatial analysis of IEW events that had appeared every few years. The question of the time accuracy of the surveys also arises, as only an open surface water estimated at the time of maximum IEW extent was recorded during an IEW event. There was no information about the changing of the extension of IEW inundations and the completely saturated soils. The effect of the subsurface drained areas on the IEW frequency has not been confirmed by our results. We hypothesized that the frequency of IEW in subsurface drained areas compared to control areas with similar water management characteristics of soils would be lower but this was identifiable in only a few periods.

It can also be stated that in the future, such studies can be significantly refined with:

- New IEW GIS databases are based on IEW recognition on satellite imagery (e.g. Sentinel 2) using automated machine learning methods. However, these kinds of database can only be used for a few years retrospectively, so building these kind of databases is very important for future studies,
- More accurate and nationwide cadastre of subsurface drained areas that includes the exact time and all technical attribute data of installation.
- Agrotechnical databases for the complex examination of the tile drained areas. The appearance of IEW in subsurface drained areas may reflect not only the poor condition of drain operations, but also inadequate agrotechnical operations. However, agrotechnical interventions can vary from year to year and data on them are rare.

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