

Risks of agricultural water management and opportunities to reduce them in V4 countries

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Summary

The food security with good and excellent nutrition quality and food safety with food quantity in the V4 countries is a strategic issue, where society is less tolerant of the risk that can be caused by a short-term disruption of supply chain. Climate change is leading to more extreme weather anomalies, with increasing frequency and intensive amplitudes of drought, floods and excess waters and serious agricultural damages. Agricultural water management problems overlap more national borders, so an agricultural geopolitical risk assessment is justified that would allow for a more coherent cross-border integrated territorial water management decision-making process. In this study, the authors review climatic, hydrological, and crop production risks based on the major river basins in the V4 countries.

Keywords: agriculture, climate change, water management, Central-Europe

Mezőgazdasági vízgazdálkodás kockázatai és azok csökkentési lehetőségei a V4-ek országaiban

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Összefoglalás

A V4-ek országaiban a megfelelő mennyiségű és minőségű élelmiszer folyamatos biztosítása stratégiai kérdés, amelynek rövid idejű zavara is jelentős kockázatokat és társadalmi feszültségeket okozhat. A klímaváltozás egyre szélsőségesebb időjárási anomáliák előfordulásával jár, aminek következtében nő az aszály, árvíz és a belvizek mezőgazdasági kártétele. A mezőgazdasági termelés az egyik legnagyobb vízfelhasználó gazdasági tevékenység a világon, így annak térben és időben történő optimalizálása a klímaadaptáció kulcsterülete. A mezőgazdasági vízgazdálkodási problémák túlnyúlnak az országok határain, így indokolt egy olyan mezőgazdasági geopolitikai értékelése a kockázatoknak, amely lehetővé tenné egy egységesebb határokon átnyúló integrált területi vízgazdálkodási döntéshozatal megalapozottságát. A publikációban a szerzők áttekintik a V4 országainak főbb vízgyűjtői alapján a klimatikus, hidrológiai és természetvédelmi kockázatokat.

Az öntözési lehetőség és a tényleges öntözés kulcsszerepet játszik a termés mennyiségének és minőségének stabilitásában. A fokozott vízigényű időszakokban fellépő aszály rontja a terméshozamot, mind mennyiségi, mind minőségi szempontból. A termésbiztonság érdekében feltételeken öntözhető északi területeken 4-5 évente (Lengyelország), a V4 országok dél-magyarországi területein 2-3 évente szükséges öntözni. Ennek hiányában akár 50-70%-os termés kieséssel is számolhatunk.

Mivel a V4-ek messze elmaradnak Nyugat-Európa és a mediterrán térség öntözési kapacitásától, így ha a jövőben az öntözési lehetőség nem bővül a V4 országokban, a társadalomnak egyre inkább az öntözés nélküli termesztés

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veszélyével kell szembenéznie. Ugyanakkor különösen a gyümölcs- és zöldségtermesztés megköveteli az öntözhetőséget. A legelőterületek és a tömegtakarmányok lehetséges csökkenő mennyisége és minősége súlyosan befolyásolhatja az állati termékek árát, különösen a vízigényes marha- és sertéshús, valamint a tejtermékek esetében.

Az emelkedő fogyasztói árak azonban egyre kevésbé megfizethetőek a társadalom szegényebb része számára. A felszíni víztározásban és a vízgazdálkodásban nagy lehetőségek rejlenek, amelyeknek a rendelkezésre álló pénzügyi források szabnak határt. A felszíni víztestek minősége gyakran nem felel meg az öntözővíz minőségi követelményeknek, így egyre nagyobb a nyomás a felszín alatti vízbázisokra, ami veszélyezteti az ivóvíz minőségét. A közeljövőben ezért fokozni kell a kapacitásépítést és a rendelkezésre álló jó gyakorlatok megosztását a határokon átnyúló fenntartó területi vízgazdálkodás szereplői között.

Kulcsszavak: mezőgazdaság, klímaváltozás, vízgazdálkodás, Közép-Európa

Introduction

The Visegrád Group, Visegrád Four, V4, is a cultural and political alliance of four countries of Central Europe (Czech Republic, Hungary, Poland and Slovakia), all of which are members of the EU, to advance co-operation in military, cultural, economic and energy matters. A number of joint projects are currently being implemented particularly in the fields of culture, environment, internal security, defence, science and education.

All countries' leaderships declared on more common political meetings that they should explore the good opportunities for co-operation in the field of environmental protection and risks: questions related to boundary waters and flood prevention. However, relatively less attention was paid to special agricultural discipline, i.e., agricultural food–water nexus. There are a number of reasons for this, that we do not wish to detail in this framework, but we would like to highlight a few of them. Water resources are in a common hydrological cycle, but water user interests are often in conflict in space and time, because the limited water supply is intended to be used for more than one purpose at a same time interval. Water decision-makers are not always able to find the right compromises, especially for transboundary water resources. A well-known example is the case of the Bős-Nagymaros hydrological power plant (*Balon–Holčik 1999*). The irrigation and melioration tasks of water authorities gradually declined over the last decades, partly due to change of land ownership structure in the Visegrád Group countries. The roles, responsibilities and human resources of water authorities partly transformed and strengthened (*Marszelewski–Piasecki 2020*) the catastrophe treatment mainly in flood management and the other part, the agricultural water extension service is less effective.

These problems affect V4 countries differently depending on their hydrological, climatic, and economic social situations. At the same time, the intensifying climate crisis in the recent period requires closer cooperation, coordination and action from the participants in solving the tasks of territorial water management.

Material and Methods

Agriculture is a large global consumer of water (*Siebert et al. 2013*). Most agricultural water management studies focus on agricultural parcel, block or part of a farm from an agronomic point of view, although from a hydrological point of view these fields are affected by both surface run-off and run-out, subsurface groundwater flow movements and evapotranspired water falling out of the farm border. It is therefore important also to evaluate agricultural activity by the complex way on a wider mezzo and macro catchment scale.

In the V4 countries, hydrological web-based map servers conforming to the inspire meta data standard have been established in accordance with the requirements of the European Water Framework Directive, which helps support spatial decision-making for the integrated management of shared river basins. To do this effectively, we need an open structured hydro database and national/international River Based Management Plan (RBMPs) tool to manage it. Fortunately, this has now been achieved in the V4 countries, although primarily for flood and drought risk management purposes. Hydroportal is a public portal on the broadly understood water issues in Poland (ISOK). It allows users to review data on the risk of flooding, preventing drought or presenting water management plans. It contains a series of data gathered in one place, regarding rivers or watersheds. The relevant international plans are available for the Danube (*ICPDR 2021*), the Elbe (*IKE 2021*), and the Oder (*ORBMP 2021*).

Hydrology and water resources of V4 countries

In V4 countries the water resources are very variable, both temporally and spatially, which results from the temporally and spatially variable distribution of atmospheric precipitation, whose course is random. The river network of Poland drains 99.7% of the region located within the Baltic Sea catchment basin with two rivers, where the Vistula catchment is 54% and the Oder 33.9% of Poland's surface. Polish rivers most commonly rise

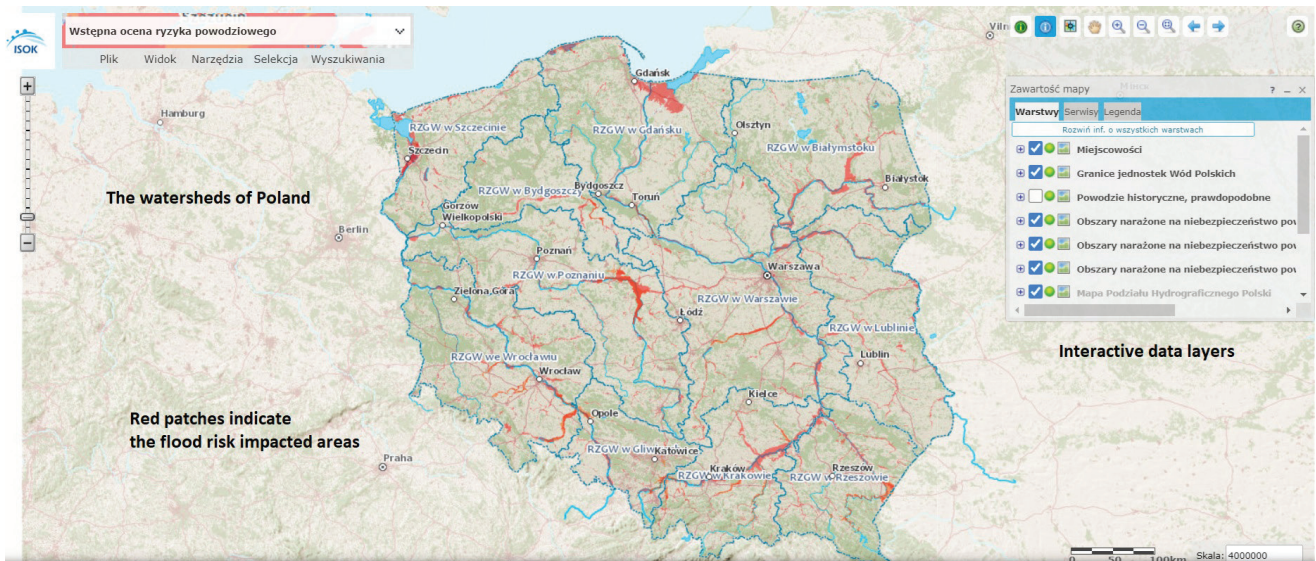


Figure 1 | HydroMap portal of Poland
Source: Informatyczny System Osłony Kraju – ISOK (2021)

from sources located in the mountainous Carpathians and Sudeten. The natural topography of Poland is dominated by lowland, which covers 91.3% of the country’s area and hills 5% in the south (Andrzejewski–Krzemień 2017). The average annual total outflow from Poland in the years 1951–2015 was about 61 km³, ranging from 37.5 km³ in 1954 to 89.9 km³ in 1981. The average unit outflow from the years 1951–2015 was 5.4 dm³/s·km² in the Vistula basin, and 4.7 dm³/s·km² in the Oder basin. The real time hydrostatistical data source available in HydroMap portal (Figure 1).

The Czech Hydrometeorological Institute is a national agency responsible for water monitoring in the Czech Republic. The operation of the monitoring networks, data collection and their primary processing and storage in databases comprise basic activities of the hydrological service. The territory of the Czech Republic lies in three international river basin districts (RBDs): the Danube River basin, the Elbe River basin and the Oder River basin. The share of the CZ republic in the respective RBDs are 2.7% (the Danube), 33.7% (the Elbe) and 5.9% (the Oder). The River Danube, which is the sec-

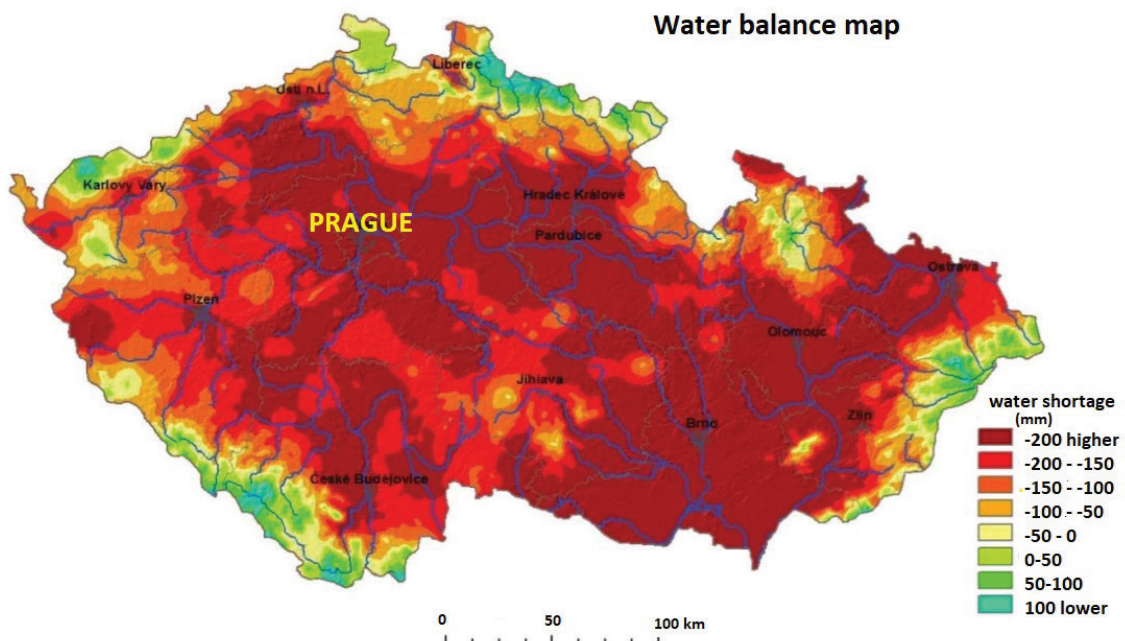


Figure 2 | Evapotranspiration balance (precipitation-evapotranspiration) from March 1st to August 16th in 2015
Source: Český Hydrometeorologický Ústav. <https://www.chmi.cz/informace-pro-vas/rocní-vyhodnocení/hydrologické-rocníky> [accessed: 2021. 10. 05.]

ond-longest river in Europe crosses through the Carpathian Basin, joined by one of its major tributaries, the River Tisza in the Pannonian plain. The waterways fed massive flood plain, excess water and drought 3-4 times per decade in Hungarian Great Plain.

Climate of V4 countries

Global temperature increases are accompanied by changes in other climatic variables. Climate change in Poland manifests itself also as a change in annual sums of precipitation. They have been slightly growing but, what is more important, seasonal and monthly distributions of precipitation have been also changing. The most visible increases have been observed during the colder half-year, especially in March. A decreasing contribution of summer precipitation total (June–August) to the annual total is observed (Szweđ 2019). Similar drought situations more frequently were observed in Czech’s main watersheds (SIVS 2021) (Figure 2).

In agro-hydrological practice, the V4 countries, similarly to European (EDO) and USA web service (NIDIS 2021), have started to introduce drought indices using similar new satellite (Landsat 8, Sentinel, Modis) data (Nagy et al. 2021), allowing for an accurate comparison of different meteorological, hydrological and agricultural drought events. A new initiative of the Hungarian Water Authorities (OVF) is the introduction of the Hungarian Drought Index, which enables the integrated

assessment of meteorological and soil available water content in root zone based on Hungarian drought monitoring system (HDM). The disadvantage is that other countries do not apply it yet. The Palfai Drought Index (PaDI) expresses the strength of drought for an agricultural year, the results are in correspondence with Palmer Drought Series Index for medium-term forecast of drought and for the assessment of the possible plant water stress scenarios regarding drought (Figure 3).

In Slovakia, a significant increase of air temperature of 1.4°C in 1951–2009 and 1.7°C in 1881–2009 was also recorded. The mean precipitation has remained relatively unchanged in 1881–2009. Contrastingly, the mean relative air humidity decreased in 1901–2009 by about 6% in southern Slovakia and less in higher altitudes. Changes in solar radiation balance variables were insignificant in the period 1951–2009 (Kindler–Thalmeinerova 2012).

Land use

Agriculture needs large amounts of clean water to satisfy the increasing demand for high quality food. However, intensive agriculture may cause quality and quantity problems of surface- and groundwater by pollution, over-abstraction and inappropriate land management endangering the status of the water bodies but also the sustainability of its own water resources (ICPDR 2021). Nutrient pollution has been identified as one of the sig-

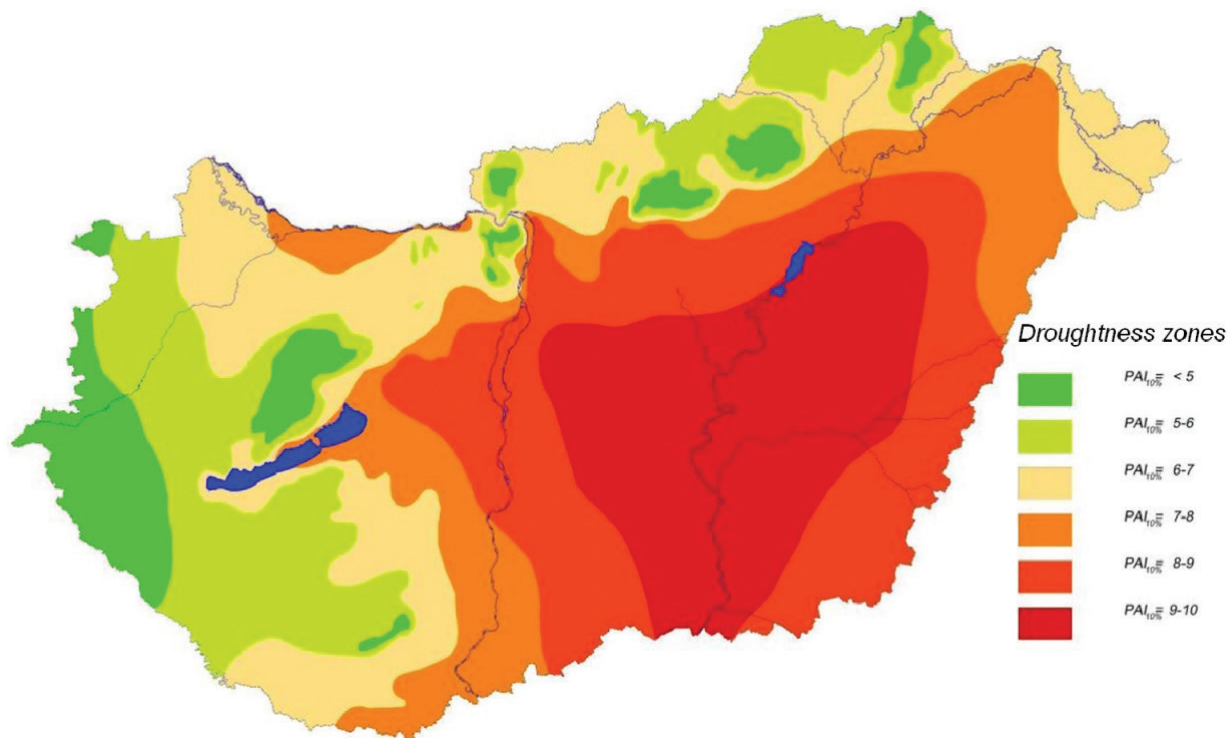


Figure 3 | The map of droughtness of Hungary, based on 10% probability of occurrence of Hungarian Palfai drought index (red color indicates more serious drought)

Source: Palfai (2004)

nificant water management issues in the Danube River Basin. Currently, about 20% of the surface water bodies are at risk of failing good ecological status/potential by 2021 due to nutrient pollution, for which agriculture is one of the main sources alongside other sources such as urban areas or municipal wastewater (ICPDR IKSD 2021). Information on spatial distribution of irrigated fields is highly relevant for regional water management and food security. Spatial information on irrigation is highly important for policy and decision makers, who are facing the transition towards more efficient sustainable agriculture. However, the mapping of irrigated areas still represents a challenge for land use classifications, and existing global data sets differ strongly in their results.

In Czech Republic the arable land, other agricultural land and forests cover approximately 39%, 15% and 33% of the country area, respectively. The main crops are maize, sugar beet, potatoes, wheat, barley and rye on the watersheds. Agriculture is an important component of the economy in many Danube countries, such as Slovakia and Hungary from V4 countries, since the geographical and climatic conditions in large parts of the Danube River Basin (DRB) are favourable for agriculture and more than 50% of the Danube River Basin territory are under agricultural cultivation (in Hungary 71%). In Poland, the country's dominant land cover categories are agricultural areas (62.7% of the country), of which the largest are arable lands (44.5% of the country) (European Environmental Agency 2015).

Results

The occurrence of drought in the period of intensified water requirements deteriorates yielding, in terms of both quantity and quality. Drought risk analysis contributes significantly to the planning and management of water resources in a given region. However, as with many other natural hazards, drought has a characteristic multivariate character, i.e., it is characterized by the correlated contemporary presence of several characteristics. In this situation, traditional univariate risk analysis based on the distribution of frequency (or probability) of individual characteristics can lead to misleading, inappropriate, or incomplete interpretations of the phenomenon (Nagy 2021). The European Drought Observatory's website (EDO 2021) provides a wealth of important information on the emerging and changing drought situation in Europe, thus also in the V4 countries. There are national drought monitoring systems in V4 countries. For instance, in Hungary besides the National Weather Service, the General Directorate of Water Management has an Operational drought and water scarcity management system. The task of drought monitoring is within the State Hydrological and Meteorological Services in Poland, and the Slovak Hydrometeorological Institute (SHMI) is the main institution to monitor meteorologi-

cal and hydrological data (Kindler–Thalmeinerova 2012). There are also methods for agricultural monitoring in riverbasin scale, applicable in the Central Eastern European region (Nagy et al. 2014; Tamás–Nagy–Fehér 2015).

The factors speeding up the development of irrigation, next to ensuring higher and stable good quality yields, include a need of enhanced modernization and competitiveness of agricultural farms and forecast climate changes in Poland (Łabędzki 2009; Rzekanowski et al. 2011).

According to Łabędzki (2007), the economic conditions of Polish agriculture irrigation is often an unprofitable measure. The existing irrigation systems and facilities are only used to a small extent. In many cases the factor preventing the use of irrigation systems is the lack of water of required quality and its availability. It is one of the main limitations in the development of irrigation in Poland, besides unfavourable economic conditions.

One way to reduce excesses and deficits of water may be to undertake small-retention reservoir projects within agricultural catchments and in urban areas (GWP 2015; EU 2014; Mioduszczyński–Querner–Kowalewski 2014). Lasy Państwowe (State Forest Holding) in mountainous and lowland areas has implemented such works in Poland as part of a small-retention programme. Climate projections for Poland predict further warming and continuation of already observed changes in the quantity of precipitation as well as its spatial and seasonal distribution.

Therefore, irrigation is mainly applied in regularly or periodically arid climatic zones, because it is in these areas where food production would not be possible without an additional water supply. It is different in Poland, placed in the moderate climatic zone, where irrigation of plants is a contingency procedure applicable to supplement the periodic shortages of rainfall in relation to the water requirements of plants. It applies particularly to sandy soils with reduced water retention capacity, situated in the central, lowland part of the country. Droughts in Poland are weather phenomena unfavourable for agricultural production, appearing quite often but irregularly. On the other hand, conditions of fully or excessively moisturized soils during growing seasons occur with a similar frequency to droughts. For this reason, the irrigated area in Poland covers only about 73 thousand hectares. The main indicators of the advisability of applying irrigation and considering its role in domestic agriculture and water management are production effects, i.e., the absolute yield increase obtained under the influence of this treatment in agricultural raw materials production. Irrigation is the most economically effective treatment in horticultural crop production, including orchards, vegetables, and berry plants. In the case of agricultural plants, the indicators of profitability are much fewer – the only positive financial effect may be obtained

in the case of table potato production (*Kúsmierek-Tomaszewska-Żarski 2021*).

Irrigation efficiency reflects the state of irrigation technology within a country. Irrigation field efficiency and irrigation project efficiency have to be differentiated. Irrigation project efficiency (EF_{proj}) is more applicable compared to irrigation field efficiency as it additionally considers conveyance losses, field sizes and management practices, while irrigation field efficiency mainly results from the irrigation practice (e.g. surface, sprinkler, micro irrigation). EF_{proj} typically ranges between 0.3 and 0.8 whereas 0.8 means that 80% of water delivered to the crop is actually absorbed by it. In Hungary the irrigation efficiency depends on irrigation technology, where surface irrigation methods show 25–35%; sprinkler irrigation 75–80%; and drip irrigation 85–95%. These numbers also emphasize that the change in technology has significant reserves in terms of water and energy savings.

In irrigation technology, one of the most important but measurable parameters with the greatest uncertainty, is the crop water requirement (Kc) factor. Therefore, instead of real measurements, it is recommended to use proxy estimates, which can show a 2-5X times deviation from the actual value, so under/over-irrigation probability is common. Therefore, it is important to measure validated Kc values for a given plant species that reduce potential water loss (*Varga-Haszonits 1977*). The values

of potato Kc determined for the Grabarczyk model were higher than those calculated for the Hargreaves formula modified by Droogers and Allen in Poland (*Treder-Wójcik-Żarski 2010*). The knowledge of the evapotranspiration (ET) of irrigated field is of fundamental importance in practical irrigation scheduling. *Rácz-Nagy-Dobos (2013)* reported descriptive statistical and sensitivity analysis of 10 commonly used ET estimation models based on Hungarian Great Plain datasource. As regards the systematic error, Makkink and Shuttleworth-Wallace showed the best agreement with pan evaporation, while Shuttleworth-Wallace, Blaney-Criddle and Makkink models were found to be the closest to the world wide used reference value of Penman-Monteith-FAO-56 method.

Zarski et al. (2017) demonstrated in drip irrigated corn study in Bydgoszcz, central part of Poland, that irrigation led to a significant 51% increase in yields and their stability in the years. Due to that practice, the coefficient of variation of the yield decreased from 89 to 12%. The production effects of drip irrigation depended significantly on moisture conditions over the period of high water needs of corn from June to July. In wet seasons the increases in grain yields due to irrigation were non-significant and about four fold lower, while in the dry periods more than half higher than the average increases. In the presented model, decision risk for fore-

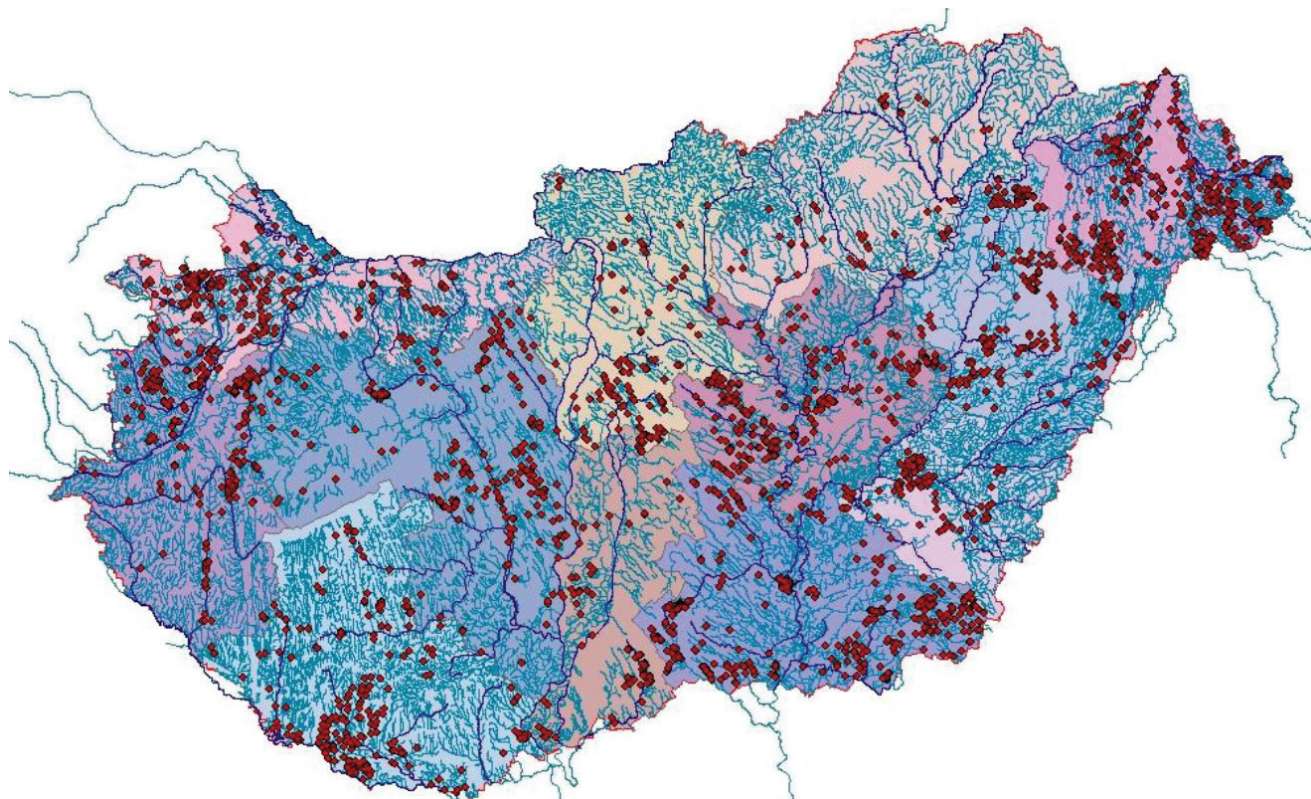


Figure 4 | Location of farms in Hungary without water rights permit and indicated that they would irrigate, but there are no available water resources

Source: National Irrigation Survey, 2014; National Water Authority, Hungary. http://vpf.vizugy.hu/reg/ovf/doc/1.10_ontozesi%20igienyek%20meghatarozasanak%20allasa.pdf [accessed: 2021. 10. 01.]

casting corn production and its economic effects as well as for planning the development of irrigation systems in a given area is effectively reduced.

In Hungary, under a new irrigation program, one ambitious goal is to increase 2–2.5 times the current 100–120 thousand ha of irrigated area. One limitation is the distance of surface waters (rivers, canals) often exceeding 10–20 km, which requires very significant earthwork (Figure 4).

At the same time, they help growers purchase water and energy-efficient irrigation equipment (linear/central pivot, microirrigation) and create irrigation communities to reduce maintenance and energy costs. The evaporation and leakage losses in open channels are reduced by surface insulation or the use of closed piping network. Agricultural governance aims to enhance cooperation among farmers with clearing land property structure by the establishment of ‘irrigation communities’, administered under the National Land Centre growing trust building among farmers and their cooperatives to reduce hectic changes of product market. Precision agriculture also plays flagship role in tailor-made irrigation management.

A separate problem related to the use of alternative water resources is the level of water intake and consumption by various sectors of the national economy. The reduction of water consumption can be achieved in various

ways. One of the simplest, but also the most severe for all users, is to increase the price of water.

Nowadays, technical solutions using rainwater in single-family houses are becoming increasingly popular in Poland. This water is most often used for watering gardens.

Especially in lowlands, a significant amount of inland excess water may concentrate more than once in a year directly hindering agricultural activities and harming crop vegetation, which is unfavourable. Though inland excess water is usually the subject of drainage by many practices to reduce damages. On the other hand, the water drained from fields is often missing in summer. Therefore the excess water should be collected and used in crop production as an alternative water source in drought-affected summer period (Lilienfeld–Asmild 2007). For instance, in Hungary, Nyírség region is poor in surface water bodies and underground water bodies for irrigation, therefore excess water, treated waste water and fermentation sludge is used for irrigation (Figure 5).

There are certain areas and, more importantly, drought-affected periods of the year, when a sufficient amount of water is not available neither from rainwater harvesting nor excess water reservoirs for agriculture (Mateo-Sagasta et al. 2013; Gatto D’Andrea et al. 2015). Therefore, the benefits of using recycled water with the food industry, or treated wastewater origin, are worth emphasizing, considering their potential contaminant or

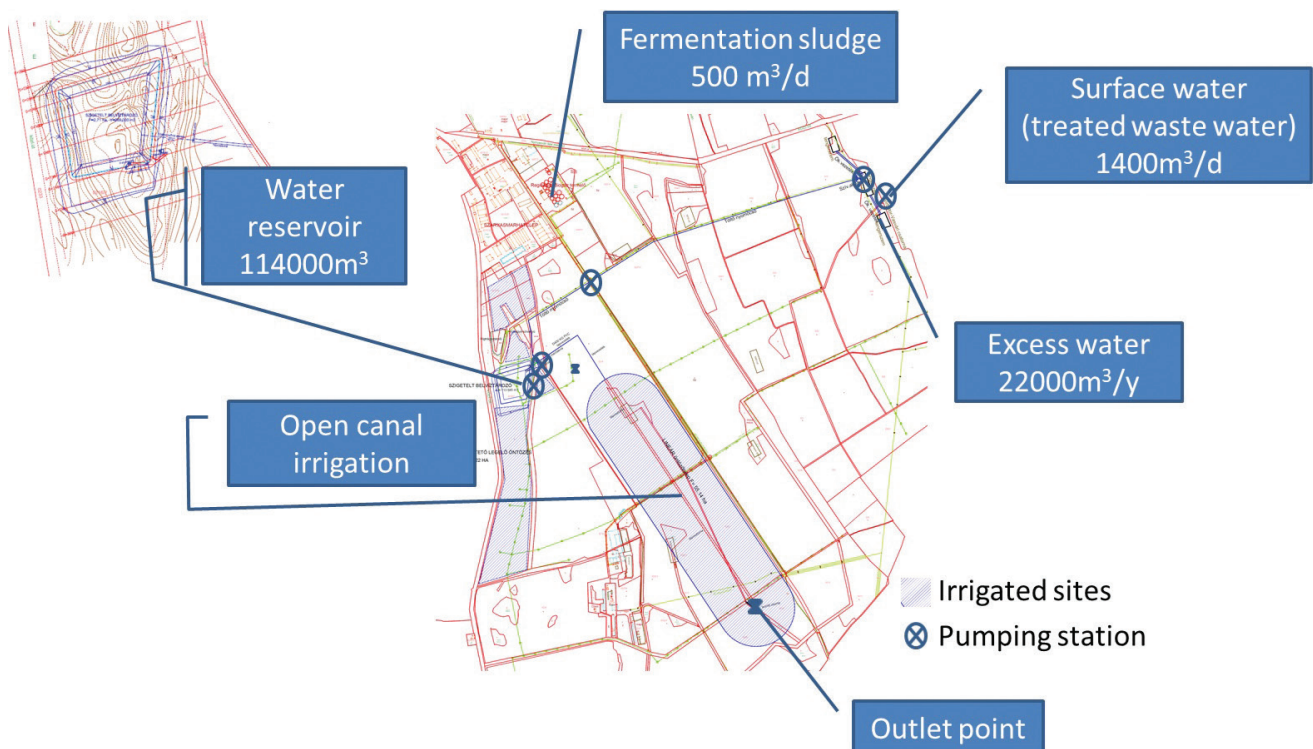


Figure 5 | Alternative water resource management at the case study site
Source: Nagy (2021)

high salt contents (*Levy-Fine-Bar-Tal 2011*). Moreover, reclaimed water is utilized in agriculture for irrigation, the nutrient content of the treated wastewater can act as fertilizer. European and national standards must be taken into consideration in each case (*WHO 2006*). However, the salt content of alternative water sources, and the high cost level of treatment are often the barrier to irrigation utilization. The most practical solution is to invest in the most modern water recovery and reuse technology in industrial plants, agriculture, and newly built residential buildings, but there is little interest in the construction of purification and reuse systems for previously used water (“grey water”), mainly due to high installation costs. Grey water recycling or rainwater management not only significantly reduce operating costs, but also have tangible environmental benefits.

Conclusions

Technically irrigation possibility and real irrigation play a key role in the stability of crop quantity and quality. In the northern regions to be conditionally irrigated, it is necessary to irrigate every 4–5 years (Poland), and every 2–3 years in the areas of southern Hungary in the V4 countries. In the absence of this, we can expect a yield loss of up to 50–70%.

As the V4s are far behind their irrigation capacity in Western Europe and the Mediterranean region, the society faces an increasing risk of non-irrigated cultivation in the future. Growing fruit and vegetable crops in particular is risky. The decreasing quantity and quality of pasture crops is seriously affecting the prices of animal products, especially for water-intensive beef and pork and dairy products.

The rising consumer prices, though, are becoming less and less affordable for the poorer part of society. There are great opportunities in surface water storage and water governance, which are limited by the available financial resources. The quality of surface water bodies often does not fit the requirement of irrigation water quality, so there is increasing pressure on groundwater aquifers, which endangers the quality of drinking water. In the near future, therefore, it will be necessary to increase the capacity building and knowledge sharing of good available practice among actors in cross border sustainable territorial water management.

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References

- Andrzejewski, M., & Krzemień, K. (2017) Doliny i koryta rzek. In: J. Jokiel, et al. (eds) *Hydrologia Polski*. Wydawnictwo Naukowe PWN, Warsaw pp. 121–127.
- Balon, E. K., & Holčík, J. (1999) Gabčikovo River Barrage System: The Ecological Disaster and Economic Calamity for the Inland Delta of the Middle Danube. *Environmental Biology of Fishes* 54, pp. 1–17. DOI: <https://doi.org/10.1023/A:1007576103855>
- European Drought Observatory (EDO) (2021) <https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000> [Downloaded: 2021. 10. 01.]
- European Environmental Agency (2015) <https://www.eea.europa.eu/soer/2010/countries/pl/land-use-state-and-impacts-poland> [Downloaded: 14.08.2021]
- Gatto D'Andrea, M. L., Salas Barboza, A. G. J., Garcés, V., Rodríguez-Alvarez, M. S., Iribarnegaray, M. A., Liberal, V. I., ... Seghezze, L. (2015) The use of (treated) domestic wastewater for irrigation: current situation and future challenges. *International Journal of Water and Wastewater Treatment*, Vol. 1. No. 2. DOI: <http://dx.doi.org/10.16966/2381-5299.107>
- Guidance Document on Sustainable Agriculture in the Danube River Basin (ICPDR IKSD) (2021) Publ. ICPDR IKSD <https://www.icpdr.org/flowpaper/app/#page=1> [Downloaded: 2021. 10. 01.]
- ICPDR, (2021): Policy Paper on sustainable Agriculture in the Danube River Basin. ICPDR – International Commission for the Protection of the Danube River. 42.
- Informatyczny System Ośłony Kraju (2021) <https://isok.gov.pl/hydroportal.html> [Downloaded: 14.08.2021]
- Internationale Kommission zum Schutz der Elbe (IKE) (2021) <https://www.ikse-mkol.org/> [Download: 14.08.2021]
- Kindler, J., & Thalmeinerova, D. (2012) Inception Report for the GWP CEE Part of the WMO/GWP Integrated Drought Management Programme. Global Water Partnership Central and Eastern Europe, 83.
- Kuśmierk-Tomaszewska, R., & Źarski, J. (2021) The Effects of Plant Irrigation in Poland. In: M. Zeleňáková, K. Kubiak-Wójcicka & A. M. Negm (eds) *Management of Water Resources in Poland*. Springer Water. Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-61965-7_19
- Łabędzki, L. (2007) Irrigation in Poland – current status after reforms in agriculture and future development. *Journal of Water and Land Development*, No. 11. pp. 3–16. DOI: <https://doi.org/10.2478/v10025-008-0001-6>
- Łabędzki, L. (2009) Przewidywane zmiany klimatyczne a rozwój nawodnień w Polsce. *Infrastruktura i Ekologia Terenów Wiejskich*, Vol. 3. pp. 7–18.
- Levy, G. J., Fine, P., & Bar-Tal, A. (2011) *Treated Wastewater in Agriculture. Use and Impacts on the Soil Environment and Crops*. Blackwell Publishing.
- Lilienfeld, A., & Asmild, M. (2007) Estimation of excess water use in irrigated agriculture: a data envelopment analysis approach. *Agricultural Water Management*, Vol. 94. Nos 1–3. pp. 73–82.
- Marszelewski, W., & Piasecki, A. (2020) Changes in Water and Sewage Management After Communism: Example of the Oder River Basin (Central Europe). *Scientific Reports*, Vol. 10. 6456. DOI: <https://doi.org/10.1038/s41598-020-62957-1>
- Mateo-Sagasta, J., Medlicott, K., Qadir, M., Raschid-Sally, L., Drechsel, P., & Liebe, J. (2013) Proceedings of the UN-Water Project on the Safe Use of Wastewater in Agriculture.
- Mioduszewski, W., Querner, E., & Kowalewski, Z. (2014) Analysis of the impact of small water retention on water resources in the catchment. *Journal of Water and Land Development*, Vol. 22. pp. 67–78.

- Nagy A. (ed 2021) *Advanced Technologies of Precision Irrigation*. University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management, Debrecen, Publ. University of Debrecen. 106. p.
- Nagy A., Riczu P., Gálya B., & Tamás J. (2014) Spectral estimation of soil water content in visible and near infra-red range. *Eurasian Journal of Soil Science*, Vol. 3. No. 3. pp. 163–171.
- Nagy A., Szabó A., Adeniyi, O. D., & Tamás J. (2021) Wheat Yield Forecasting for the Tisza River Catchment Using Landsat 8 NDVI and SAVI Time Series and Reported Crop Statistics. *Agronomy*, Vol. 11. No. 4. p. 652. DOI: <https://doi.org/10.3390/agronomy11040652>
- National Integrated Drought Information System (NIDIS) (2021) drought.gov [Downloaded: 2021. 10. 01.]
- Oder River Basin Management Plan (ORBMP) (2021) <https://www.mkoo.eu/> [Downloaded: 14.08.2021]
- Pálfai I. (2004) *Belvizek és aszályok Magyarországon. Hidrológiai Tanulmányok. Közlekedési Dokumentációs Kft. Budapest, 492. old. + 2. melléklet.*
- Rácz Cs., Nagy J., & Dobos A. (2013) Comparison of several methods for calculation of reference evapotranspiration. *Acta Silvatica et Lignaria Hungarica*, Vol. 9. pp. 9–24. DOI: <https://doi.org/10.2478/aslh-2013-0001>
- Rzekanowski, C., Żarski, J., & Rolbiecki S. (2011) Potrzeby, efekty i perspektywy nawadniania roślin na obszarach szczególnie deficytowych w wodę. *Postępy Nauk Rolniczych*, No. 1. pp. 51–63.
- Siebert, S., Henrich, V., Frenken, K., & Burke, J. (2013) Update of the Global Map of Irrigation Areas to version 5. Project report, pp. 178.
- Systém integrované výstražné služby (SIVS) a související výstupy ČHMÚ (2021) <https://www.chmi.cz/files/portal/docs/meteo/om/sivs/sivs.html> [Downloaded: 2021. 10. 01.]
- Szwed, M. (2019) Variability of precipitation in Poland under climate change. *Theoretical and Applied Climatology*, Vol. 135. pp. 1003–1015. DOI: <https://doi.org/10.1007/s00704-018-2408-6> [Downloaded: 14. 08. 2021]
- Tamás J., Nagy A., & Fehér, J. (2015) Agricultural biomass monitoring on watersheds based on remote sensed data. *Water Science and Technology*, Vol. 72. No. 12. pp. 2212–2220. <https://doi.org/10.2166/wst.2015.423>
- The International Commission for the Protection of the Danube River (ICPDR) (2021) <https://www.icpdr.org/main/icpdr/about-us> [Downloaded: 14.08.2021]
- Treder, W., Wójcik K., & Żarski, J. (2010) Preliminary assessment of the possibility of estimating water requirements of plants on the basis of simple meteorological measurements. *Zeszyty Naukowe Instytutu Sadownictwa i Kwiaciarnictwa w Skierniewicach*, Vol. 18. pp. 143–153.
- Varga-Haszonits Z. (1977) *Agrometeorologia. Mezőgazdasági Kiadó, Budapest.*
- Visegrad Group <https://www.visegradgroup.eu/cooperation/contents-of-visegrad-110412> [Download: 14.08.2021]
- Visegrádi Négyek Wikipedia https://en.wikipedia.org/wiki/Visegr%C3%A1d_Group [Downloaded: 14.08.2021]
- WHO (2006) WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater - Volume IV: Excreta and Greywater Use in Agriculture. World Health Organization (WHO), Geneva, Switzerland.
- Zarski, J., Dudek, S., Kusmierek-Tomaszewska, R. (2017) Drip irrigation as a factor mitigating drought impact in corn cultivation in central Poland. In: Raupeliene (ed), *Proceedings of the 8th International Scientific Conference Rural Development 2017*, 182–186. DOI: 10.15544/RD.2017.167

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