Perspectives of integrated climate change and water policies in Hungary

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Abstract
The paper aims to outline the climate impacts induced and transferred by water and the socio-economic factors that exacerbate them. It also seeks to provide a common and integrated policy framework for climate change adaptation and water management. The climatic and non-climate drivers, the risk chains and options for policy integration are assessed in four complex thematic areas: (i) ecosystem services, (ii) food supply chain: agriculture, food processing industry, food safety; (iii) industrial and service activities, energy and water supply, infrastructure, built environment, and (iv) human health and well-being, social justice. In these complex thematic areas, we examine the risk cascade chain, the current state of impacts and expected future challenges within a coherent framework and then make concrete proposals for possible specific areas of policy integration. Finally, in the conclusions, we present municipal-level good practices in water-resilient climate adaptation and formulate the horizontal actions needed to implement integrated climate-water policy.

Keywords
Water-related climate adaptation, integrated climate and water policies, climatic and non-climate drivers, risk chain, strategic integration of water to sectoral policies.

Az integrált klímaváltozás- és vízpolitika perspektívái Magyarországon

Kivonat
A tanulmány célja az, hogy felvázolja a víz által kiváltott és közvetített éghajlati hatásokat, valamint az ezeket súlyosbító társadalmi-gazdasági tényezőket, továbbá, hogy közös és integrált politikai keretet biztosítson az éghajlatváltozáshoz való alkalmazkodáshoz és a vízgazdálkodáshoz. Az éghajlati és nem éghajlati tényezőket, a kockázati láncokat és a politikai integráció lehetőségeit négy összetett tematikus területen értékelik: (i) ökoszisztéma-szolgáltatások, (ii) élelmiszer-ellátási lánc; mezőgazdaság, élelmiszer-feldolgozó ipar, élelmiszer-biztonság; (iii) ipari és szolgáltatási tevékenységek, energia- és vízellátás, infrastruktúra, épített környezet és (iv) emberi egészség és jólét, társadalmi igazságosság. Ezeken az összetett tematikus területeken koherens keretek között vizsgáljuk a kockázati kaszkádláncot, a hatások jelenlegi állapotát és a várható jövőbeli kihívásokat, majd konkrét javaslatokat teszünk a szakpolitikai integráció lehetséges konkrét területeire. Végül a következtetésekben bemutatjuk a vizekkel kapcsolatos klímaalkalmazkodás önkormányzati szintű jó gyakorlatait, és megfogalmazzuk az integrált klíma-víz politika megvalósításához szükséges horizontális intézkedéseket.

Kulcsszavak
Vízzel kapcsolatos éghajlati alkalmazkodás, integrált éghajlat- és vízpolitikák, éghajlati és nem éghajlati tényezők, kockázati lánc, a víz stratégiai integrálása az ágazati politikákba.

INTRODUCTION

The water cycle is the nexus between planetary systems and ecosystems, as well as through water uses and social and economic systems. Water is not only a bearer of climate impacts but also a transmitter and multiplier of them. In the Carpathian Basin, the problem of “too much water, insufficient (not enough) water” *(MTA 2011)* caused by climate change has become more acute in recent times and is likely to become even more so in the future. The impact of climate change does not occur but mainly through multiple interactions of climatic and non-climatic drivers. In this context, climate change can be seen as an "accelerator factor" of the non-climatic drivers, with consequences affecting almost all socio-economic performance and security levels. According to an analysis by the European Environment Agency *(EEA 2024)*, economic losses related to these damage events in Hungary averaged €210 million per year from 1980-2022. If the damage costs are compared to GDP, Hungary is in the most vulnerable quarter of EU Member States.

In the Carpathian Basin, the highest risks of climate change are related to water and manifest through the decline of water as an ecosystem service and natural resource with socio-economic relevance. The consequences of climate change will be exacerbated by water, resulting in complex security and competitiveness challenges for, among others, crop production, livestock production, industrial security of water-intensive technologies, infrastructure systems, water utility services, biodiversity and ecosystem services, as well as human health and well-being. This cross-sectoral, socio-economic impact chain requires complex and holistic responses. This article outlines the framework for a joint and coordinated climate and water policy, with a particular focus on the options at the regional and municipal levels. First, an overview of the main climatic and non-climatic drivers is provided, with a typology of drivers that can be grouped and analyzed in a common framework. We then analyze risks and consider options for policy integration in four complex thematic areas:

1. Ecosystem services
2. Food supply chain: agriculture, food processing industry, food safety
3. Industrial and service activities, energy and water supply, infrastructure, built environment
4. Human health and well-being, social justice

In these complex thematic areas, we examine the risk cascade chain, the current state of impacts and expected future challenges within a coherent framework and then make concrete proposals for possible specific areas of policy integration. Finally, in the conclusions, we present municipal-level good practices in water-resilient climate adaptation and formulate the horizontal actions needed to implement integrated climate-water policy.

GENERAL TYPOLOGY OF WATER-RELATED CLIMATE RISKS AND DRIVERS

The climate of the Carpathian Basin is warming at a rate considerably higher than global warming (*ITM 2020*). Since the eighties of the 20th century, the intensity and frequency of extreme precipitation events have increased significantly, the seasonality of precipitation patterns has changed, increasing in the winter-spring and decreasing in the summer-autumn half of the year (*Jánosi et al. 2023*). Melt floods of lowland rivers are shifted earlier, rainfall-induced floods become more frequent, and their peak flows may increase. Flash floods in local catchment areas will become more frequent. The water balance of the lakes will decline, and persistent low flows will become more frequent (*RBMP 2021*). The accelerated water cycle and increased evaporation will reduce infiltration, and precipitation will not be sufficient to recharge groundwater. Deteriorating soil moisture content will increase drought vulnerability (*Toreti et al. 2022*), increasing the frequency of drought years and the potential for drought to spread over a larger area than today. The low water levels of regulated rivers also divert residual quantities of groundwater during the summer. The persistent phenomenon of groundwater depletion, especially in areas east of the Danube, is one of Hungary's most adverse hydrological consequences of climate change (*RBMP 2021*). The groundwater situation is further exacerbated by increasing industrial water demands and illegal water abstraction (*Bednar-Friedl et al. 2022*). The main impact categories of the risks transmitted by water are as follows:

a) **General risks of „insufficient water" include droughts and water scarcity.** The persistent and increasingly frequent droughts are a combined " coincident " of heat waves and rainfall shortages. Droughts increase the vulnerability of water-dependent ecosystems and socioeconomic systems (*Buzási et al. 2021*) and cause severe economic damage in many sectors. Water supply risks are increasing for domestic, industrial and mainly agricultural water needs. The droughts of the last decade have caused significant crop losses in central and southern Europe and damage to the health of forests and other ecosystems *(Bednar-Friedl et al. 2022)*. Persistent drought conditions increase the risk of forest fires, facilitate the spread of some epidemic diseases, and may hinder water transport on the Danube and other inland waterways. Water scarcity and rising water temperatures lead to a deterioration in water quality, which threatens aquatic ecosystems (*EEA 2017*), negatively affects recreational water uses (e.g., fishing lakes), and poses a risk to water-based tourism. Increased water temperatures impair the efficiency of power plants through cooling water use, and in extreme cases, cooling water shortages may occur. Some non-climatic factors, such as land use, urbanization, degradation of agricultural soils, and loss of semi-natural floodplains, amplify the adverse risks and vulnerabilities associated with droughts.

b) **General risks of "too much water": floods.** According to a study (*MultiContact 2023*), in 2011-2020, municipal vis maior events typically included extreme precipitation events and their consequences (storm damage, flash floods). In the last decade, almost 42% of the country's municipalities have been affected by damage caused by extreme hydrological events (*Figure 1*).

The severity of droughts and floods and the resulting human, social and economic losses are also significantly influenced by certain non-climatic factors (e.g., land use, infrastructure and settlement structure). Based on the above general risks, the following typology of drivers can be identified (*Figure 2*).

The spill-over cascade effects include:

- **Imbalance between water demand and water availability** (especially in the Alföld): exploitable surface and groundwater resources are shrinking, while water demand for domestic, industrial and agricultural uses is rising. Droughts are causing some minor watercourses to become intermittent and lakes increasingly dry. A seasonal shift in the water balance is expected, with the winter runoff more likely to increase and the summer runoff to drop. Increasing local water conflicts are expected: navigation conditions on our major rivers are deteriorating, and the water level and quality conditions of small lakes with welfare purposes are deteriorating.
- **Water-based ecosystem services are weakening**. Global warming is expected to increase water temperatures, increase the frequency of adverse water quality conditions, reduce natural self-regulating capacity, reduce the resilience of watercourses, and increase adverse ecological impacts. Increased frequency and intensity of prolonged dry periods will lead to more frequent, persistent, and severe soil moisture shortages. Deteriorating soil moisture availability may increase drought stress, and reduced infiltration will also reduce groundwater's natural recharge, thereby reducing drinking water's availability as an ecosystem service. Both climatic and non-climatic effects (increased extraction of groundwater, afforestation, increased use of groundwater for irrigation) may have played a role in groundwater depletion,

- **The challenges to water security are steadily increasing.** The risk, severity and frequency of significant floods are increasing, and flash floods are growing in frequency and intensity. Increasing water damage is expected, and the risk of flooding (e.g., industrial sludge ponds, sewage treatment plants, landfills) is also expected to increase.

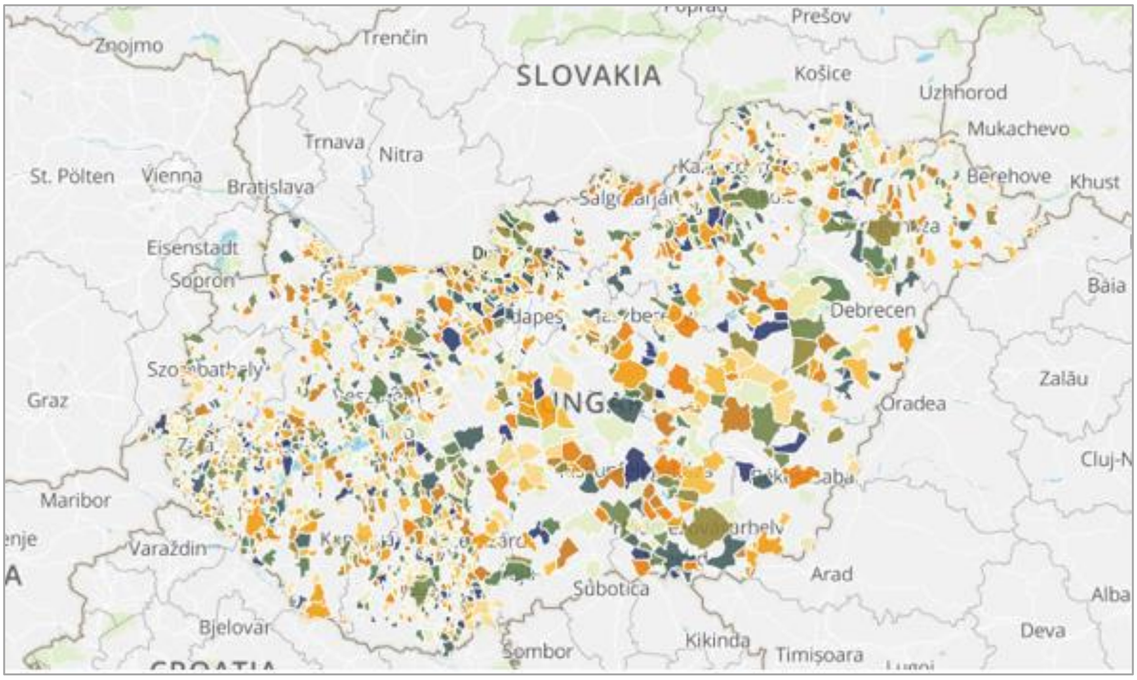

Figure 1. Municipalities affected by "vis maior" events (cloudburst, storm surge, flash flood) in the period 2011-2020 (MultiContact 2023)

Note: the different colors in the figure are only used to distinguish the administrative boundaries of the settlements

1. ábra. "Vis maior" kárbejelentéssel rendelkező települések (felhőszakadás, viharkár, villámárvíz) a 2011-2020 közötti időszakban (MultiContact 2023)

Megjegyzés: az ábrán szereplő különböző színek csak a települések közigazgatási határainak megkülönböztetésére szolgálnak

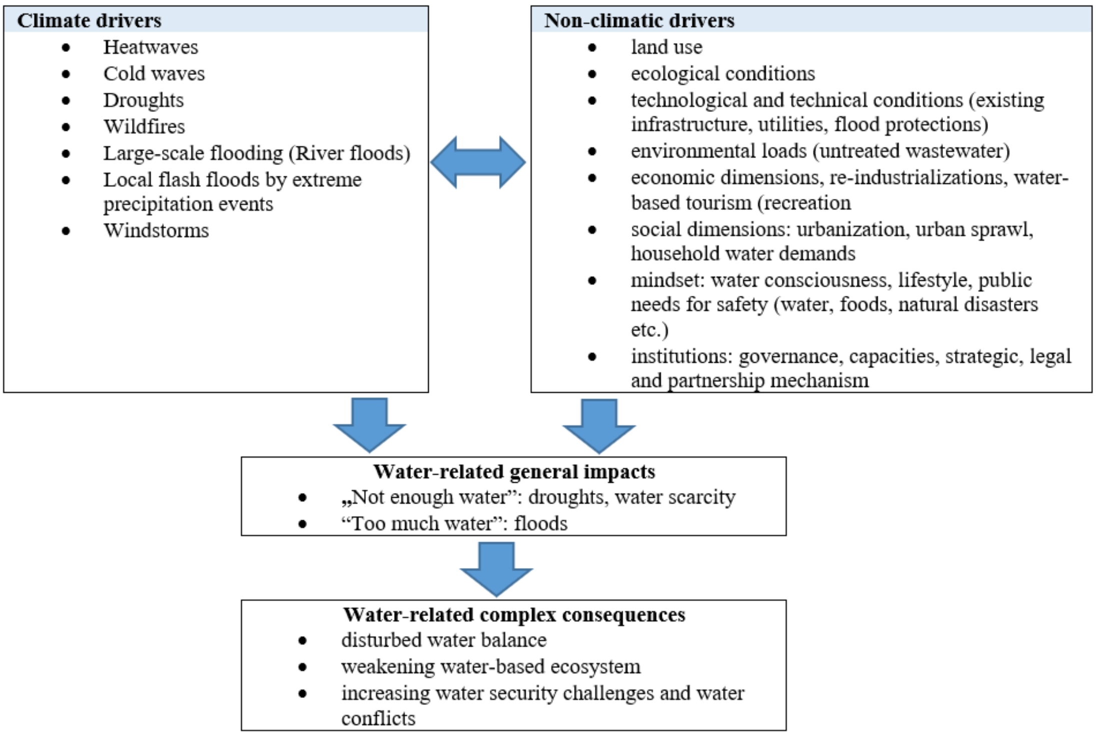

Figure 2. Typology of water-related climate risks and drivers (own edition)

2. ábra. A vízzel kapcsolatos éghajlati kockázatok és tényezők tipológiája (saját szerkesztés)

ECOSYSTEM SERVICES

One manifestation of water-related climate impacts is the degradation of ecosystem services. In particular, the biodiversity of water-related ecosystems (wetlands, aquatic ecosystems, freshwater habitats of lakes and rivers) are under threat. However, forests, natural grasslands and urban green spaces are also adversely affected. Climate-water-biodiversity-nexus requires a coherent, risk-based strategic response.

Drivers and key risks

Disturbed water balances have multi-level ecological impacts (*Deitch et al. 2017*), which can exceed sensitive species' tolerance limits, weakening biodiversity. The loss of biodiversity and ecosystem degradation is a significant barrier to the sustainability transition in Hungary (*NFFT 2023*). The main climate risks affecting water-dependent ecosystems include disrupting the food chain and metabolism of flora and fauna, spreading invasive species, and declining native species (sometimes extinction of individual species, especially in freshwater ecosystems). Ecosystem services are also threatened by increased risk of forest fires due to higher temperatures and extended periods of drought. Forest fires also lead to air pollution, soil destruction and habitat degradation.

The most severe impacts on ecosystem services are the loss of soil biodiversity due to climate change (climate drivers) and unsustainable land use and agro-technology (non-climate drivers). Soil plays a pivotal role in nutrient cycling, carbon storage and water pollution filtration, contributing to climate change mitigation and flood and drought prevention. Soil is also a habitat and an irreplaceable resource in the food chain. Climate change impacts soil through soil moisture deficit and erosion, potentially leading to habitat loss. The quantitative and qualitative degradation of soils weakens their water-retention capacity and negatively affects groundwater quality, undermining drought resilience. Soil is a common 'ecosystem victim' of climate change and unsustainable sectoral policies in agriculture, infrastructure development, land use and water management. Simultaneously, the degradation of soil ecosystem services can spill over to other sectors, such as food and water security, human health and well-being.

Present status and future impacts

In the case of wetlands and water-dependent terrestrial and freshwater ecosystems in Hungary, climate change has been shown to exacerbate adverse anthropogenic impacts (*NFFT 2023*). Similar processes are occurring in forests, where forest health and resilience to climate change are steadily declining. In both fauna and flora, we are witnessing the rapid expansion of less climate-sensitive invasive species, displacing native populations that often have significant conservation value. Drought and flash floods lead to further habitat fragmentation, thus weakening the resilience of ecosystem services. Particularly dramatic changes are observed in wetland birdlife and pollinator insect viability.

Without nature-based solutions to water retention, the increasing frequency and length of droughts could lead to widespread and irreversible damage to water-dependent ecosystems. Even in the short term, increases in temperature and evapotranspiration will cause further declines in wetland habitats, affecting species complexity and the biological, physical and chemical processes of the wetland ecosystem services (*Loisel et al. 2021*). Increasing organic matter loading and residues of fertilizer spreading to surface waters is expected to further degrade the water quality of these water bodies (especially in smaller lakes), with negative impacts on biodiversity and ecosystem functions *(Meerhoff et al. 2022*). Increased extreme rainfall events and flash floods also raise freshwater pollution risks from overflowing wastewater treatment plants or mine and industrial ponds (*Rosenzweig et al. 2019*).

Climate change trends in the Carpathian Basin anticipate further soil degradation, primarily if our policies and measures related to land use, spatial development and agrotechnics do not change. Restoring soil water balance benefits soil-related ecosystem services and supports integrated and sustainable water management by making soil our largest and most cost-effective water-retaining natural resource.

Implications for integrated policies

Integrated policies should protect critical ecosystems (particularly soils, wetlands and water-dependent flora and fauna) from large-scale degradation of biodiversity and ecosystem services. A joint gap in current policies is that they do not adequately address the spill-over effects of biodiversity loss due to water imbalances, such as the decline of specific biological and landscape values or the adverse effects of rural farming and lifestyles. At the same time, several good practices across Europe and Hungary demonstrate that complex nature-based solutions can deliver multiple benefits, including socio-economic benefits and climate adaptation.

The integration needs of existing policies should be fostered, particularly for soils, wetlands and water-dependent ecosystems. Thus, the strategic and legal frameworks for land use, spatial development, infrastructure development, agricultural subsidies, tourism development, territorial water management and climate adaptation should be targeted. Planning a series of measures to improve soil water retention in the short term is essential.

„FARMS-TO-FORKS" SYSTEM: AGRICULTURE AND FOOD SUPPLY CHAIN

The characteristics of the climate-water-food nexus are determined by the combination of natural water supply resulting from climatic conditions and the land use pattern. The local functionality of this interdependent system can be sustained if land use patterns are adapted as closely as possible to the natural landscape conditions (climate, soil, topography, natural water supply). Agricultural land use and the economic constraints that influence it are key barriers to developing drought-resilient food systems.

Hungary has an outstanding agroecological potential. The composition and quality of Hungarian soils are exceptionally favorable, allowing the quality of agricultural products to be above the European average. However, warming temperatures and prolonged, more frequent and severe droughts lead to unpredictable yield variations, which, like in the Mediterranean, also affect a large part of the Carpathian Basin (*Ceglar et al. 2019*).

The impact of climate change, effects of water management, agriculture and food supply are interlinked, with mutually reinforcing negative effects that can only be overcome through coordinated policies focusing on water-retain land use and water-saving agricultural production.

Drivers and key risks

Agriculture can suffer severe damage and yield losses due to extreme climatic events such as droughts, floods and storms. Arable crops may be particularly vulnerable to the negative impacts of climate change, but the horticulture and fruit sector and livestock production (e.g., due to new infectious diseases) are also particularly vulnerable to climate change. In addition to climate impacts, the food supply will be affected by land use change, loss of habitat and forage areas, unsustainable water use, land use and agricultural support schemes. Intensive production systems, which threaten the health of agricultural soils and pests and diseases, all hurt the food supply chain.

Climate and non-climate drivers jointly lead to uncertain yields, reduced competitiveness of food production, increased dependence on food imports, and higher food prices. The complex effects are unfavorable for vulnerable social groups (e.g., low-income households and small farmers). A decline in the production of higher value-added agricultural and food products, such as horticulture and livestock production, has characterized the agricultural product structure in recent years. In contrast, the output of crop sectors that are less resilient to climate change has increased. The composition and complexity of the agricultural product structure are shrinking, and agricultural productivity and efficiency are far below the EU average. As a non-climate driver, this modernization deficit exacerbates the adverse effects of climate change on the food supply chain.

Present status and future impacts

The heat stress and drought are already harming crop production in Hungary, causing significant yield losses and crop productivity reductions, affecting the entire food supply chain. Climate change and non-climatic impacts pose significant economic and social risks to farmers and SMEs in the food processing industry. The livelihoods of these vulnerable actors depend on food production and imports of dumped, low-quality foods. Limited access to healthy and affordable domestic food can lead to spill-over socio-economic effects; for example, it can also affect human health and social well-being.

A further negative impact can be identified in water pollution from agricultural sources. Nitrate pollution, biocides and pesticide residues, unusable irrigation water and low groundwater levels combine to exacerbate the poor chemical status of soils and near-surface groundwater. When looking at forestry activities, water imbalances adversely affect tree growth and harvestable timber yields and can, in combination with heat waves, weaken forest health and even kill trees (*Hartmann et al. 2022*).

Finally, an indirect negative impact can be identified in the international transport of agricultural products. The Danube is an important transport route, with 23% of its river transport output being agricultural and food products (*CCNR 2022*). Drought periods (such as the droughts of 2018 and 2022) lead to low water level impacts, with severe consequences for the commercial shipping of agricultural products and foodstuffs.

Prolonged hot and dry conditions and soil degradation can also increase the risk of desertification. The food supply chain, already vulnerable to climate change, could be deeply affected by large-scale, severe, more intensive and frequent droughts, leading to significant crop losses in the Carpathian Basin. At the same time, not all crop production sectors will be negatively affected by climate change if water-saving practices and water-efficient irrigation can be more widely applied. Yields of vegetables, fruit and grapes could even increase, but the expected growing risk of frost in spring and hail in summer will make yields uncertain. At the same time, arable crops may be particularly vulnerable to the adverse effects of climate change. Yields of spring-sown crops, especially in the southern parts of the country, could fall by more than 30%, while production of water-intensive crops could even cease in Hungary (*ITM 2020*). Livestock production could face new infectious diseases and heat stress. Heatwaves, droughts and complex hot-dry events are expected to be fundamental drivers of risks to forest carbon sinks, directly reducing forest productivity and growth but indirectly increasing vulnerability to forest health (e.g., limited resilience to insects and pathogens).

Implications for integrated policies

The changing climate significantly affects the entire food supply chain, intensified by the non-climatic effects of agricultural land use: 80% of the country's cultivated area is under arable crops. Thus, in addition to climate change, the main non-climatic policy drivers are land use legislation and area-related payments to encourage arable farming. Other policy gaps can also be identified in the context of unsustainable agricultural practices (e.g., soil degradation, agrotechnology, drainage of agricultural land, etc.).

To mitigate drought vulnerability, landscape management in cooperation with nature ("water in landscape" concept) provides a near-natural solution (NBS) (*IUCN 2018*). Ancient water and land use infrastructure that spreads water transported by rivers and rainfall needs to be re-established. A mosaic system of watercourses, floodplains, high banks, wetlands, grasslands, plows, and field protection forest strips, adapted to the natural topography, should be developed, especially in the lowlands. It is also essential to develop a new technical and legal basis for water management, allowing for water discharge in the event of flood surpluses. This would also entail a significant change in land use: lower-lying areas would be used primarily for water retention, while elsewhere, a mosaic of cultivated areas and natural ecosystems (grasslands, wetlands, forest fragments) would be maintained. This would also reduce flood and inland water risks, reduce drought hazards and improve biodiversity.

Transitioning to a "water in landscape" system will require significant coordination and co-planning between different sectors. The transformation will require a significant role in the spatial planning, water, agriculture, industry, residential, nature conservation and tourism sectors. The development of a climate-resilient food chain can only be achieved by strategically integrating the "water in the landscape" concept.

Strengthening food sovereignty can be one of the key policy drivers. If the agricultural and rural policy is strategically focused on the triple bottom line of 'security of supply – competitiveness – sustainability,' the 'water in the landscape' concept could be a high-priority implementation tool. This could be complemented by a more diversified product mix, with many small producers, and by innovative agrotechnologies that are environmentally friendly and resource efficient. A food sovereignty policy, deeply integrated into policies, would also reinforce the climate resilience of ecosystem services (soils, pollinating insects and biodiversity), thus mitigating the impact on farmers' economic stability.

INFRASTRUCTURES, BUILT ENVIRONMENT, INDUSTRIES, SERVICES

The consequences of climate change are not leaving infrastructures or certain industrial and service activities untouched. Some public services (e.g. water and energy utilities), some water-intensive industrial activities and waterside tourism are affected. Energy security, both in terms of power generation, energy transport and distribution systems, is a particular area of concern. Relevant impacts and responses can also be identified in the climate-water-urban green infrastructure nexus.

Drivers and key risks

Climate change has a significant impact on public **water utilities**. On the one hand, warming temperatures and more frequent and prolonged droughts will increase domestic water demand which may be further exacerbated by some water-intensive industrial activities (e.g., battery industry). Also negatively affected by the drinking water supply is that higher water temperatures lead to the spread of pathogens, limiting the use of reservoirs for drinking water and recreation (*EEA 2017*). Wastewater drainage is also challenged by potential water restrictions during severe droughts, leading to sedimentation and clogging of sewer drainage infrastructure networks. Further negative impact chains can be identified in urban stormwater drainage infrastructure. The frequency of urban fast-running floods increases, and unseparated stormwater drainage systems increase the amount of pollution entering the sewers. The capacity of watercourses receiving treated urban wastewater is also reduced during prolonged water scarcity.

Significant climate drivers and risks can be identified in the **energy infrastructures**. Thermal power plants (fossil and nuclear) are sensitive to two factors through the cooling water supply. On the one hand, higher cooling water temperatures have a negative impact on the thermal efficiency of power plants, leading to business losses (*Payet-Burin et al. 2018*). On the other hand, in the case of extremely high water temperatures, the discharge of used cooling water into freshwater bodies must be suspended to protect freshwater ecosystems, which, in extreme cases, may lead to restrictions in the regular operation of power plants. Deficient water levels may also lead to shutdowns if other sources cannot meet cooling water demand. Biomass power plants are indirectly affected by climate change. Droughts and possible wildfires in forest areas that supply firewood present a significant yield hazard and, thus, an economic risk. Finally, it should be mentioned that climate change also presents new drivers for energy networks. Electricity grids may be disrupted in areas at risk of flash floods, but forest fires may also pose a higher risk. Storms, droughts and heat waves can damage information and communication technology (ICT) infrastructure, affecting telecommunications as critical infrastructure (*Dale and Frank 2017*).

Among **industrial activities**, climate change directly affects industries with high water demand, notably chemicals, food and battery manufacturing (*Gasbarro et al. 2019*). Reducing water demand in these sectors through transitioning to circular water use could be a positive driver. Production in just-in-time logistics systems is indirectly affected by the impact of climate change on transport infrastructure, particularly the climate vulnerability of roads and railways. The **building stock** is at risk from flooding and events leading to higher groundwater levels, especially for outdated detached houses without adequate underlayment and waterproofing. These risks are further compounded by inadequate or outdated stormwater infrastructure that does not provide adequate drainage capacity.

Urban green areas, as well as water and waterside ecosystems (**urban green infrastructure**), provide a range of environmental, social and economic benefits and are multifunctional resources capable of providing multiple ecosystem services. However, green infrastructure is vulnerable to droughts and temperature extremes and is also affected by air pollution, fires, invasive species and disease as non-climatic drivers. The decline in soil moisture affects vegetation health and reduces the aesthetic attractiveness and recreational value of green spaces and water bodies. The overall status of infrastructure vulnerability is presented in *Table 1*.

Table 1. Vulnerability of the infrastructures to climate drivers (own edition, based on EEA 2017)
1. táblázat. Az infrastruktúrák éghajlati tényezőkkel szembeni sebezhetősége (saját szerkesztés, EEA 2017 alapján)

Sector	Infrastructure	Heat-waves	Droughts	Wild-fires	River-floods	Storms, flash-floods
Energy	Power plants (fossil, nu-clear)	+	++	+	++	+
	Power plants (biomass)	++	+++	+++	++	++
	Solar power plants (PV)	-	-	+	+	+
	Wind turbines	-	-	+	+	++
	Electricity grid	+	-	+++	++	+++
	Gas pipelines	-	-	+++	+	-
Built environment, transport infrastructure	Roads	++	-	++	++	+
	Railways	++	-	++	+++	+
	Inland waterways	+	+++	+	++	++
	Airports	-	-	+	+	++
	Buildings	-	-	+	++	+++
	National heritages	+	-	-	+	+++
Industry	Chemical industry	+	+	+	+	++
	Food processing industry	++	+++	+	+	++
Services	Utilities (water and waste)	++	+++	+	++	+++
	Tourism	+++	++	+	+	++
Urban land use	Urban green infrastructure	++	+++	+	+	++

Legend: +++: high vulnerability, ++: medium vulnerability, +: low vulnerability, -: no vulnerability
Jelölés: +++: erősen sérülékeny , ++: közepesen sérülékeny, +: kissé sérülékeny -: nem sérülékeny

Present status and future impacts

Across Europe, cities and their agglomerations are increasingly vulnerable to water scarcity (*Caretta et al. 2022*), and negative trends are already evident in Hungary. Urbanization, aging infrastructure and disrupted water balances, combined with increasing water demands, are intensifying competition for water and exacerbating local water conflicts (*Xanke and Liesch 2022*). The modernization deficit of water utilities also represents a persistent lock-in effect and weakens the potential for climate change adaptation. New, innovative "green industries" (e.g., battery production, hydrogen industry) are a positive trend for sustainable energy management. However, they also represent significant additional water demands that may also intensify local water conflicts.

Extreme precipitation in the Carpathian Basin will likely increase, so the frequency and magnitude of pluvial floods are expected to increase (*Kundzewicz and Pińskwar 2022*). Extreme peak flows exceeding the 100-year return period are projected to increase across Europe (*Alfieri et al. 2017*). Considering the expected infrastructure impacts of the "too much water" problem, it is essential to note that although the increasing flood risk has climate-related causes, flood damage to the built environment is, to a significant extent, not a consequence of climate impacts. On our major rivers, flood damage is caused by deficiencies in the appropriate flood defenses, on small watercourses by the sprawl of settlements (sometimes illegal developments) and the general obsolescence of buildings and roads.

Socio-economic conditions, particularly those accompanied by social vulnerability and/or an aging population, adversely affect the ability to recover from floods. Crucially, water damage to housing and property also creates social problems (*UNDRR 2019*).

Implications for integrated policies

An integrated policy response to floods should be based on three equally important pillars: (i) technical and technological development of flood protection, (ii) early warning, raising flood awareness in society and among stakeholders, and (iii) integration of nature-based solutions.

In addition to the traditionally high performance of flood protection measures in Hungarian water policy, progress is needed to ensure that **infrastructure planning** also considers climate risks. It is an appropriate initial step to make climate change adaptation assessment mandatory for some infrastructure developments. However, this does not cover priority investments and is not adequately integrated into the permitting processes. In this respect, it is essential that the standards used in the engineering design, the best available techniques reference documents, and climate risks are considered more explicitly for new infrastructure and substantial renovation projects. Public procurement policies can also be important in integrating climate risks into infrastructure design and construction.

It would also be essential to carry out **complex hazard assessments and stress tests for specific sectors or infrastructure networks** (e.g., water utilities, electricity and telecommunication networks, transport infrastructures) at fine spatial resolution (*León-Mateos et al. 2021*). The hazard assessments for investments should assess whether water saving, and water retention considerations are addressed and whether implementing the investment will not create new water conflicts. This information should be included in the licensing processes. Similarly, spatial and municipal development plans should integrate resilient infrastructure requirements, including water-retaining stormwater management, flood-resilient buildings and integrated green space development to enhance the overall climate resilience of settlements. These plans should prioritize improving the built environment's resilience, focusing on deteriorated and obsolete housing and historic monuments.

At the global and EU levels, the issue of early warning and partnership for preparedness s is also receiving considerable attention (UN). In recent years, several extreme precipitation events across Europe, including severe damage and loss of life, have demonstrated the public and economic stakeholders' lack of awareness and preparedness (*Cunge and Erlich 2014*). In this respect, it is essential to strengthen the state's public information and alert functions (e.g., water authorities, disaster management) and municipalities through developments based on innovative applications of data integration and analysis, forecasting and communication (e.g., big data, artificial intelligence). Two target groups should be given particular attention in preparedness for extreme weather events. Firstly, training and networking of property operators and facility managers should be promoted. On the other hand, architects, designers, building services engineers, and experts in building automation (BIM) can consider preparedness for extreme events during the planning phase.

Finally, the resilience of the built environment can be improved by **nature-based solutions** integrated into flood protection. The starting point is that the restoration of wetlands, old river channels and floodplains, the creation of water retention areas or, for example, the installation of micro-reservoirs and green roofs in cities can contribute to preparing for extreme rainfall events (*Sørup and Arnbjerg-Nielsen 2021*). Nature-based solutions address social, economic and environmental challenges effectively and adaptively while delivering benefits for human well-being, ecosystem services, resilience and biodiversity.

HUMAN HEALTH, WELL-BEING AND SOCIAL JUSTICE

Climate change impacts are also reflected in human health, welfare and social equity dimensions. Climate drivers related to infectious and cardiovascular diseases may be intensified by specific non-climate drivers, such as social deprivation related to poverty and housing, health care, food security and health awareness.

Drivers and key risks

The increase in the frequency and intensity of extreme climatic events (floods, droughts) accelerates the spread of various infectious diseases by increasing the survival, reproduction and geographical spread of pathogens and their vectors. Notably, climatic conditions are increasingly favorable to spreading waterborne and foodborne diseases such as Campylobacter and Salmonella. Water also plays a pivotal role in this problem: disease-carrying species (such as mosquitoes and birds), adapted to shrinking surface water stocks, gather around remaining water bodies, increasing the chances of transmitting diseases such as Zika, malaria and dengue fever. In urban areas, inadequate stormwater drainage during floods caused by extreme rainfall can lead to sewage overflows, increasing the risk of infectious diseases, especially in children (*Semenza et al. 2021*).

Social, economic, cultural and lifestyle factors also influence people's vulnerability to disease. People with low incomes, the elderly and people with chronic diseases are likely to be at particular risk, and special attention should be paid to improving their resilience.

Present status and future impacts

Current health status and age are key risk multipliers for many **climate-related health impacts** (e.g., heat waves as an associated health risk and vector-borne diseases). It is expected that the vulnerability of pregnant women, infants, young children and the elderly will be increased, which may be exacerbated by social and housing conditions (*Van Daalen et al. 2022*). Another area of health impacts of climate change is through the food supply chain; water and food security are also closely linked. The food supply chain (for example, through irrigation and food processing) highly depends on the quantity and quality of available water, which can be adversely affected by droughts and floods.

Climate change has significant implications for **social justice and equity**. The adaptive capacity of low-income households and marginalized communities is inherently limited. However, they are also expected to be more vulnerable to increases in food and water prices resulting from climate change (*Breil et al. 2018*). There may also be increased vulnerability to climate change for some groups of employees, e.g., outdoor workers in agriculture and construction), but indirectly, those in the tourism sector may also be more adversely affected.

Traditional, **self-sufficient households** depend heavily on ecosystems and are also at risk. It can be expected that the rural deprived regions with small villages and remote farms may be more vulnerable to climate change, as these communities are more dependent on local ecosystem services that are being degraded by climate change.

A further negative social impact chain is that floods (particularly flash floods) and their response can result in new risks and associated inequalities. The information, housing and lifestyle conditions of disadvantaged social groups can compound their flood-related losses.

Implications for integrated policies

Hungary is at the forefront of research into the direct health impacts of climate change, the deployment of health-related climate change adaptation measures, and the legal and policy framework to address them. However, further integration is needed in some water-related areas, such as early warning systems, awareness raising and knowledge sharing on extreme weather events. Education and training of health and social professionals is a priority target group in this area. Climate adaptation for health also requires coordination of public information activities in the fields of water, disaster prevention and public health.

Social policies mainly fail to consider the climate aspects of poverty (e.g., food poverty, housing crisis, hunger). The combination of climatic and non-climatic drivers increases social inequality. It leads to significant welfare inequalities, and therefore, a support program for vulnerable groups in deprived areas should be launched to reduce their climate vulnerability.

CONCLUSIONS

Climate change is adversely affecting water resources. This negative impact is compounded by the increase in water demand, which together increases competition for water between water users and can raise conflicts in sharing water resources. The persistent and worsening disruption of the water balance, together with other non-climatic drivers, will lead to spill-over effects in terms of ecosystem services and socio-economic processes. Both the socio-economic drivers and the policy responses have in common that they cannot be addressed within the strategic framework of a single sector but require complex and integrated solutions. In the following, we present good practices of integrated responses in Hungary and summarize the most critical aspects and areas of intervention for integrated climate and water policy planning.

Best practices in policy integration

In Hungary, several implemented projects and good practices support the feasibility and complex benefits (e.g., water management, biodiversity, and socio-economic development) of climate-water policy integration, of which two "flagship projects" are presented. It should also be noted that project-based policy integration is in its initial phase worldwide (*Rogers et al, 2023*), but success factors and uncertainties can be identified. Success factors include, for example, a legal and regulatory environment that facilitates integration, local political commitment, and the existence of administrative and professional capacity. Another key issue is the organizational and governance culture and the involvement of local stakeholders in implementation. However, there are also considerable uncertainties. For example, there is no universal method for measuring outcomes (*Singh et al, 2021*), especially in the absence of longer empirical data series. There is also no clear guarantee that the results can be replicated or scaled up elsewhere.

Preparing for flash floods in Püspökszilágy: Developing an integrated natural water retention system.

Püspökszilágy is highly vulnerable to flash floods, while droughts are frequent in summer, both of which cause severe damage to the municipality. The LIFE-MICACC project (2017-2021) (*https://vizmegtarto-megoldasok.bm.hu/hu/nwrm/5_pilotrol_reszletesen*) aims to address both problems through nature-based solutions.

The administrative area of Püspökszilágy is affected by two small watercourses, the Gombás Stream and the Szilágyi Stream, which is more relevant for local water damage control and affects the inland area. The Szilágyi stream has a total length of 6.8 km, an average width of 1.3 km and a catchment area of approximately 10 km^2. Before the MICACC project, there were no reservoirs in the catchment areas above the inner part of the municipality of Püspökszilágy. The nearest reservoir is a stormwater reservoir and groundwater pond located southeast of the settlement, but their outlet canal is located below the inland section of the Szilágyi stream. Due to its geographical location, the lake system did not contribute to preventive protection against fast-moving flash floods (*Budai 2018*).

Sloping agriculture is common on the surrounding hills, which contributes to and accelerates the run-off of water from the arable land above the settlement, which may be accompanied by a significant amount of sediment transport. The development of the settlement structure has resulted in an increase in the extent of paved surfaces, but the main surface stormwater drainage system in the village, the Szilágyi stream and its associated drainage network has not been developed. Due to these geographical and hydrological conditions, the most crucial surface water body in the municipality of Püspökszilágy is the Szilágyi Stream, which has been subject to record flooding every 2-3 years in recent decades. This leads to significant soil erosion and damage to the building stock. At the same time, in summer, the valley floor dries out completely, negatively impacting agriculture, the ecosystems and the groundwater resources. Four wooden sediment barriers (bottom thresholds) have been constructed in the Szilágyi stream. The retained water ensures the water supply of the higher-lying cultivated lands and forests. A wetland and pond system will be created in a part of the Szilágyi stream floodplain to capture and store floodwater and sediment to increase water retention capacity and reduce drought risk.

Among the solutions implemented under the project, the lateral reservoir will play a significant role in water retention. At the inflow points of the reservoir, easily cleanable sediment traps have been constructed to prevent the reservoir from silting up. The reservoir was constructed on meadow and pastureland, and efforts were made to balance flood protection and nature conservation functions. The ecological needs of the reservoir were met by ensuring water flow, maintaining mosaicism, integrating wooded communities and wetlands, and protecting natural values. A complementary solution was to build seepage log dams on the erosion ditches over the settlement, which flow into the Szilágyi stream. During flash floods, the high water flows and the resulting sediment and debris are retained above the settlement, and the water is released slowly and in a controlled manner through the gap between the logs, thus flattening the flood peak. Another advantage is that they are incredibly cheap, especially as they are built using locally harvested timber. The small-scale water retention solutions (reservoir and log dam) implemented under the project contribute to stabilizing groundwater levels, allowing the use of retained water, helping preserve and enhance biodiversity, resulting in a better microclimate, and thus creating recreational opportunities.

Activities included raising awareness and acceptance of nature-based solutions among local people. The central "message" was that the reservoir and the adjacent leisure center would be used for recreational purposes. Another co-benefit was to improve flash flood preparedness and to involve the local community in the design of nature-based solutions. Among the social impacts, the project's results in raising the awareness of local stakeholders are essential. The reservoir is also widely used for recreation by residents of the surrounding villages, hikers and groups visiting the Recreation Centre next to the reservoir.

Strengthening the climate change adaptation and coordination capacity of local authorities

The LIFE LOGOS 4 WATERS project (2021-2025) aims to improve the climate resilience of municipalities, mainly through disseminating good practices of NWRM (Natural Water Retention Measure) at the municipal and river basin levels. The project will design and implement complex integrated solutions based on natural water retention at the river basin level on a demonstration basis coordinated by municipalities. Partnership groups have been set up in 9 catchments in Hungary at risk of flash floods and erosion, including the municipalities in the catchment, the regional Water Management Directorate, the permitting authorities, farmers, the National Parks, NGOs and local stakeholders (*https://lifelogos4waters.bm.hu/en/home/*).

The project is under implementation, and one of its "early results" is the central role of municipalities in the implementation and planning coordination of locally integrated climate-water policy actions. This coordination may include developing and implementing local water conservation strategies and raising community awareness. Under the project, municipalities can carry out social and institutional coordination of river basin management, as well as community involvement and awareness-raising. In this way, the integrated implementation tools contribute to flood protection and improve the quality of community life.

Horizontal and holistic policy planning

Water policies, in general, have typically focused on the direct risks but have largely not considered the systemic and multiple hazards (often exacerbated by non-climatic drivers) arising from climate change. Integrated policy planning is based on the recognition that the chains of impacts presented in this paper are interlinked and cannot be effectively addressed in 'sectoral silos.'

The common ground for integrated policy responses is the 'water in landscape' approach, which prioritizes the restoration of ecosystem services through the retention of water in local areas. "Water in the landscape" should focus on ways of retaining water optimized for local conditions. This may include water stored in soils, wetlands, recreational lakes, and reservoirs, as well as the circular reuse of used water and the rational control of socio-economic water needs. New options for flood protection include " making more space for the river," widening the narrow floodplain, increasing the flood discharge capacity of the floodplain, and, in the case of major floods, diverting part of the water to deep floodplains or reservoirs on the flood-sheltered side. Integrated water-related planning can also resolve conflicts over competing water uses based on reasonable compromises.

Another common feature of integrated policy measures is that they address socio-economic risks resulting from climate change and non-climatic drivers in addition to the hydrological and climatological dimensions.

The flexibility and spatial differentiation of integrated responses are also required. Cross-sectoral climate adaptation governance considers the geographical characteristics of drivers and risks, as well as socio-economic and ecological diversity (*Pálvölgyi and Reich 2024*). This also means that the policy solutions presented in this research need to be 'tailored' and implemented in a spatially differentiated manner, with an understanding of vulnerability and along the lines of effectiveness (*Pálvölgyi and Kovács 2023*).

The main **horizontal, cross-sectoral priorities** for integrated climate and water policies are:

- Achieving multifunctional land use and strengthening ecosystem services, promoting soil restoration and improving the resilience of water-dependent ecosystems.
- Implement a systemic, holistic planning framework, including the establishment of local, cross-sectoral coordination organizations and consultative platforms
- Community development, strengthening local identity and responsibility
- Developing a green economy and recreational opportunities, creating a healthy environment, improving well-being

Research and development, as well as awareness raising and training, are two other priority horizontal areas for integrated policy planning. Complex research on climate-water-sustainability nexus is an urgent priority. An institutional framework and sustainable funding for this, based on networking, must be developed ("VITUKI network"). Research should be multidisciplinary and strongly focused:

(a) strengthen the existing monitoring and modeling systems for forecasting and alerting to extreme climate events with fine spatial and temporal resolution, in particular droughts and flash floods,

(b) socio-economic valuation of water-related ecosystem services; costs of adaptation options and costs of non-action; and quantitative integration of risks into public service, governance and business decisions.

The effectiveness of integrated policy planning depends essentially on the knowledge, expertise and perception of the wider stakeholders. In Hungary, there is considerable experience and a well-developed institutional background for implementing environmental awareness-raising in public education. Existing infrastructures (forest schools, visitor centers in National Parks, etc.), programs (e.g., Student Work Programme, Borderless Programme, TeSzedd Programme) and initiatives by local actors, initiatives and NGOs - with appropriate professional coordination - are suitable for increasing young people's knowledge and attitudes towards climate adaptation concerning water.

At the same time, further action is needed in science communication related to the topic. Knowledge transfer channels outside schools (e.g. social media platforms) are currently underused in awareness raising on the topic.

Another important target group for training and awareness-raising related to integrated policy planning is experts and decision-makers who implement development policies. A profession-specific, tailor-made water-related adaptation training system should be developed, e.g., for all target groups of development projects (decision-makers, tender consultants, project developers, design engineers, agricultural contractors, water management professionals). Cooperation between universities, professional chambers and other public bodies is justified, for example, in the following areas of competence:

- environmental and nature conservation knowledge
- knowledge of sustainability and climate change
- water management and technical knowledge
- urban planning and landscape architecture
- economic, financial and management skills
- conflict resolution, partnership building and communication skills

Finally, the failure of the integrated climate and water policies would set back our resilience in the face of adverse effects of climate change. The climate-water-food nexus poses complex climate security challenges to which only integrated responses can be effective. The absence of cross-sectoral climate and water policies can lead to maladaptation (*Schipper 2020*).

As stated in the National Water Strategy (*NWS 2017*), "*the complexity of water management and the proven validation of synergies should be a prerequisite for the approval and financing of water management interventions (...). Water management and water protection cannot be treated in a separate way, and integrated water management aspects should be mainstreamed into other sectoral policies (agriculture, energy, transport)*." Hence, the water policy framework is open to policy integration, but the need for this is not sufficiently reflected in sectoral strategies. An important driver could be interdisciplinary and cross-sectoral dialogue, for example through the institutional forum of the Water Management Science Council. Further "accelerator" of policy integration could be the strengthening of cross-sectoral coordination of financial resources and the opening of " silo-like" sectoral funding mechanisms to shared objectives (e.g. area-based agricultural support for water retention).

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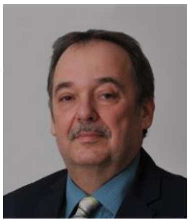

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LAJOS KOVÁCS started his career in the 12th district of Budapest as a civil servant, and from 2006 he continued his public activities as deputy mayor. During his appointment, he was responsible for many professional areas, but during his service, urban development, environmental protection and climate protection were constantly part of his work. In 2020, began his studies at the Doctoral School of Safety and Security Sciences at the Óbuda University, he will research the security challenges of climate change at the settlement level. He is a founding member of the Association of Climate-Friendly Municipalities, founded in 2009, and has been its president since 2014. He tries to represent the issue of climate and environmental protection nationally as an active member of the National Council for Sustainable Development and internationally as an active member of the European Union's Committee of the Regions.