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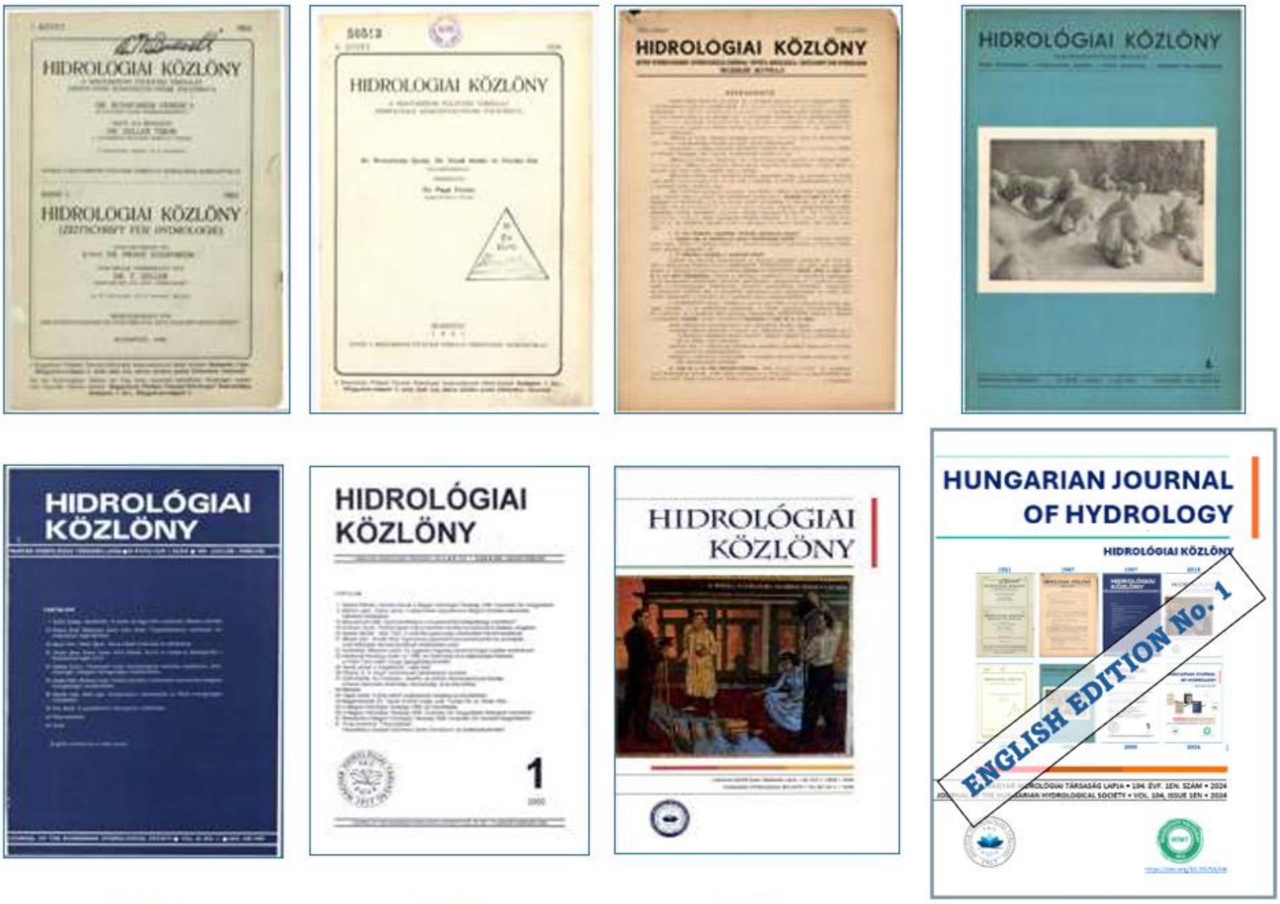

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Tartalomjegyzék

Címlapkép: A Hidrológiai Közlöny címlapjának fejlődése napjainkig

Foreword

It is with great pleasure that we present the first English volume of the Journal of Hungarian Hydrology (HK), the official periodical of the Hungarian Hydrological Society (MHT). This English volume marks significant milestone in the history of our journal. Since its inception, the Journal of Hungarian Hydrology has been a vital platform for disseminating water related research and findings, primarily within the Hungarian scientific community. Today, as we extend our reach to the global stage, we reaffirm our commitment to fostering international collaboration and knowledge exchange in water management. The front page of the first English volume shows the path that HK took from 1921 to the first regular English Edition.

Water related sciences transcend geographical boundaries, influencing ecosystems, water resources management, and environmental sustainability worldwide. In an era marked by climate change and enhancing water-related challenges, we must share our insights and innovations beyond linguistic boundaries. By publishing in English, we aim to bridge gaps, connect researchers from diverse backgrounds, and contribute to a more comprehensive understanding of water phenomena on a global scale.

This issue features a selection of papers that reflect the breadth and depth of contemporary urban and regional water management research. From cutting-edge studies on water cycle dynamics to practical applications in water resource management, these articles embody the professional exaction and innovative spirit that the Journal of Hungarian Hydrology stands for. We are confident that our international and Hungarian audience will find these articles both informative and inspiring.

The articles in volume 104/1/ENG cover a wide professional field.

The context of Landscape-Soundscape-Waterscape is recommended to serve as a conceptual model of dialogues to set consensus. This is the message of *János BOGARDI*'s article, entitled "Landscape – Soundscape – Waterscape; Concept for an inter- and transdisciplinary framework for regional integrated water and land management and the water-, energy- and food security nexus".

How can we manage water-induced and mediated climate impacts, as well as the socio-economic factors that aggravate them? *Tamás PÁLVÖLGYI* answers this question in his work titled "Perspectives of integrated climate change and water policies in Hungary".

Is it possible that we can gain a better understanding of the essence of law through system analysis? The publication of *Sándor FÜLÖP* "System behavior of water and environmental law" gives the answer to the question through two examples.

The discourse of *Tamás KLOKNICER, Dániel Benjámin SÁNDOR* and *Anita SZABÓ* entitled "New containerized wastewater treatment technology: system description and evaluation of treatment capacity of a highly efficient MBBR system" presents an innovative biofilm microcarrier developed by Inno-Water Inc., which is significantly smaller in size than conventional carriers. The examined biofilm layer has an ideal thickness and a slightly low colonization rate.

The article of *Mohammad Ali KHODABANDEH, Katalin KOPECSKÓ,* and *Gábor NAGY* entitled "The effect of expanded perlite and metakaolin on the physicochemical properties of collapsible soils" shows, that the expanded perlite and metakaolin were examined as soil stabilizing agents. The results demonstrate that soil improvement with expanded perlite and metakaolin can improve soil engineering characteristics in any construction application. However, expanded perlite is a more cost-effective material than metakaolin.

In our LIFE PATH section, Professor Hans WESSEL is greeted, because Professor WESSEL received the honorary foreign membership award of Hungarian Hydrological Society (MHT) in 2024. With this acknowledgment, the MHT expresses its honor and thanks for what Professor WESSEL has done to promote the international and European integration of water management both in Hungary and all over the world.

We extend our heartfelt gratitude to our authors, reviewers, and editorial board for their unwavering dedication and support in making this inaugural English issue possible. As we embark on this new era, we look forward to the continued growth and evolution of the Journal of Hungarian Hydrology, and to the vibrant exchange of ideas that will undoubtedly enrich our understanding of the world's water systems.

Welcome to the first English edition of the Journal of Hungarian Hydrology. We hope that our readers will also enjoy journey with us.

Veronika MAJOR
Editor-in-Chief

Landscape – Soundscape – Waterscape
Concept for an inter- and transdisciplinary framework for regional integrated water and land management and the water-, energy- and food security nexus

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Abstract
This paper argues that integrated resource management (both stocks and fluxes) must be embedded into a transdisciplinary context. Preliminary, yet essential debates, plans and formulation of aspirations need to be formulated with the active participation of legitimate stakeholders and affected citizens. This implies, that next to the key integration of land- and water resources management voices articulating local needs, expressing and protecting cultural values and social preferences are to be heard and understood.

The context of Landscape-Soundscape-Waterscape is recommended to serve as a conceptual model of dialogues to set consensus-based objectives and constraints for the detailed professional elaboration of development, restauration and protection plans for water-dominated landscapes and resource use. This multi-dimensional dialogue is even more important when several sectoral concerns are to be taken into a so called nexus consideration.

The trans- and interdisciplinary model framework of Landscape-Soundscape-Waterscape is proposed to be tested first in case studies where the spatial extent of most of the resource use and protection interactions correspond with the living space (or homescape) used, intimately known and loved by those whose "sounds" should be captured and considered for the sake of sustainable future.

Keywords
Landscape, soundscape, waterscape, integrated management, water-, energy-, food security nexus.

Tájkép – hangkép – víztáj
Egy regionális integrált víz- és tájgazdálkodás inter- és transzdiszciplináris keretének koncepciója a víz-, energia- és élelmezésbiztonság kapcsolatában

Kivonat
Ez a tanulmány azzal érvel, hogy mind a készletekkel, mind a fluxusokkal való integrált gazdálkodást egy transzdiszciplináris kontextusba kell ágyazni. Az előzetes, de lényeges vitákat, terveket, törekvéseket a legitim érintettek aktív részvételével kell mind lefolytatni, mind megfogalmazni. Ez azt jelenti, hogy a táj- és vízkészlet-gazdálkodás kulcsfontosságú integrációja mellett a helyi igények megfogalmazását, a kulturális értékek és társadalmi preferenciák kifejezését és védelmét nemcsak meghallani de megérteni is kell.

A Tájkép-Hangkép-Víztáj kontextusa javasolt hogy párbeszédek modelljeként szolgáljon, amelyek során konszenzus-alapú célokat és korlátokat megfogalmazó koncepciókhoz juthatunk el, melyek a víz uralta tájak és az erőforrás-használat fejlesztési, helyreállítási és védelmi terveinek részletes szakmai kidolgozásához kiindulópontként szolgálhatnak. Ez a többdimenziós párbeszéd még fontosabb, ha több ágazati érdeket és célt kell egy ún. nexus kapcsolatban figyelembe venni.

A Tájkép-Hangkép-Víztáj transz- és interdiszciplináris modellvázat először olyan esettanulmányokban javasoljuk tesztelni, ahol a legtöbb erőforrás-használati és védelmi interakció térbeli kiterjedése megfelel az érintett emberek által használt, közelről ismert és szeretett élettérnek (vagy otthontájnak). Ezeket a „hangokat" kell felfogni és figyelembe kell venni a fenntartható jövő érdekében.

Kulcsszavak
Tájkép, hangkép, víztáj, integrált gazdálkodás, víz-, energia-, és élelmezésbiztonság nexusa.

INTRODUCTION
This concept is developed further on the basis on an article published in the Vasi Szemle journal in September 2021, introducing the Institute for Advanced Studies (FTI–iASK) operating in Kőszeg, which was written by myself, Gergely Tóth and Zoltán Mizsei under the title "Landscape, Soundscape, Waterscape: Outline of the principles of future-oriented regional development" (*Bogárdi et al. 2021*). The fact that this article appeared first in Hungarian language in a journal published for a general audience in Vas County can be considered a program in itself. According to its message, the basis for successful integrated stock and resource management must be wider, "more integrated" as we previously thought. At the beginning, the debates, plans, and ideas of traditional professional circles need to be "socialized" involving representatives of the civil society, affected citizens and other legitimate stakeholders. Perhaps this is the way to "level the playfield" for successful and sustainable integrated water and land management. The "Landscape, Soundscape, Waterscape" (L-S-W) concept was introduced (also in Hungarian language) to the water resources management community in late 2022 *(Bogárdi 2022)*.

The word landscape may have an undisputed meaning for both professionals and the public. However, if we are looking for the action-related (verbal) form of the word (landscaping), the concepts of park creation or landscape modification come up, while for example landscape management is interpreted as an agricultural concept. If we wanted to take into account everything that characterizes a landscape, either aesthetically or economically, as well as everything we want to consider in its utilization, transformation, or even preservation and we would try to summarize that all in one word, we could easily get confused. Yet, if we wanted to express the physical appearance, functionality, and cultural aspects of a certain part of land (which of course includes the built environment) in a broader context simply, in one word, we could do it best with the single word "landscape".

We would search in vain for the word *soundscape* in English or American dictionaries 30 or 40 years ago. However, its definition appears on the internet as a virtual emotional environment that we create with the help of sound. The expression clearly gets a musical interpretation, which another definition of the word expresses as "electro-acoustic composition". But similar to landscaping, there is also a different interpretation. I do not want to elaborate on these in a paper dealing primarily with water and land management. However, it should be added to what has been said so far that, for example, "soundscaping" refers to the architectural creation with which we can create special sound effects. The origin of the word dates back to the 1950s, from when it began to be used primarily in relation to the description of a city's sound environment. The thinking together and collaboration of music teachers, composers, and urban planners began, which is at least as ecological as it is musical. The process seems to develop in both ways. The integration of music and sound into efforts to implement the sustainable development goals is discussed by *(UN 2021)* and *(Grant et al. 2021)* whereas research in musical history started to investigate how non-musical sound events and effects are reflected in musical compositions. The term “soundscape” can be also interpreted as a “reincarnation” of antique/medieval terminology using a classification of the different spheres of the world based on their sounds like “musica mundana” (music of the cosmos, referring to the harmony in nature), “musica humana” to describe the unity and harmony of soul and body and “musica instrumentalis” to describe audible music, human singing but also industrial sound pollution.

The word *soundscape* therefore, as a collective name for the acoustic characteristics of the built and natural environment, includes the perception of the sounds and echoes of a landscape through our hearing. They can be mapped, recorded on sound recordings.

Formulating development or change proposals and recommendations can have an impact on the livability of the present and future of a given landscape. Broadening the concept further, the *soundscape* can characterize the cultural and social "sounds" of a landscape or region, which can be harmony or even dissonance depending on how proposed changes, or development ideas are perceived. Moreover, moving away from the acoustic sphere, we can also characterize the history, heritage, and intellectual radiation of the landscape with this collective term. Similar to the term *landscape* describing the concept related to the landform, settlements, vegetation and use of the considered area, we can say that the *soundscape* is the most poignant term that summarizes the intellectual, cultural, political, in short, social vibrations of a region and the "noises" they cause, which we must take into account from the perspective of both the *landscape* and the *waterscape*.

The word *waterscape* is defined by the *Merriam Webster dictionary (1980)* as a water or sea view. Of course, water, in whatever form it appears, is an integral part of the landscape. With the word *waterscape*, we want to emphasize two important roles of water. Those landscapes whose main feature is the presence of water can be called *waterscape* due to this fact. This includes valleys of larger rivers, islands, interconnected lake systems, river deltas, but also marshes and wetland habitats. Even if the water that gives the name is not necessarily visible, like in a posh spa or karst cave system, both can be mentioned as a waterscape. The essays of *Z. Karvalics (2016)* and *Takács (2023)* can be mentioned as excellent examples of the description and interpretation of waterscapes in contexts of urban settlement type land use and rural landscape respectively.

The term *waterscape* does not monopolize the landscape for water, but emphasizes the landscape-forming role of water, its dominance in the landscape, and its interweaving with the other elements of the landscape. Beyond this role, water is not only a prominent part of the given landscape, but – especially in the case of watercourses – it is also a connecting link between several consecutive or even distant landscapes. Due to its liquid state, its dissolving and transporting capacity, a certain dependency relationship is also established between the landscapes formulated along the watercourses. It is no coincidence that in this interpretation, human civilization began to develop in those landscapes whose existence and productivity were associated with the presence of water. We could also say that the ancient river civilizations were predominantly *waterscape*-based.

In our country, primarily the Danube valley, the backwaters of the Tisza and the Tisza Lake, the inner continental delta of the Danube in the Kisalföld (Little Plain, the areas around Szigetköz and Hanság) and our lakes can be referred to as a *waterscape*. Despite being a standing water, Lake Balaton is a decisive connecting and landscape-forming factor in the integration of the northern and southern coastal regions including the surrounding natural and managed wetlands.

WHY IS THE LANDSCAPE – SOUNDSCAPE – WATERSCAPE CONCEPT NEEDED?

It became clear in the last decades of the 20th century that the management of natural resources, goods and ecosystem services within the development of regions at any scale will not be sustainable if the proposed interventions consider the different factors of development separately. The plans and the subsequent interventions, infrastructure, and other technical solutions needed to implement them were generally discussed and developed within a traditional, technically defined professional system. All this during a process in which the voice and opinion of those involved mattered little. This so-called top-down planning and implementation practice is not only outdated within the frameworks of pluralistic democratic societies, but increasingly unfeasible. Continuing the terminology of the above-mentioned triple "scape" concept, we can say that traditional development paradigms almost completely neglected the *soundscape* as an integral part of planning and implementation. At that time, the *soundscape*, if at all, could have been imagined as the noises of belated social resistance. The example of the planned nuclear power plant on the Rhine River at Wyhl, Germany showed that a "soundscape", which articulated previously ignored emotions and resistance loudly, albeit late, was enough for the project to be shelved and abandoned at the level of hydraulic laboratory experiments (*Bogárdi 2022*).

The disadvantages of the practice of implementing separate efforts are sought to be eliminated by numerous initiatives. Using the example of water resources management, the idea of integrated water resources management has a history of more than three decades (*Ibisch et al. 2016*). Some sources trace its origin even further back, but the practical efforts were not really attempted in implementations before the early 1990s. According to the principle of integrated water resources management, it focuses on the different forms of water, the different uses and their stakeholders, but also explicitly considers other related natural, social and planning processes. This multifaceted definition indicates that integrated resources water management is highly case-dependent. This can easily lead (and has led) to the practice of trying to get all completely different approaches accepted as integrated water resources management by the protagonists of the given use.

Integrated landscape management similarly goes beyond the aspects of the suitability of natural elements for a given form of use, and also considers factors related to the purpose of the use of physical elements. These can be economic, social and environmental elements and impacts. The land evaluation guidelines published by the Food and Agriculture Organization of the United Nations (*FAO 1976*) already reflect this approach when it formulates the following aspects:

- The characteristics of the landscape (suitability) should be examined in relation to the purpose of land use.
- The evaluation should take into account the investment (input) and profit (output) factors required on different types of land. (Material, energy and other expenditures and profits.)
- In accordance with special needs, there is a need for cooperation between professionals working in different fields (ecology, pedology, agriculture, economics, etc.).
- The evaluation should be carried out with extensive consideration of the individual characteristics of the area under investigation. It is natural that the land use proposal must be realistic, for this purpose local socio-economic factors should also be taken into account when preparing the complex study.
- Appropriate land use also implies sustainable land use.

In the nearly half a century since the publication of the FAO's cited guidelines (*FAO 1976*), efforts to implement integrated landscape management in practice have most often aimed at integrating agricultural and ecological aspects, rarely reflecting the cultural and emotional needs of the people living in the landscape. It seems that we still have to wait for the holistic approach to fully unfold. The FAO's latest "Landscape for Life" publication also reflects the sustainable food production priority of landscape management (*FAO 2017*). Of course, ecological considerations cannot be disregarded, nor can efficient landscape use be adopted without taking into account the nature and potential of the available resources. This should be rooted in tradition, open to innovation, and consider aesthetic and other aspects (local social groups and various perspectives of visitors to the area in order to achieve a truly integrated landscape management).

The situation is similar with integrated water resources management. While professional representatives of water resources management tried to implement integrated water resources management by considering the relationship between surface and groundwater, balancing the competing demands of user sectors, ensuring coverage based on compromise, and simultaneously ensuring the health of ecosystems, for the interested and affected citizens, integration meant much more about how much their opinion was heard or how much they were able to influence or prevent certain plans.

The consideration of the soundscape here primarily means not Johann Strauss's *Blue Danube Waltz*, numerous popular songs about the Tisza River, or Smetana's symphonic poem titled *Moldau*, but the loud manifestation of the will of the inhabitants of the *landscape* and *waterscape*. Nota bene, the connection of the aforementioned musical gems to the *waterscape* indicates the aesthetic and emotional importance of the landscape and water, which should not be underestimated. I recall the effect of the Russian song "Volga, Volga, maty radnaja" (Volga, mother of our homeland), which did not even need to be sung, it was enough to mention it in a heated professional debate for the opponents of the integrated approach to soften their stand against interdisciplinary approaches in describing possible futures for the Volga Basin in Russia (*UNESCO 2004, Bogárdi 2022*).

In such a situation, it is difficult to take into account the interests and values of those affected, even if the willingness exists, because not everyone is considered to be affected by the given water resources management project, even in the case of a smaller country. There are civil organizations which automatically consider themselves authentic representatives of any affected area anywhere and act as if this were completely their case, irrespective of being residents of the area or not. It is important that the *soundscape* really characterizes the affected region’s “sounds” and does not degenerate to some ideological cacophony.

Despite the problems associated with practical application, the sustainable development goals adopted by the United Nations General Assembly in 2015, contain, as part of the 6th, the water-related goal, that integrated water resources management is to be used in achieving the set targets of the goal.

In addition to integrated water resources management, as the "internal" method of water affairs, the "nexus" principle has gained more and more ground in the last two decades. Here we primarily refer to the most commonly considered „Water-Energy-Food" (W-E-F) security relationship, although one can imagine other nexuses with even more dimensions. The essence of the nexus is the mutual consideration of sectors that have been managed separately so far. The difference between integrated water resources management and the nexus can perhaps best be described by considering the nexus as a "framework condition" for a modern (integrated) water resources management to establish connections to other concern areas (e.g., energy and food security, soil and waste management) beyond its principal focus on water. This role of setting the framework naturally applies to other sectors involved in the nexus as well. The idea of the nexus is a result of the Davos World Economic Forum, which has been widely spread since the Nexus Conference held in Bonn in 2011 (*Hoff 2011*, *Lawford et al. 2013*). The originally sectoral integration-oriented, resource-centered integrated (water) management has expanded into a multi-sectoral task with the introduction of the nexus concept.

Like integrated water resources management, the principles of the nexus are widely accepted. However, the application of both presents serious difficulties in practice. In relation to the nexus, beyond the complexity inherent in it, we can refer to the historically developed strongly different governance and value structures of the sectors involved in the W-E-F nexus, which can be extremely diverse in themselves. In energy supply, we face prices dictated by the world market and mostly private, or at most semi-state suppliers. In many countries (and not only poor ones), food supply, although mostly in private hands, still enjoys massive political and financial support - whether we think of regulated food prices or EU agricultural subsidies. In water-using sectors, primarily in the highly water-demanding agriculture, water charges – if at all collected - are often set below real costs. While no one would doubt that water and daily food are more immediate needs than anything else, the value system and monetary power of the respective sectors are far behind that of the energy sector. Therefore, maintaining the balance of the nexus is only possible by defining and maintaining political priorities. From the perspective of water resources management, this means that it is not just an engineering or other professional/scientific problem but is inseparable from the social aspirations of the time, the value system that defines them, and social discourses. It is with a heavy heart to say, but the sad fact is that water resources management is primarily politics, or in other words, it is led by the reins of politics.

Both the *landscape*, and the *waterscape* economic exploitation, protection, or other transformation usually affects long periods and is, with few exceptions, irreversible. The consequences of misguided steps can thus become a problem for generations. The significant investment needs of the projects involved further underline their social importance and mutual dependence. This, of course, also means political dependence, which cannot be ignored. The *soundscape* to some extent is the social, historical (and of course musical) accompaniment, or even initiator – and as we have seen in the planned nuclear power plant at Wyhl, in Germany – can also be the thwarting of these physical and biological changes.

WHAT DOES THE LANDSCAPE-SOUNDSCAPE-WATERSCAPE CONCEPT OFFER?

The above summary has pointed out some fundamental problems related to the real-world application of the current principles and methods of water and landscape management. Many of these stem from the fact that it is not clearly defined to what extent integrated management and the various nexuses can be considered a philosophy, a professional principle, or even a method, the application of which could (and should) be formulated in user manuals. It is also difficult to decide at what scale and in how many dimensions of the nexus we need to think and act in order to qualify the search for a solution to a problem as integrated, nexus-appropriate and ultimately, which is our main goal, sustainable. The situation is similar with landscape management, with the many approaches to integrated land use, the foundations of which also look back over many decades (see, for example, the FAO land evaluation guidelines from 1976), but the practice of which is still far from harmonious solutions. Worth to mention in this context the politically very "opaque" land- (and hence also water) grabbing practices by certain countries and international firms, especially in Africa. Corruption, the lack of governance and government control would render all of our integrating and nexus efforts futile in face of the fait accompli created by secret land deal contracts.

The starting point of the Landscape–Soundscape–Waterscape concept is similar to integrated management in that it is based on the natural features and stocks of the area considered. In contrast to integrated water resources management, the proposed Landscape-Waterscape integration adopts the repeatedly formulated (and professionally "demanded") integrated consideration and joint management of land (soil) and water resources. This integration, which seems inevitable in the long run, would be greatly facilitated if sectoral governance were in one hand (under the purview of one common agency or ministry). It should not be concealed that this integration is not simple, because these two basic natural treasures - similarly to what I mentioned in connection with the nexus - face the problem of different governance systems that have historically developed. We can mention that we can buy land, which can thus be private property, which, however, cannot apply to waters. Water is a mobile resource. Partially it can be considered as a stock, but for sustainable use even more its feature as a flux with an annual cycle should be emphasized. In comparison land is practically "fixed", although its quantity (through land use changes like construction, or erosion) and quality (soil degradation) are also variable. This signifies a fundamental problem. We are convinced that we can only attempt the integrated management of land and water primarily in well-defined, human-scale regions. Such a region could be a landscape with its contained settlements, infrastructure, agricultural or forestry, and nature conservation areas, or a *waterscape* (relatively homogeneous watershed, island, lakes with their coastal zones, etc.) which may be perceived by the affected citizens as their "homescape".

A project area to be tangible by the principles and emerging practices of the Landscape-Soundscape-Waterscape concept should remain perceivable (able to oversee it at one glance) by the individual stakeholders. It may be called a "human scale" approach. Consequently, the dialogue within the Landscape-Soundscape-Waterscape framework must be based on genuine "sounds" originating from the landscape/waterscape, rather than resonating ideologically formulated general opinions.

We are convinced that the Landscape–Soundscape–Waterscape connection does not define a method where the successive steps could almost be "ticked off", regardless of whether we are talking about an agricultural or industrial landscape, whether we are on a plain or in the mountains. The concept of "three scapes" is an attempt to go beyond the strongly technical and administrative nature of previous development ideas, and to formulate goals and seek solutions to problems with active transdisciplinary participation. No doubt that the Landscape – Soundscape – Waterscape consideration and associated discourse and target setting exercise should be started well before any technical planning and implementation.

Although the proposed integration is based on the joint evaluation and exploitation of natural and human resources, we do not consider it exclusive that the line of thought necessarily has to start from a problem related to water or land. The Soundscape, as the voice (or echo) of the region, can articulate an important social value or need, a future-oriented aspiration and hence the Soundscape can also be the starting point of contemplations and setting goals, targets and constraints for the subsequent professional planning.

The researchers and colleagues belonging to various scientific and cultural fields working together within the Institute for Advanced Studies in Kőszeg (FTI-iASK), and their research partners, need to make a joint effort to develop further the concept outlined here and test its practical usability.

The integrated water resources management (IWRM) has been conceived more than three decades ago. While the principle is widely accepted, officially endorsed and recommended, its practical use and the targeted improvements in water resources management are still lagging behind expectations. This is partially due to the different definitions and interpretations of the concept *(Johannesburg Plan of Implementation 2002, Bogardi and Szöllősi-Nagy 2003, Karthe et al. 2021).*

A proposed PhD research should be based on a comparative analysis of the diverging conceptual and attempted practical applications. Based on these results the research should lead towards a widely acceptable and practically relevant model of IWRM. Particular emphasis is needed to highlight and tackle the differences between integration of various professional concern areas and disciplines (such as water engineering, soil science, land use, agriculture, environmental protection, transportation etc.) and the incorporation of societal actors (affected citizens, civil societies etc.) in the decision making and implementation processes.

In this regard the viability of the landscape-soundscape-waterscape concept and its possible linking with IWRM (and eventually also that of appropriate nexuses) should be elaborated and tested.

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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.

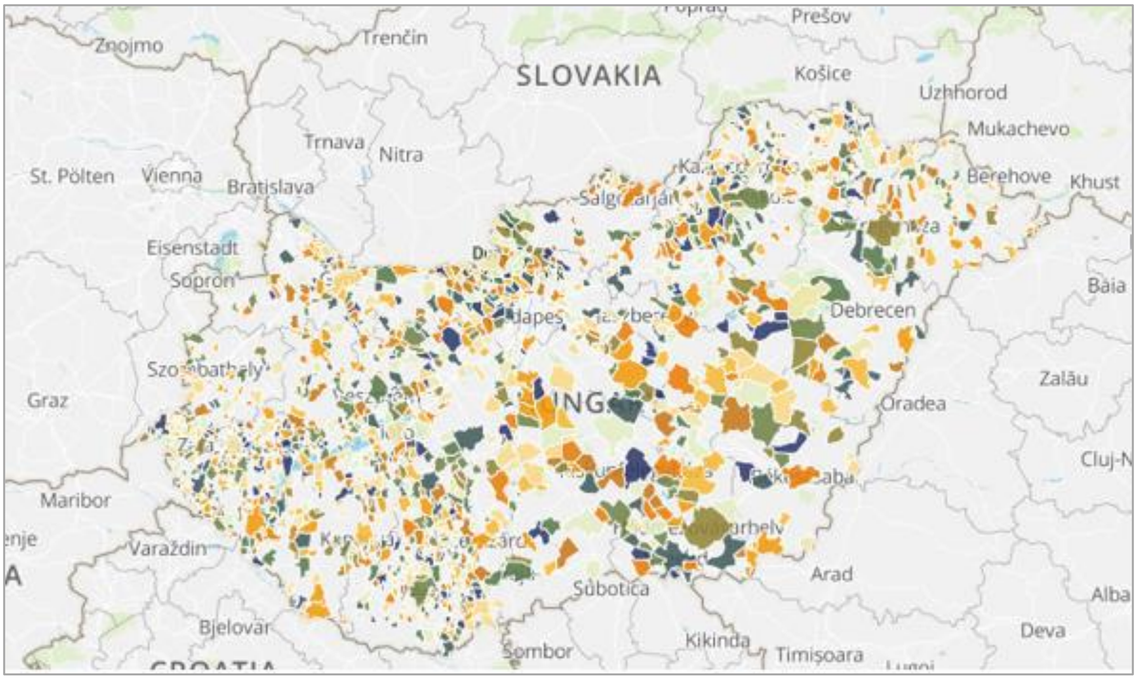

Figure 1. Municipalities affected by "vis maior" events (cloudburst, storm surge, flash flood) in the period 2011-2020 (MultiContact 2023)

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

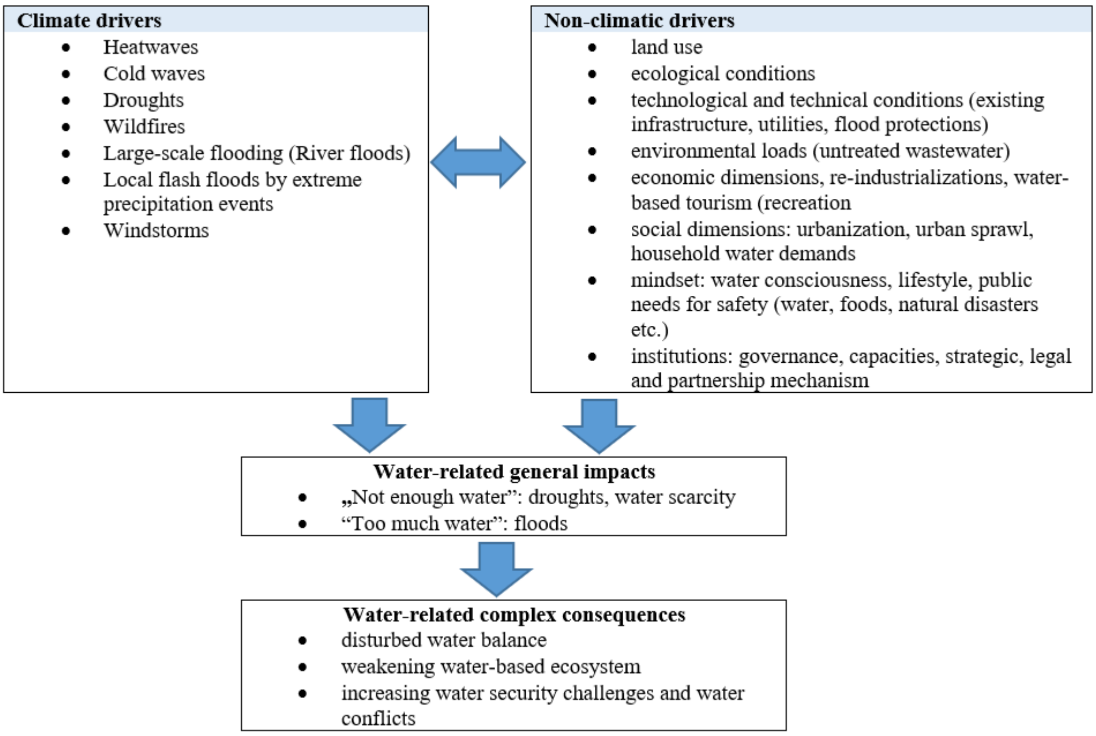

Figure 2. Typology of water-related climate risks and drivers (own edition)

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, nuclear)	+	++	+	++	+
	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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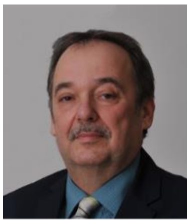

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System behaviour of water and environmental law

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Abstract

Rules and procedures of mechanical things might be revealed by a piece by piece, linear analysis, while large unorganised masses can be approached by means of statistics. However, there is a vast middle layer of entities with complex structure and hardly calculable non-linear procedures that offer themselves for system science. System thinking makes possible that we understand wicked problems, perfect storms and other similar phenomena that otherwise resist the old, positivist, silo-thinking. In these cases, we learn that elements of a system form structures, develop procedures through which they together produce such results that could have been unimaginable solely by the elements alone.

Is it possible that with the help of system thinking we will be able to better grasp the essence of laws, moreover, we can design and implement laws with higher effectiveness? Is law a system? Or rather a complex tiered system of sub-systems, embedded into larger social-economic systems? In order to test these questions we analyse two intriguing sets of legal problems, to learn if we can describe and interpret them as systems that are – like systems generally – protecting their integrity with accommodation and resilience. The first example is the development of the segment of water laws that regulates drilling of small size wells for farms, where we see a 140 years process off gradual, more and more successful accommodation to the double social needs of protecting the interests of small farmers and sustainable development in respect to underground waters. This system resisted successfully an abrupt change that would have not fit to its goals. The second example is climate law as such – a relatively new development in the short history of modern environmental law, which can be hardly called a success story, because of the stiff resilience of the relevant branches of law. Indeed, resilience of law, as a complex, flexible and effective system does not always work according to our wishes.

Keywords

System thinking, emergent features, accommodation, resilience, legal systems, water law, small wells, environmental law, climate law, energy law.

A víz- és környezetjog rendszer viselkedése

Kivonat

A mechanikus dolgok sajátosságait megismerhetjük az elemeik részletes vizsgálatával, szisztematikus elemzéssel, lineáris logikával. A nagy, de szervezetlen tömegeket statisztikai módszerekkel kutatjuk. Van ugyanakkor a jelenségeknek egy nagy közbenső rétege, amit nehezen kiszámítható, nem-lineáris folyamatok jellemeznek. Ezeket legjobban a rendszertudományok segítségével értelmezhetjük. A rendszer megközelítés lehetővé teszi, hogy megoldjunk olyan komplex problémákat (wicked problems, perfect storms stb.), amik egyébként ellenállnak a hagyományos pozitivista siló-gondolkodásnak. Feltárjuk, hogy a rendszer elemei hogyan szerveződnek struktúrákba, milyen folyamatokat alakítanak ki és együtt hogyan hoznak létre olyan eredményeket, amikre külön-külön az elemeik képtelenek lennének.

Lehetséges, hogy rendszer elemzéssel képesek lehetünk a jog lényegének jobb megértésére, sőt hatékonyabb jogszabályokat tudunk alkotni és eredményesebben alkalmazhatjuk azokat? A jog is egy rendszer? Vagy még inkább alrendszerek egymásra épülő rendszere, ami maga is beágyazódik nagyobb társadalmi-gazdasági rendszerekbe? Avégett, hogy ezeket a hipotéziseket ellenőrizhessük, két jelentős konkrét jogi problémát vizsgálunk meg és megkíséreljük őket rendszertudományi fogalmi keretben értelmezni, különösen azért, mert szembetűnően őrzik a rendszerük integritását, ellenállnak a külső változtatási törekvéseknek. Az első példa a vízjog egy részének, a kis kapacitású mezőgazdasági kutak létesítésével kapcsolatos szabályoknak mintegy 140 éves organikus fejlődése. A jogterület fokozatosan alkalmazkodott a helyi agrárérdekek és a felszín alatti vizek fenntartható kezelésének kettős feladatához, viszont figyelemre méltó sikerrel ellenállt egy hirtelen, rendszer-idegen változtatásnak. A másik példában a klímajognak, ennek a viszonylag új jogágazatnak a fejlődését elemezzük, ami közelről sem nevezhető sikertörténetnek, éppen azért, mert a vonatkozó jogforrások rendszere szívósan ellenáll a változtatásnak. Azt találjuk, hogy a jog, mint összetett, rugalmas rendszer képes megőrizni az integritását, akkor is, ha ennek nem mindig örülünk. Ennek megértéséből, felhasználásából ugyanakkor talán új megközelítések, hatékonyabb jogfejlesztési, jogalkalmazási stratégiák is következhetnek.

Kulcsszavak

Rendszer megközelítés, emergens tulajdonságok, alkalmazkodás, ellenállás, jogi rendszerek, vízjog, kisméretű kutak szabályozása, környezetvédelmi jog, klímajog, energia jog.

SYSTEM THINKING: FOCUSING ON STRUCTURE, PROCEDURES, AND EMERGENT FEATURES

Theories of science establish the existence of a scientific topic when it has a clear-cut, generally agreed definition. In the case of systems science, we might observe that the three basic elements of systems are consequentially mentioned in various sources, together or separately, mostly in a concise, aphoristic manner:

- Complex systems are ones in which the properties of the system are difficult to infer from the properties of the parts.
- Complexity comprised of dynamic relationships rather than the sum of segmented parts.
- An organization is best understood and improved if all parts of the system — people, procedures, norms, culture, technology, infrastructure, and outcomes — are understood as relational and interdependent parts of a complex system.
- Systems of law can be described as a collection of elements and — crucially — the connections between and among them (*Ahlström 2021, Klonick 2023*).

From other sources we can add some more:

- A systemic view embraces the idea that a system is a set of interconnected parts that, over time, produce a unique pattern of behaviour.
- According to systemic view the performance of the whole cannot be reduced to the performance of the individual parts.
- Emergent properties of an entity are properties possessed only by the entity, not by any of its components or by the simple aggregation of the components (*Heijden 2020*).

This line of opinions can convince us that system science has arrived at the core definition and at a generally shared understanding of the concept of systems. It does not change this statement that instead of structure' and „procedure" some authors use „patterns" and „interrelationships" (*Freeman et al. 2014*), which fully cover the basic twin concept in system sciences. Furthermore, Donella Meadows, one of the leading representatives of system sciences uses the terms „stocks" and „flow", which I think are closely related terms, as well (*Meadows 2008*). Possibly, coming from the more cybernetics-oriented school of Jay Forester, Meadows opted for terms that are easier handled by mathematical equations.

We can conclude that the basic tenet of system thinking is that in a system certain elements get together, they interact, and their continuous or regular flow of information will build up regular paths that solidify in a structure. The structure, in turn, will make some procedures easier or preferential. This way *structure* and *procedure* mutually determine each other, and they represent the central terms of system thinking. Structures can be hierarchical, cyclical and, most importantly, they can take a form of a grid, or network, with nodes, where several parts of the structure meet.

A system, furthermore, will produce some new qualities the elements in themselves could not. We call these new qualities *emergent features*. These products, results or events are readily observable in connection with the operation of a system. However, like the large, submerged base of an iceberg, patterns of the structures and procedures that give rise to them are not always as perceptible as the emergent features themselves (*Pierson-Brown 2020*).

As follows from the three basic parts of its definition, system thinking means a holistic evaluation (we call systemic) of the whole, rather than just a systematic, piecemeal examination of the elements. Such a complex approach allows for deeper understanding and more efficient management of several natural and social phenomena. However, it is up to us, which parts of reality we are willing or able to encompass.

Boundaries of the systems

In studying systems, one of the first tasks we must cope is to determine a reasonably scope of our examination, namely with delineating what shall constitute a system for us and what shall remain outside our scrutiny as the outer environment for our system. Usually our means, goals or expectations from the system determine our selection of the boundaries (*Meadows 2008*).

Surfacing is a related discipline. While universal connectivity is a central tenet of systems thinking, when it comes to system recognition, the goal is not to identify the infinite breadth of connectivity. Surfacing involves raising one's conscious awareness of a discrete set of structures responsible for a behaviour or outcome of interest. Setting boundaries moderates the set of elements at play, focuses the scope of our problem, in the same time it defines the context and highlights the outside connections that might be important for the observer (*Pierson-Brown 2020*).

Examples of system approach from all walks of life

System thinking can better explain a line of dynamic non-linear behaviours, complex socio-economic problems from cognition to social networks. The literature offers a very colourful collection of practical (and sometimes less practical, but very spectacular) examples:

- the ocean and the waves
- the forest and the trees
- predator-prey relationships and changes in population
- market reactions to new product introductions
- inventory oscillations in supply chain management
- instability in some developing countries
- the failure of drinking water systems in Togo
- the rationale behind John Hinckley's attempted assassination of President Reagan
- apparently self-destructive behaviour and provocative actions of extremist groups
- the failure of research in motion to remain competitive in the Smart Phone industry
- the community platforms on the Internet a „global online speech controlled and governed by private platforms"
- why many well-intended systematic and reductionist optimisations of regulatory systems such as for instance marijuana laws often do not achieve their desired results (*Heijden 2020, Klonick 2023, Monat and Gallon 2015*).

Types of systems

We might see some merits in dividing the multitude of systems according to several viewpoints. Quite obviously, they can be big or small, the scale of a system may range from extensive *global systems* (such as, the global financial system) to much *smaller systems* (such as the supply of electricity to customers within a community network or down to the microscopic world) (*De Sousa 2020*).

There is a classification of systems that closely relates to the previous topic, recognising or setting the boundaries of our examination. In certain cases, these boundaries are quite rigid, in other cases more flexible. Based on their interrelations with their environment, *closed systems* are systems in which no elements enter or leave the system – this might be an extreme case or even only theoretical. Most living systems, such as society and its (sub)systems, are *open systems* i.e. systems where there is a flow or exchange of several elements, resources, information etc. between the system and its environment (*Heijden 2020*).

A further important grouping of systems is a division of *human made vs. natural systems.* The latter category encompasses living ones, such as plant and animal species and their groups (colony, pack, herd – we have amazingly long list of names for the same phenomenon: group of animals following a pattern of behaviour different from that of the individual animals*)* and non-living systems. In some systems the non-living systems serve as the habitats of living systems, while in the case of soil, for instance, the living systems represent a specific part of a complex system of mixed type. Human made systems might also be nonliving, such as *technological systems* (e.g. systems that transform, transport, store or control materials, energy, or information) and *socio-economic systems* comprising people, institutions, elements of culture, practices, and services (*De Sousa 2020*).

From the above groups, naturally, systems of *humans or of human groups* deserve special attention. Reflexivity of humans and the different worldviews (their unique personality and the way they perceive themselves and their relations with other persons and with their circumstances) might make it difficult to understand these so-called *soft systems*, let alone to predict their behaviour (*Heijden 2020*). Even if so, system structures, procedures and behaviour are not totally altered in such systems, either. Moreover, system thinking will not model individuals, but rather handle empirical quantities that are associated with aggregates of individual behaviours (e.g. market confidence). This is not yet the abstraction level of statistics, but way beyond the individual specialities, therefore it belongs to the realm of system science.

Methodological differences in understanding and managing systems might make sense to forming further groups of systems. Here we can differentiate *complicated vs. complex systems*. A complicated system has many elements and procedures, but the parts and their interactions are calculable, predictable. In such complicated systems causes and effects operate mostly linearly. In the complex systems, though, there are many unknown, incalculable elements and procedures, often non-linear, and they are, therefore, less manageable (*Meadows 2008*).

These different categories of systems are overlapping, naturally, but these most certainly countable types of systems encourage us to examine the systems' behaviour in more depth.

Protection of the integrity of systems: adaptation and resilience

If we consider the system as an organised unit in its environment, we will see that it strives to maintain its borders and internal composition through *adaptation*. In case an outside force threatens with intrusion or an inside force with rebellion, the active set of responses from the system might be called *resilience*. Adaptation seems to be forward looking, an action directed by the system as such, resilience might be rather an answer to a challenge. They are usually not rigid procedures; systems are likely to be in a state of *dynamic equilibrium*. A system can always move or be pushed out of balance, factors within or outside the system sometimes may affect the overall behaviour of the system in an unexpected way. In other words, systems often show *nonlinear* behaviour in which a small change in initial conditions can lead to a radical change in a later state of the system or, inversely, a large change in initial conditions might not lead to any significant change in later states of the system (*Heijden 2020*).

Integrity of the systems is ensured by their self-producing, autonomous, and self-referential nature that is called *autopoietic*. Through autopoiesis durable systems can keep internal mutations and external enactments at bay (*Heijden 2020*). We can add that the autopoietic systems maintain a delicate balance between openness and closeness in order to protect and develop themselves (*Faragó 2017*).

The most important tools a system achieves and maintains its integrity with, are the different internal procedures we call feedback. The *balancing or stabilising feedback* (also referred to as negative feedback*)* mechanism aims to direct the system towards equilibrium by correcting imbalances. Just to bring an example of social level regulatory system that many authors use: if the level (stock) of infringement of the laws and regulations at a certain field of administration grows (flow), the regulatory agency may provide feedback, such as more and more careful inspections and more severe punishments for those found in noncompliance. The *reinforcing or amplifying feedback* (also referred to as positive feedback) can be shown in a related example from the same administrative system. Once the members of the regulated community perceive rare and lenient enforcement actions, most of them will spare the compliance-costs (in Heijden's words: „a sector may result in firms seeking to cut corners"). Other role-players in the given sector will experience that, probably as an unfair competition and will have to infringe the law themselves, too, pushing the system out of its original equilibrium (*Heijden 2020*). Positive and negative feedback loops exist together. In the above example, some of the firms might start experiencing the initial turn in the policy of the administrative authorities and change their behaviour for better, while others still happily wade into the swamp of noncompliance. Positive and negative feedback loops can be quite complicated, going through a line of internal stations (stops, perceptions, evaluations, decisions etc.) and this way they form a complicated pattern in most systems. That will create unforeseen effects and delays following (we avoid here the expression „resulting in") any of the internal and external effects exerted on the system.

People on the regulatory side might see this complexity as a terrible disorder, a kind of policy resistance that should be broken down with even stronger measures. *Freeman* cites Sterman „Our decisions provoke reactions we did not foresee. Today's solutions become tomorrow's problems. The result is *policy resistance*, the tendency for interventions to be defeated by the response of the system to the intervention itself." Freeman refers to California's failed electricity reforms, and road building programs that led to increased traffic congestion, and another generally cited example, the evolution of antibiotic-resistant pathogens owing to stronger and stronger healthcare measures. These are all the same from system science viewpoints: 'At the root of this phenomenon lies *the narrow, event-oriented, reductionist worldview* most people live by... There are no side effects – only effects. Those we thought of in advance, the ones we like, we call the main, or intended, effects, and take credit for them. The ones we didn't anticipate we might account to policy resistance (*Freeman et al. 2014*).

Systems are in a state of constant change. A forest, for instance, typically goes through cycles of growth, collapse, regeneration, and new growth. In the early part of the cycle's growth phase, the number of species and of individual plants and animals increases quickly, as organisms arrive to exploit all available ecological niches. The forest's components become more linked to one another, enhancing the ecosystem's „connectedness" and multiplying the ways the forest regulates itself and maintains its stability. However, the forest's very connectedness and efficiency eventually reduce its capacity to cope with severe outside shocks, paving the way for a collapse and eventual regeneration (*Green 2016*). We might notice that this evaluation of a forest history depends on our scope of vision again: if we consider the forest and its environmental resources a system, we will not see circularity, just simple feedback mechanisms.

Changing the systems

Why lasting change on a system is so difficult to effect? Structural resilience is a system's ability to survive and persist within a variable environment. However, while relatively stable, systems are adaptable and can be changed - depending on the weight, or consequence of that outside force. Leverage (opportunities to intervene in and disrupt systemic outcomes) can be created in several ways. Donella Meadows in her famous book has set 12 levels of leverage tools, organised into an order of their expectable effectiveness (*Meadows 2008*). At the beginning of this line, we find changing the elements of a system that can possibly alter what the system produces, but often systems stay intact even after a full turnover in their elements. Systems can dramatically change, however, by reorganising their structures, while it usually demands big investment. Systemic outcomes can also be affected by altering procedures, or quality of the connections (e.g. information channels) between the elements. Whenever the intervention is not significant or consequential, the system may prove resistant to reforming efforts. Changing the goals and values that underlie the formation of a structure is perhaps the most impactful, as well as the most elusive means of effecting systemic change, because it leaves the work of actual changes on the system itself.

Generally, we must be careful not to hurry with our evaluation that a system is capable for changing or not. The system will work through our interference. It needs time to observe or perceive the effects of the complex effects of balancing or reinforcing feedback. Urgent and forceful effects can cause overreaction, while influences that last too long can be ignored in favour of more immediate stimuli (*Meadows 2008, Pierson-Brown 2020*).

In complex systems, a significant change results from the interplay of many diverse and apparently unrelated factors. Those of us engaged in seeking change need to identify which elements are important and understand how they interact instead. A good example of long-range systemic work is education. Raising a child is iterative, an endless testing of assumptions about right and wrong, a constant adaptation to the evolving nature of the child and his or her relationship with their parents and others. This example highlights the importance of time and application of the proper attitudes (*Green 2016*).

Attitudes when working with systems

All these features of system behaviour teach regulators on cautiousness and patience (*Meadows 2008*). Such situations require an *increased tolerance of failure,* continuous feedback on effectiveness, and a *willingness to foster diversity and innovation* (*Freeman et al. 2014*). The so-called *wicked problems* that allude our regular, linear way of thinking, are best resolved through a planned process with input from multiple sources in an atmosphere where scientific certainty is tempered by the perspectives of community stakeholders (*Töpfler et al. 2011*). Therefore, system planning, influencing, managing complex systems cannot be managed in one step, it is an *iterative, tiered* procedure, where the actors shall stop time to time, consult as much as possible and see what the possible next steps (*Green 2016*) could be.

The unavoidable uncertainty of system thinking is usually handled by system modelling that enables several rounds and versions of „what-if analyses" and designing a line of potential interventions through scenario analysis using the known rules of endogenity, positive and negative feedback, delays, and mutual causality (*Freeman et al. 2014*). From communication science approach, the possibility of such remote, abstract way of handling of serious life and social-political problems reminds us to the basic function of languages. From this angle, system thinking might be called as a future, second language of humankind that will allow us brave imaginations about our environment and development paths without having to try all of them. This way, system thinking, similarly to the great invention of languages, can help humans to experiment without pain and exchange their results quickly and effectively. No doubt, system thinking has the capacity significantly transform human thinking and communication.

IS LAW A SYSTEM?

Bertalanffy (*1968*) argued that the ideas about the basic operation principles of natural organisms could be extended to complex systems of any kind. The relationship between structure and behaviour observed in organic systems, like cells and ecosystems, could also be observed in human social systems. Therefore, the methodology of understanding and managing such more complicated systems will follow the same logic as in the case of simpler systems (*Bertalanffy 1968, quoted by Heijden, 2020*). Naturally, systems are themselves organised in larger systems, where at upper layers there appear usually more and more complex, therefore newer, and newer emergent qualities. This means that while we accept the general system nature of such complex social systems as governance and law, we observe the differences, too.

Indeed, law is a very complex, hierarchical system, where we have the choice of at least four levels of systems for our investigation. (1) Even a single piece of legislation shows the basic system features: elements (people, organisations, territories, situations belonging to the scope of regulation, legal orders, sanctions etc.), their structures (persons and institutions of legal subjects, their rights, and responsibilities) and procedures (inherent or explicit procedural rules, mostly of feed-back nature, such as monitoring and enforcement). (2) Certain legislative goals are usually served by a set of laws, for instance a parliamentary act (determining the basic functions and tasks), a governmental decree (focussing on principles, scopes of authority and many other issues) and a ministerial decree (containing the technical details). (3) A branch of law (water management law, water protection law, environmental law, construction laws etc.) will also behave as a system, with added financial, institutional, educational, and socio-cultural elements. (4) The whole legal system (named this way, not by chance) will form a coherent system, too, with constitutions as a major goal setting and structure determining element, with legal principles and with rich international legal connections (which we might call level 5). Furthermore, we need to signal that law is inherently part of the larger system of governance and administration (level 6). Many of the system features, especially the emergent features of one certain level of law can be realised most clearly with the help of examination taking place on one or two levels higher.

Some scholars, whom we can strongly agree, argue that for effective legislation and successful legal practice an inherent (instinctive) or explicit system thinking is indispensable. One cannot understand an area of law from just reading a single provision of law not even a single judge's opinion in a case. Moreover, to really understand how legislation operates as a system, one must pay attention to many of the social, economic, and political structures, institutions, and organizations with which it interacts, which we called level 6 in our above description (*Pierson-Brown 2020*).

Nevertheless, this system approach breaks through with difficulties in our inherently linear way of thinking, especially in social sciences. Heijden, who made an exhaustive survey on the intersection of system sciences and law, had to establish: „we have little evidence that thinking in systems will improve regulatory performance" (*Heijden 2020*). Other scholars are even more sceptical. Vinuales, for instance, doubts that the environmental laws and policies of, say, the United Kingdom, Japan, South Africa, or Brazil have any specific coherence or systematicity (*Vinuales 2023*). This latter comment in the field of comparative environmental law can also be an argument for the other side, though. It would be hardly possible to compare several laws or legal branches of several countries of quite different history and legal culture, unless there are systemic backbones in all of them, ensuing from their identical social functions and roles.

Interestingly, debate on the system nature of law had had a long history that started way before the tenets of system sciences crystallized.

Law as purpose, law as tool: acceptance and denial of its system nature

Acknowledgement and almost a sheer denial of integrity of law were both present in the history of thinking about the nature and essence of law. *Kjaer* (*2022*) has an elegant analysis of the development of social functions and scientific understanding of law. He establishes that in the 19th century and especially in the German Historical School legal scholars observed law as a coherent and rational system, where norms fit and support each other. Moreover, according to them, law is built up largely on its own basis and not on external moral, political, religious, or other factors. As they put: „the law became an end in itself", in the sense that the content of law emerges from „the people" and is a faithful reflection of „society" rather than of „state". This concept was closely related to a line of important achievements of social sciences and movements of the Enlightenment, starting from the division of powers and a strict formal equality of all persons, in a perfectly legally regulated society. Understanding law as a purpose enhanced the progressive liberal ideas of a democratic state and promoted a neutral public bureaucracy after the dark age of arbitrariness of kings and their local and regional lords.

In the first half of the 20th century, though, law was rather understood as a tool for accomplishing ideological projects, i.e. legal scholars started to deny its independent system nature. This idea came from both the extreme right and extreme left, or later, even from the welfare society – on a formal level, all the three ideological streams have embarrassingly similar concept of the social-political nature of law. Notably, the differences and ramifications of the two approaches have formed the central part of the famous Schmitt-Kelsen debate, too (*Baume 2009, Scholz-Karl 2021*). This way the winning concepts of „law as a tool" seemed to prevail all over the world, up until in the 70ies, when the neoliberal wave of „law as an obstacle" has swept them all away (*Kjaer 2022*).

From system science approach, we need to observe, first, that such historical analyses are unavoidably linear, they have difficulties in revealing the parallel and circular processes and the surviving or recurrent effects of past events. For us, law as a system that strives to maintain its integrity and protects its borders, structures, and procedures, is not a historical momentum, but rather a steady element of the definition of law. However, it might be true, that under several socio-political constellations, integrity of law as a system might work better, while in other times it might give up easier for myopic intrusions from here-and-now political forces. We will see, however, from our two case studies below that, even if environmental law counts to be a brand-new branch of our legal systems and it was formed quite consciously by the realisation of the emerging system of ecological catastrophes, we might call a „voluntarist intrusion into the organic development of law", it has considerable integrity. For the sake of simplicity, we use here the term „environmental law" as a branch of closely related administrative laws, such as nature protection, water protection, water management, landscape, land and soil protection, animal protection and many others. This new-born environmental law fiercely fights against newer interferences that it senses „system alien". Environmentalists and those who are anxious about the future of our civilisation are happy to see when the system of environmental law resists direct economic or political actions that would harm its integrity, especially its long-term goals. On the other hand, as we will see sadly from our second example, environmental law resists the progressive changes, too, if they overlook its system nature and are introduced too hastily.

Progressive or destructive resilience of law

It is a question therefore, if the resilience of the environmental law stems merely from the system nature of law, i.e. it is mostly *value neutral*, or we can expect that the positive changes will be better supported by this kind of system operation. Some of the already existing elements of environmental law indeed, might predetermine a better capability of receiving progressive new impetus. The Rio principles of sustainable development that soon turned out mandatory legal principles in our legal systems, might play a key role in ensuring such positive protection.

Unfortunately, however, at the time being the list of examples of the „negative resilience" of the environmental law systems seems to be much longer than that of the positive examples. Just to mention a few: hopeless fight against city noise and air pollution – „Cleaner Air for Europe" Directive does not seem successful if we consider that almost all Member States have been subjects to infringement procedure; critical waste management problems stay unsolved – implementation of the Environmental Liability Directive is mostly ineffective (*Fulop 2021*); climate law is just in its *nasciturus* phase in Europe and elsewhere and we see no major effects of it on the key policies of the states, such as energy, transport, mining or agriculture (*Fülöp 2023*).

Even though the presumed autonomy and objectivity of law has long been debunked, most traditional legal education courses continue to promote the view that law is a distinct and a self-contained logical system. For a traditionally trained legal scholar, most solutions for any social problems start and end with law. If a certain law's objectives are not achieved, the instinct is to seek explanations for the failure either in the rule making or in the interpretation and application of the rules. However, expanding the scope of examination provides a wider context in which legal rules are made, applied, and contested. By examining law through social-economic sciences, sociology, anthropology, political science, amongst others, one can assess what law can and cannot do, no matter how „perfectly" designed it is. In certain cases, the influence of authoritarian political culture is the most viable explanation for why the declared progressive goals of laws will not fulfil, whereas fundamental rights of people are routinely overlooked or violated without redress. Such cases indicate that the basic assumptions of classic rule-of-law concepts, such as the primacy of the basic legal principles and human rights, do not fully hold. Taken an example from cultural anthropology research, in several developing countries officers in the environmental protection agency responsible for the enforcement of anti-pollution regulations are reluctant to enforce the law when the violation is caused by a government entity, and when confronted with that by outside researchers, they are indignantly saying that the government cannot sanction the government (*Hanschel et al. 2022*).

EXAMPLE 1: WATER MANAGEMENT SYSTEM DEFENDS ITSELF FROM NEW LAW ALLOWING UNCONTROLLED DEEP DRILLING OF SMALL-SCALE AGRICULTURAL WELLS

Wells serving the needs of households and surrounding smaller agricultural wells represented a steady legal-political dilemma in the last two centuries. As a rule in the history, while left wing, liberal governments favoured city population, right wing governments kept relying on the countryside dwellers and tried to support their strives (*Cribb 2019*). In all cases, however, reasonable water management regimes tried to balance between these political drives and the sustainable use of underground waters, representing larger and larger value, as surface waters become less reliable because of overuse, pollution and changing climate. Roughly, these factors have been strongly influencing the behaviour of the system of water management law relating to small agricultural wells.

Directions of legal regulation on the control of small agricultural wells

The nineteenth century water law stipulated that „new well in the villages and in their populated surroundings shall be drilled at least 3 meters away from existing other water sources, such as wells, lakes, springs or channels, while in the central parts of the villages this distance shall be 15 meters". Those wells shall be limited to the regular needs of local life.

After the long life first water act, the 1964 communist Water Act established a stringent general permitting procedure, and exempted only those wells that did not reach further than the first water layer. After the change of regime, a 1992 Governmental Decree lightened the permitting responsibility with decentralizing it to the local notary. The newly established independent environmental inspectorate, as well as the water management directorate formally could have a say in these cases as co-authorities. [Governmental Decree No. 18/1992. (I. 28.)]. However, this milder permitting regime related to all kinds of agricultural wells.

From 1996, the new Water Management Act and its executive decree narrowed the scope of authority of the municipality clerk to wells serving only domestic water needs. [*Article 28 (1) of Act LVII of 1995., Article 24 (1) of Governmental Decree No. 72/1996. (V. 22.)]*.

A 2010 modification of the Water Management Act, turned into an overly liberal direction with establishing the category of „activities bound only to announcement to the authority" [*A modified Article 28 (1) of the Water Management Act*]. The environmental and water management authority could have the right to visit the site and monitor the activity, while it was not realistic, considering the very limited capacity of this authority.

The modification of the Water Management Act in 2018 opened the way to a totally free drilling of small household wells in the country. The modification was explained by the minister forwarding the bill in more details: the goal of the government was to free from all permitting and announcement responsibility the small household wells which are shallower than 80 meter.

In the following chart (*Figure 1.*) we try to describe the one and a half century long development of the regulation of drilling wells for small countryside users.

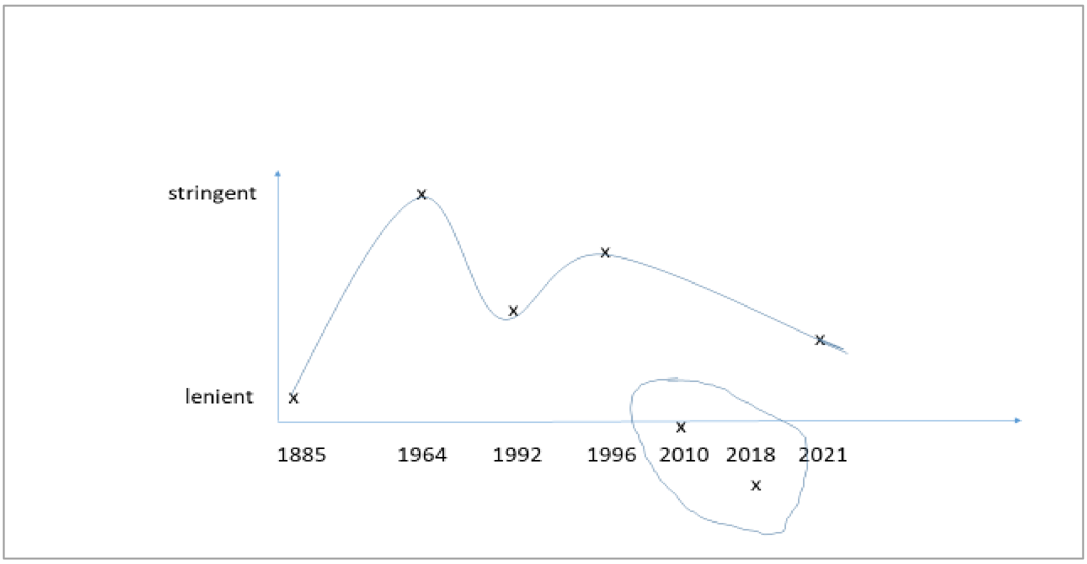

Figure 1. Development of the regulation of drilling wells for small countryside users (Edited by Author)
1. ábra. A kis kapacitású kutak létesítésének szabályozása (Saját szerkesztés)

Until 1996 we see a normal accommodation history of the system, through which it continuously refined its effectiveness in fulfilling its double goals: sustainability and the interests of small farmers (we show it on the stringent-lenient axis). The earlier stage of system development in 1885 started from a lenient position, but in the second step in 1964, it used a strong feedback mechanism in an attempt of establishing a new equilibrium with the other goal, sustainability (and a strong state control of the activities of the small farmers). In 1992 and 1996, thereafter, we see two quick fine-tuning efforts, also with the help of harnessing the experiences from the practical implementation of the water laws, and further amending its provisions (clearly recognizable feedback mechanisms). However, in 2010 and 2018 this accommodation mechanism was broken by a forceful outside impetus, arbitrarily overlooking the system balance. Yet, in 2018 a very important thing happened: the water management legal system started to defend its integrity (and maintaining its positions serving the original goals of water management in the field of groundwater management and support of smallholders in the countryside). This is what we called resilience in the system science introduction part above, to make a difference from the similar „peace time" integrity manoeuvres of accommodation. Let us see the (almost fully) successful resilience efforts of the water management legal system!

The role of non-governmental state institutions in resilience of water and environmental laws

In the matter of small agricultural wells, the President's Office was who formally turned to the Constitutional Court asking it to repel the modification of the Water Management Act. The main argument of the president was a major procedural concern about the preparation of the Act: no *strategic environmental assessment* (SEA) was performed, strikingly missing in such a legislation that undoubtfully exerts significant effects to the environment. Furthermore, the modification was contrary to some leading principles of sustainable development, environmental law and in general and rule of law: the *precautionary principle and the non-retrogression principle.* The president's proposal to the Court explained that the stake is high, because 94% of drinking water supply of the country comes from underground waters, while the quality of these reservoirs is fragile, and a close inventory of their quantities is indispensable. Finally, the President's Office added a basic constitutional and civil law argument: underground waters are *exclusive State property* that cannot be left without supervision and control.

The president was not alone in the case. He consulted the Environmental Deputy Ombudsman, too, who forwarded his opinion to him. According to the Deputy Ombudsman, the planned measures of the Water Management

Act would have led to uncontrolled use of underground waters, endangering both quality and quantity of several layers of underground waters. Furthermore, the Deputy Ombudsman, who is officially called Advocate for the Future Generations referred to the fact that the proposal vastly overlooks the interests of the *future generations.*

The Hungarian Academy of Sciences contributed to the debate, too. According to the unified opinion of several chambers of the Academy, the planned legalisation would have led to several hundreds of thousands of unknown wells, whereas such situation would have seriously endangered nature and agriculture at large. The leading scientists referred to some structural interrelations, too: serious arguments against the modification could be found in the *National Environmental Program and in the National Agriculture Strategy.* Such way the opinion of the Academy further broadened the scope of examination and reinforced the system of legal arguments in the case.

It is important to mention that all these state organisations took into consideration the contribution of 11 independent networks of professional hydrology organisations, public health organisations, water engineers' chambers and civil environmental organisations. They all highlighted several practical aspects of the planned modification that all could have led to low quality, *unprofessional well drilling* and wasteful use of underground waters.

The Constitutional Court *repelled* the amendment of the Water Management Act, based on Article P and Article XXI of the Constitution and having taken into consideration of all these aspects raised by several stakeholders in the case. [*Decision No. 13/2018. (IX. 4.) AB.].* The new text of the Water Management Act, following this procedure prescribes *preliminary announcement* and *water management authority consent* to every well serving agricultural purposes (of any size), with the exception of territories where such an activity would not endanger the quality and quantity of underground waters. In order to underpin the decision on the probability of endangerment the Government was called in the Act to prepare a national database and map on the sensitivity of underground waters. Apart from this the Act determined a line of conditions for giving such consent, including that the new wells do not disturb *protection zones* of drinking water reservoirs, karst waters and are not located on registered areas of soil or underground water pollution. Furthermore, such wells cannot be deeper than *50 meters* and cannot break through the *first water insulation* (clay, etc.) layer. We see therefore that the curve of *Figure 1* might turn back upward soon.

Conclusions of Example 1

We have introduced here a part of water law behaving as a resilient system. For a better interpretation of this situation we need to solve a couple of identification problems between general system science terminology and the legal and water management concepts in the actual case. To start with, we need to determine our scope of examination. As we have seen in the system science introduction part, the borders of a system will be determined primarily by the goal of our examination. In the present case, in order to understand the whole procedure, we need to draw the borders of the system rather broad: apart from the water management law we have to take into consideration some social-political and institutional factors, too.

The historical goal was on one hand to support of drilling household and small farm agricultural wells, and on the other side such a fair, socially sensitive regulation should be harmonized with the sustainability of our underground water resources. These goals are both served by the provisions of Water Act, together with some adjoining governmental and ministerial decrees, legal practice, procedures, and institutions. At a certain point in the balanced operation of this double goal system, one of the goals (ensuring better position to small farmers) prevailed disproportionally, therefore a serial of negative feed-back mechanisms stepped into work. The system used institutions that are less obliged to the direct political agenda of the government, general principles of sustainable development and rule of law that seemed to be able to give bigger stress to the water security issues.

The institutional side of the case study deserves more attention: the narrower sense water management setting was enriched by a line of relevant institutions from the periphery of the system (or from neighbouring or superseded systems). They all sensed that one of the main goals in the system was endangered, therefore they moved towards the centre, and – as we expect from system elements – indulged into a concerted action.

These fringe authorities activated some important background materials for their purposes that all represented the approaches of larger, higher level systems: constitutional provisions, sustainable development principles, one specific environmental rule of law principle (non-retrogression) and a serial of principal, general professional arguments.

Active participation of the independent professional and environmental civic organisations signalled the importance of consultations, in system science terms, enhancing and activating procedures and communication between the elements of the system. The system, as a rule does not let its members fight alone, while the central elements of the system, where in trouble, do count on the support from otherwise passive elements. Consequently, public participation, as usual, had an important auxiliary role in this case (*Leroux-Martin and O'Connor 2017*).

EXAMPLE 2: ENVIRONMENTAL LAW SYSTEM DEFENDS ITSELF FROM NEW, MORE AMBITIOUS CLIMATE PROTECTION PLANS

The Hungarian Climate Act (*Act XLIV of 2020.*) is the leading piece of the branch of law that determines the most important goals of the system of climate law in the country. The first goal is stipulated broadly: mitigation of the emission of greenhouse gases and decreasing their presence in the environment with the help of sinks, mostly by restoring and expanding the forest coverage. The second large group of goals are connected to adaptation to climate change, prevention of damages in the environment and human health. These very general goals are broken down into more actionable parts by the second National Climate

Strategy [*NÉS-2, endorsed by the Parliamentary Decision No. 23/2018. (X. 31.)*]. This plan details the decarbonisation path of our society and economy, with some references to geo-storage of carbon-dioxide. On the accommodation side NÉS-2 gives examples of protection and restoration of the national resources, namely natural, human, and economic ones, plus preparation of flexible responses to climate change in all these three fields. Quite progressive elements of NÉS-2 are climate partnership (deliberative formation of climate policies by all the stakeholders), awareness raising and the positive exemplary behaviour of state organisations in the field of energy saving, climate-friendly public procurement, amongst others.

Immediately we can sense that these goals need a lot of efforts for being implemented in the practical life. We have seen that the first logical step of implementation of the general climate goals in the Climate Act has correctly happened through their development into a highly professional climate plan. The second indispensable step would be the creation of a system of likeminded sectoral plans, which could carry the general climate protection and accommodation messages to all relevant branches of administration.

The Hungarian Institute of Social Reflection run an overall research in this field (*Fulop 2022, Fulop and Szamek 2022*). In the following table (*Table 1.*) I try to summarize the results in respect to the three major groups of relevant state plans, their climate relevant goals, legal and institutional tools, expected effects of the foreseen measures, as well as the fact if they use of the sustainable development principles or not, which is a major element of climate law systems that establish connections to social and economic sectors of our society. In the last column, most importantly, we exhibit the results of a piecemeal research effort about the fourth and most important step of fulfilling the goals of the Climate Act: namely that how many parliamentary acts, governmental or ministerial decrees refer concretely to these sectoral plans in their text as an indication of intents to further break down the general text of the plans into implementable or enforceable legal commitments.

Table 1. Characteristics of relevant state plans
1. táblázat. A vonatkozó állami tervek jellemzői

Plan	**Climate relevant goals**	**Legal and institutional tools**	**Expected effects of**	**Use of SD principles**	**Source**	**Year**	**Refers**
A) General development plans							
National Reform Program	yellow	yellow	green	red	Gov.	cont.	green
National Development Concept	green	green	green	yellow	Parl.	2014	red
Kárpát Home Development Concept	yellow	green	red	red	SRI.	2014	red
Clean Development Strategy	green	green	green	yellow	Gov.	2021	red
Just Transition Plan	green	green	nd.	nd.	Gov..	2021	red
B) Decarbonisation and energy plans							
National Energy Strategy	yellow	yellow	green	red	Parl.	2011	green
National Energy Efficiency Action Plan	green	green	green	yellow	Gov.	2015, 2017	green
National Construction Energy Strategy	green	green	green	red	Gov.	2015	red
Energy and Industry Development Action Plan	yellow	yellow	green	red	Gov.	2018	red
National Hydrogen Strategy	green	green	green	red	Gov.	2021	red
Energy and Climate Awareness Action Plan	green	green	green	red	Gov.	2015	red
C) Other sectoral plans							
Transport Infrastructure Development Strategy	green	yellow	green	yellow	Gov.	2014	red
Electro-mobility Plan	green	green	yellow	red	Gov.	2015, 2019	yellow
Innovative Industry Development Plan	yellow	yellow	green	red	Gov.	2016	green
National Countryside Development Strategy	green	green	green	green	Gov.	2012	red
National Forest Strategy	yellow	yellow	green	red	Gov.	2016	red
Biodiversity Strategy	yellow	green	green	yellow	Gov.	2015	yellow
Environmental Technology Innovation Strategy	yellow	yellow	green	green	Gov.	2011	red
National Landscape Strategy	yellow	yellow	green	yellow	Gov.	2016	red
National Water Strategy	yellow	yellow	green	yellow	Gov.	2017	yellow
National Security Strategy	green	yellow	yellow	yellow	Gov.	2012 2020	yellow
National Military Strategy	yellow	yellow	yellow	red	Gov.	2021	red
Food-chain Safety Strategy	yellow	yellow	green	red	Gov.	2013	red
National Tourism Development Strategy	yellow	yellow	green	yellow	Gov.	2017, 2020	red
Environmental Technology Strategy	green	green	green	yellow	Gov.	2011	yellow

Colour code: green: proper, yellow: just on the border of acceptability, red: not acceptable.

The content of the first column is somehow self-reinforcing: naturally, the climate protection goal appears in all the examined plans (actually, that was the leading viewpoint of their selection). On the other hand, these climate goals are mostly just very general ones, we could find only a fragment of goals set in the above general decisions (*Climate Act and NÉS-2*). In the second column we did not always find measures in harmony with the Climate Act and with the Second National Climate Protection Strategy, while seemingly the authors of these sectoral plans were familiar with their content. In the third column we were looking for the signs of foreseeable effectiveness of the examined plans in the legal practice. We counted a plan effective, where we detected the institutional and budgetary conditions of implementation, especially of the climate related sections. Furthermore, the professional quality of climate provisions would also raise the level of probability of their proper implementation. High professional quality, however, is hardly ensured without transparent and patient consultations with the concerned scientific, professional, and civic communities, which were seldom reported by the introductory parts of the sectoral plans.

Taking all of these, in the first three column, the quality of the plans relevant for climate protection seems to be of average level. In the fourth column, though, the situation worsens, while the fifth, last column shows much worse results. Practically no actual, detailed, directly implementable laws refer to these plans. Why? As if the fourth column contained a warning for this total ineffectiveness. That column examines the presence of sustainable development principles in the climate related plans – we found much less than expected. This is bad news, because sustainable development principles form the most basic bridges between scientifically well based, widely consented professional plans and their actual implementation. In other words, these principles contribute to the interconnections of the elements of the system of climate law. Without them, these connections are week, as our findings reinforced this general statement. In addition to all of these, we have to notice that the otherwise progressive texts of these plans with climate relevance do not communicate with each other, they contain no cross-references, they do not use the same concepts, not even a harmonised set of terminology and sectoral principles.

We have a line of speculations about what might cause this total failure of our climate law, which is parallel to the respective failures of global, regional, national, community and individual level climate protection efforts. Paradoxically, accommodation, too, has serious deficiencies at all levels. One would think that once mitigation is totally ineffective, legal subjects will pay attention at least to accommodation as a second choice, but this is not the case.

Climate change is a system of global phenomena, so that we would need a harmonised set of actions from all levels that are closely interrelated and share destiny even they are not aware of that. Unfortunately, in the field of climate protection all stakeholders at all levels keep waiting for each other. Those participants of the game on the top levels, who are unable to pass the responsibility to higher levels, are just simply paralysed, entangled in serious, unsolvable trap situations. Any governments or regional-international bodies that tried to install meaningful climate programs would lose their position within a blink of eye. The lethal paradigm of capitalism that forces everyone to grow (pay back bank interests etc. – this phenomenon has libraries full literature) would prevent the governments or large companies from any ‘suicidal’ restriction of producing capacities or their markets. They would risk losing the economic and political race. Once they try to conclude agreements to shrink their consumption and pollution in a concerted way, they just open the playing field for cheaters and free riders. Feed-back mechanisms such as IPCC (not without serious political and economic influences, though), WMO, UNEA, independent scholars, large networks and local cells of environmental protection civic organisations are at place but muted down by the cacophony of our communication systems (mass media, internet social network systems etc.). Perfect storm, wicked problems – we have the vocabulary to address these complex problems, the analyses of Oxford Martin School or the GPACT program of the World Future Council are really good examples. But most certainly a wide scale social and political understanding of climate change is still missing.

We cannot say, however, that some people do not try to move out the climate system from this stalemate. We have already hinted in connection with the previous example that instead of the paralyzed governments and administrative systems non-governmental state organisations, such as ombudspersons, presidential office (where they do not have direct governmental responsibilities), chambers of relevant professions undertake some role in climate protection. Courts in this group of institutions deserve special attention because of having the largest possible independence from the executive power in the modern states that still maintain the remainders of the idea of division of power. The so-called *court activism* might be a key element in the system of climate mitigation and resilience, together with the creative legal strategies of the NGOs or groups of citizens who start climate cases. Based on a Columbia University survey, the UN published some statistics that inform us that in the last 10-15 years on more than 60 domestic, regional, and international courts more than 2000 climate cases were heard – in most of the cases with relative successes. (*United Nations Environment Programme’s Global Climate Litigation Report 2023*). Enhanced role of the non-governmental state institutions are largely parallel to the case of Example 1 above.

BETTER UNDERSTANDING AND MANAGING ENVIRONMENTAL AND WATER MANAGEMENT LEGAL SYSTEMS

Law in general, but environmental law especially is an open system. Yet, the *borders* of several levels of legal systems are very important. They serve as means of differentiation and interconnection between different dimensions of politics, economy, and society. Since the end of the Medieval, this function is unchanged: to make social relationships calculable, to build mutual trust between people, groups and nations and defend the weak. This bordering and skeleton function is especially important in the Anthropocene World, where systems are more *interconnected* than ever. The current technological and social innovations, environmental-, socioeconomic-, and political feedbacks, such as financial crashes and disease outbreaks, propagate more quickly than in the past and with greater geographic spread (*Ahlström 2021*).

Certain *elements* of the legal systems behave as they told, others have more leeway to follow their own agendas (both authorities and clients have discretionary rights), while, until they are part of the rule of law system, their freedom is limited, too. Some elements, partly as a response to this flexible situation have monitoring, controlling functions, some of them undertake such functions voluntarily, as civil „watchdogs". They are the non-governmental organisations and the local communities who have key roles in environmental protection, therefore they need reinforcement. Legal, procedural rules of public participation shall be user friendly and shall contain capacity building elements.

Structures, such as organisations and networks represent the most static parts of legal systems. Contrary to other social, natural or non-living systems, legal structures are historically built up, they can be changed only at a high price and difficulties. They shall be transparent and accountable in the face of the whole socio-political system. In our examples, the society need continuous *feedback* from the work of water and environmental law (transparency and accountability) and about the outcome of the operation of the system (sustainability monitoring). Poor level of ventilation of data and conclusions, as well as distorted communication might be very significant causes of inefficiency and failures of work of legal institutions.

The *procedures* and the directions of communication between the elements of legal system are typically hierarchically arranged, they mostly follow top-down or bottom-up patterns, but not always. Activities of non-governmental state bodies (ombudspersons, state auditing organisations, certain sections of prosecutors' offices etc.) and courts might (shall) be aligned with the local communities and non-governmental organisations. The non-governmental state bodies are less bond by the direct political-economic influences from the society and from the political sphere, while their constituency, source of important, independent information could be much widespread.

Social, political demands and orders towards law, especially water and environmental laws often can change quite abruptly. When decision-makers try to change a sector of law, they might set new or modified specific *goals* to them. Reformation of goals, in principle, might be the key leverage points of the legal systems: once the society and the economy changes, the political and legislative organisations sense the need to influence the social-economic procedures (as they always do), the most obvious first measure to take is to sentence new, modified goals to a given body of law. Once the new goals resonate with the given parts of the legal system, including the solid structures (institutions) and legal subjects that apply, implement, or enforce them, they will change the respective social-economic fields. However, when the changes in legislative goals are sensed arbitrary, premature or not organically fitting to the existing structures and procedures, the legal system will reject them. If the change is forceful enough, it might create brand new laws and establish brand new institutions to implement them, but then it will turn out that the system can change its borders, it can involve more and more peripheral elements and activate them to maintain or restore the previous equilibrium of the respective part of the legal system.

CLOSING REMARK

While there is a growing body of research about the interconnection between law and system science in general, the next logical step, namely application of system thinking in better understanding and resolving certain complex legal problems is still mostly ahead of us. I hope that this approach will prove itself fruitful in the future, while I do acknowledge that systematic (rather than systemic) analyses of the facts and their legal ramification will stay for long the main methodological tool for lawyers. The piecemeal examination of all the elements of legal system forms the bulk of work of theoretical and practicing lawyers, while, I am convinced, it will not hurt if they apply system thinking as an auxiliary methodology. Lawyers, indeed, are more similar to carpenters who are interested in the structure and applicability of individual pieces of wood. However, they might find it useful sometimes to talk to the foresters, too.

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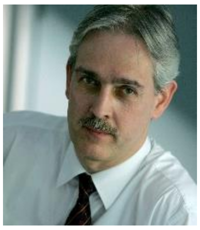
AUTHOR



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New containerized wastewater treatment technology: system description and evaluation of treatment capacity of a highly efficient MBBR system

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Abstract
In a recent R&D project, an innovative biofilm micro-carrier was invented by Inno-Water Inc., that has a much smaller size compared to the traditional carriers. In this article, we show the capacities and structure of a new wastewater treatment system, that contains this new type of biofilm carrier. The "MICROBI" technology has an average of 99,4% ammonium, 94,3% COD, and 75,0% total nitrogen removal rates in municipal wastewater. During the period of bacterial colonization, we measured chemical parameters (COD, NO_3-N, NO_2-N, PO_4-P, NH_4-N) of the inflow and effluent twice a week for seven weeks. After that, a 24-hour measuring campaign was carried out to determine the full capacity of the system. Simultaneously we measured dissolved oxygen, pH, temperature, and conductivity in the reactor, and monitored the development of biofilm on the carrier with the light microscope and TTC colouring method. The results show a significant nitrification ability and high COD and ammonium removal at an inflow of 27-28 m^3/day. Future improvement plans include the optimization of denitrification and increasing the daily wastewater treatment capacity.

Keywords
Biotechnology, MBBR, wastewater treatment, biofilm monitoring, technology introduction.

Új, konténer alapú szennyvíztisztítási technológia: a technológia ismertetése és a tisztítási kapacitást vizsgáló kísérletek bemutatása egy nagy hatékonyságú mozgóágyas biofilmes rendszerben

Kivonat
A közelmúltban zajlott kutatási és fejlesztési projektben az Inno-Water Zrt. innovatív biofilm mikrohordozót fejlesztett ki, amely jelentősen kisebb méretű, mint a hagyományos hordozók. Ebben a közleményben egy új szennyvíztisztító rendszer kapacitását és felépítését mutatjuk be, amely rendszer biológiai tisztítási lépcsője erre az új típusú biofilm hordozóra épül. A „MICROBI" technológia átlagos szennyezőanyag eltávolítási hatékonysága kommunális szennyvízben 99,4% az ammónium, 94,3% a KOI és 75,0% az összes nitrogén komponensre . A bedolgozási időszak alatt hetente kétszer mértük a szennyvíz kémiai paramétereit (KOI, NO_3-N, NO_2-N, PO_4-P, NH_4-N). Ezt követően egy 24 órás mérési kampányt végeztünk a rendszer teljes kapacitásának meghatározása érdekében. Vizsgáltuk a reaktorok oxigénszintjét, pH értékét, hőmérsékletét és vezetőképességét, valamint fénymikroszkóppal és TTC színezési módszerrel nyomon követtük a hordozón lévő biofilm fejlődését. Az eredmények kiváló nitrifikációs képességet és magas KOI és ammónium eltávolítást mutatnak 27-28 m^3/nap hidraulikai terhelés esetén. A jövőbeni fejlesztési tervek között szerepel a denitrifikáció optimalizálása és a szennyvíztisztító kapacitás növelése.

Kulcsszavak
Biotechnológia, mozgóágyas biofilmes rendszerek, szennyvíztisztítás, biofilm vizsgálatok, technológia bemutatás.

INTRODUCTION

In the modern world, there is a trend that more and more people move out of large cities, for example, smaller suburban towns around big centres. Another tendency since COVID-19 is the opportunity of working from home (home office). These trends led to expanding towns around large cities, which has created an urgent need for the increasing capacity of infrastructure, like roads, wastewater management, etc. It is difficult to solve the problem of the ever-growing need for more wastewater treatment capacity because building new wastewater treatment plants is expensive and needs a large space as well as redesigning the sewage system of a city. Not to mention that these new trends can change quickly, and not many large wastewater treatment plants can follow. To solve these problems, mobile, flexible, and effective systems need to be developed. MICROBI technology is the size of a standard container, yet it can clean wastewater up to 25-30 m^3 per day. Its core element is the freshly developed biofilm micro-carrier, which is significantly smaller than traditional carriers. To study the carrier's capacity and measure the amount and activity of the biofilm on this carrier, new methods are required, as described in this article.

STATE-OF-THE-ART

Traditional biological wastewater treatment technologies are based on activated sludge reactors and were invented over a century ago, which has a well-known literature and performance. The most widespread used wastewater treatment technology is the activated sludge (AS) system, where the treatment process includes „active" microorganisms, such as bacteria, fungi, protozoa, and even animals like rotifers, insect larvae, and worms. These microorganisms live (among non-living particles, organic and inorganic matter) in flocs, which are the core of the process. These flocs are continuously circulated with oxygen and the influent wastewater to reduce their organic substances to as low as possible, as soon as possible (*Wang et al.*

2009). The AS system performance is based on the settleability of flocs and usually cannot handle more than 5 g/l biomass constantly. Also, there is a massive sludge production, that needs additional treatment methods to work with less biological waste (*Barwal and Chaudhary 2014*).

In MBBR (moving bed biofilm reactor) systems, the flocs are mainly replaced with different-sized and shaped carriers, that host a high specific surface area for the microorganisms to attach (*Kawan et al. 2016*). *Schmidt and Schaechter (2011)* studied that over 90% of biomass is on the surface of the carriers in MBBR systems. These carriers are usually made of HDPE, PE, or PP with a density of 0,95 g/cm^3 (*Barwal and Chaudhary 2014*). Their typical size range is 2,2-50 mm in length and 9-64 mm in width (*Barwal and Chaudhary 2014*).

In MBBR systems, *Ødegaard (2006)* says the suggested volume of carriers is 67% of the reactor, but not above 70%. This means around 500 m^2/m^3 surface area for the biofilm resulting in a growth of around 350 m^2/m^3 (70% colonization rate). *Ashkanani et al. (2019)* used different carrier sizes 500-800 m^2/m^3 and 1 200 m^2/m^3 surface area and had a 30% colonization rate. *Kermani et al. (2008)* applied a scale laboratory-scale MBBR reactor with a specific surface area of 260 m^2/m^3.

Madan et al. (2022) found that the concentration of fixed biomass can be up to 10 000-12 000 mg/l, however, *Benakova et al. (2018)* had a biofilm mass of 12 000-16 000 mg/l. The biomass thickness is also important in the effectiveness of an MBBR system. *Dezotti et al. (2011)* suggest that to maximize the substrate diffusion, a maximum biofilm thickness is 100 µm. *Torresi et al. (2016)* found that a biofilm thickness over 200 µm does not significantly increase the functionality of nitrification activity.

Chu and Wang (2011) showed that PCL (polymer polycaprolactone) carrier has TOC and ammonium removal rates of 72% and 52% with a 14 h HRT (hydraulic retention time). *Ashkanani et al. (2019)* reached 87.3%, 71.8%, and 47.2% ammonium removal rates at 20 °C with different surface areas. An HRT of 6 h revealed that 86.67% and 91.65% ammonia removal was achieved from aquaculture wastewater *(Shitu et al. 2020).* With MBBR systems *Goswami and Mazumdar (2016)* reached a 90% COD removal rate for tannery effluent, and in the textile industry, *Erkan et al. (2020)* reached 98,5% COD removal. *Martin-Pascual et al. (2016)* carried out a pilot-scale study with an MBBR system with urban wastewater. With 24-hour HRT, they reported that 86% COD removal rate. *Kermani et al. (2008)* used 4 reactors in the laboratory with a clarifier in an MBBR system and reached 84,6% total nitrogen removal rate at 24 h HRT. *Phanwilai et al. (2020)* reviewed different types of MBBR systems and concluded that a total nitrogen removal rate was between 64% and 77%, with an HRT of 5-11 hours.

MBBR systems have several benefits over traditional AS systems, like reduced sludge production, smaller footprint, and the ability to operate with higher biomass concentration which might have a higher specific activity than AS. Another great advantage of these systems is that they are more resistant to overloading and toxic compounds (*Kawan et al. 2016*). However, there might be drawbacks compared to AS like the settling characteristic is poorer in some cases (*Lee et al. 2006*), the carriers might cause mechanical failures (*Kawan et al. 2016*), and it is more difficult to separate the carriers from the sludge (*Lee et al. 2006*).

DESCRIPTION OF THE TECHNOLOGY

The concept of using special micro-carriers for wastewater biofilm was tested in earlier research on a lab scale (*Fleit et al. 2008, Sándor et al. 2009, 2012, 2017*). Early experiments used PVA-PAA (polyvinyl alcohol/polyacrylic acid) hydrogel micro-carriers that could be produced only in small amounts using materials with high environmental risks.

Based on the early results, researchers of Inno-Water Inc. have invented new types of micro-carriers, first on a laboratory scale, then a production technology has been developed for the automatized synthesis of micro-carriers.

During the recent R+D project, we implemented the production of micro-carriers with special structures, defined durability and sedimentation properties for bacteria responsible for pollutant transformation processes in wastewater treatment, as well as laboratory, semi-industrial, and operational scale testing, which can be used to optimize the performance of wastewater treatment by regulating the properties of carriers bacterial culture properties and thus processes that degrade/remove contaminants.

Our goal was to create different micro-carriers having a compact structure but surface unevenness, helping to form surface biomass. To achieve this, a special additive has been incorporated into hydrogels. To ensure suitable mechanical properties, such as pumpability and applicability under conditions of municipal wastewater treatment, the degree of crosslinking of hydrogels has also been optimised.

"MICROBI" technology is based on freshly developed, innovative hydrogel biofilm micro-carriers. In our pilot system described in this article, we utilize micro-size copolymer hydrogel micro-carriers synthesized with iron oxide. The special composition and structure of the biofilm carrier allow high biomass concentration with high specific activity and a magnetic separation that can be much more efficient than single sedimentation.

"MICROBI" is a unique system offering a technical solution to the problems of spontaneously formed flocks, thereby providing an engineering solution in the field of biological wastewater treatment with controlled parameters (sedimentation/separation rate, size distribution range, and other functional characteristics).

The mobile "MICROBI" technology pilot system is placed in a 6.0 x 2.4 x 2.7 m standard container. The walls are made of EPS sandwich panels and the bottom is marine plywood. The interior of the container is full of reactors, which are reachable from the top. The pilot unit examined contains:

1. Primer clarifier, net. volume 2.2 m^3,
2. 2 aerated tanks with a separation wall in the middle, net. volume 6.9 m^3 each,
3. 2 micro-carrier separator with magnets,
4. after clarifier, net. volume 2.16 m^3,
5. blower for aeration, the compressor for pneumatics, pumps, etc.

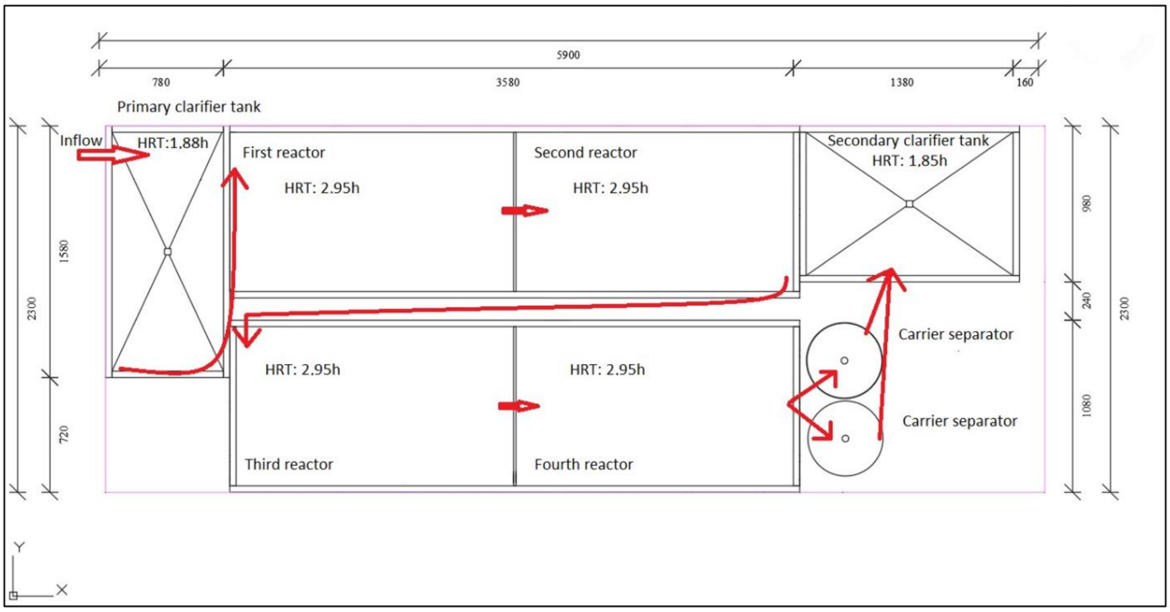

Figure 1. The schematic draw of the container with reactors
1. ábra. A reaktorokkal felszerelt konténer sematikus ábrája

In *Figure 1,* the overview of the containerized MICROBI technology is shown, where the red arrows mean the order of the wastewater flow. Raw wastewater arrives in the primary clarifier tank. Primary sludge is removed by a pump from the bottom of the tank. After that, the wastewater flows to the first reactor. The first and second reactor separated with a polypropylene wall, that has holes in the bottom and at the top. After the second section wastewater flows to the second aerated part, which is like the first one, except that it has a moving wall after the fourth reactor, around 40 cm from the outlet. Its purpose is to settle the biomass from the water phase. After this, two simultaneous reactors, the carrier separators receive the wastewater. They have electromagnets inside them to separate the carrier from the sludge. The last step of the technology is the secondary clarifier tank.

The containerized pilot technology is proven to handle 28 m^3/day of communal wastewater. The path of the wastewater and the HRT times of the units are shown in *Figure 1*.

The overall retention time in biological reactors is 11.8 hours, which is lower than *Chu and Wang (2011)*'s and *Martin-Pascual et al. (2016)*'s experiments (14 h and 24 h HRT), but almost double that of *Shitu et al. (2020)*, they had 6 h of HRT.

MATERIALS AND METHODS

Pilot experiments lasted from 12.10.2023. to 08.12.2023. In the first period (until 01.12.2023.), point samples were taken from the effluent and the influent for chemical analysis. In this period, the following parameters were measured twice a week for seven weeks:

1. Temperature.
2. Dissolved oxygen (DO) concentration.
3. Chemical oxygen demand (COD).
4. Phosphate-phosphorus.
5. Nitrite-nitrogen.
6. Ammonium-nitrogen.
7. Nitrate-nitrogen.

At the end of the experiment, a continuous sampler was set to each end of the container, that took samples every 15 minutes and made an average sample each 2 hours. Besides the same parameters measured in the first period, total nitrogen was also monitored.

MSZ ISO 6060 (COD), *MSZ 1484-13:2009* (nitrate-nitrogen, nitrite-nitrogen), *MSZ ISO 7150-1:1992* (Ammonium-nitrogen), *MSZ 448-18:1977*, *LCK238* (total nitrogen) standards were used during the laboratory measurements. pH, dissolved oxygen, and temperature were measured on-site using a Hach HQ40 portable multimeter.

The pollutant removal efficiency was determined after the first stage of biofilm development, considering the 12 hours of HRT of the biological reactors.

The surface and biofilm formation of carriers were monitored by microscope measurements. The average sample from the four sections was taken. 0.5% triphenyl tetrazolium chloride solution was used in the laboratory to colour the living (active) biomass on the surface of the carriers. Zeiss AXIO Lab.A1 light microscope, and Zen 3.1 (Blue Edition) software was used for taking the microscopic photos. 35-50 pictures of each sample were taken and analysed with Image Pro software to measure the overall diameter (mean, min, max) and area of the carriers, and to measure the area of the active biofilm attached to the surface of the carriers.

RESULTS

The rate of biological processes is strongly determined by temperature and oxygen levels of water, therefore DO level was measured in each section of the biological tanks and temperature was monitored in the influent and effluent (*Figure 2*).

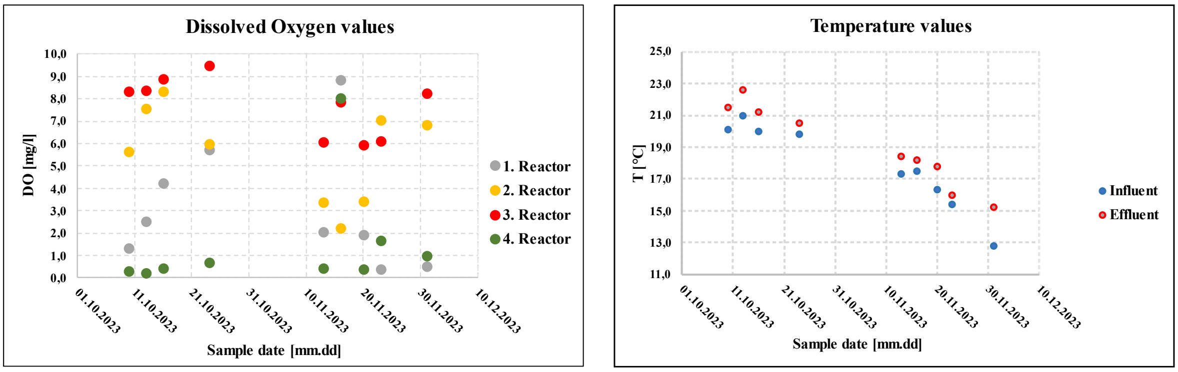

Figure 2. Temperature and DO levels at each reactor space and influent, effluent.
2. ábra. A térrészenként és a be- és elfolyóban mért hőmérsékleti és oldott oxigén értékek

Temperature values are decreasing, due to the colder weather. Aeration was different in the fourth reactor due to the more efficient settling process. In a non-aerated reactor, both flocs and carriers are easier to be settled. In the first reactor Dissolved Oxygen (DO) levels were significantly lower than second and third reactors, that's because of the COD removal processes. At the second and third reactor sections the DO levels stay almost always above 3 mg/l, which is required for the nitrification process. DO concentration of the third reactor exceeded 6-8 mg/l, however, lower values would also be sufficient. In the first part of the experiment in Reactor 1 a higher DO level was aimed to maintain COD removal and nitrification. Later, the aeration was cut to achieve an anoxic environment necessary for denitrification.

In the first phase of the experiment, it was aimed to monitor the removal rates of the main wastewater pollutants during the growth of the biofilm on the carrier's surface. We observed COD removal indicating that heterotroph organisms begin to grow in aerobic conditions quickly (*Figure 3*). The simultaneous decrease of ammonium-nitrogen concentration shows the build-up of nitrifying biofilm and the efficient process of nitrification despite a significant variation of the pollutant concentrations in the inflow.

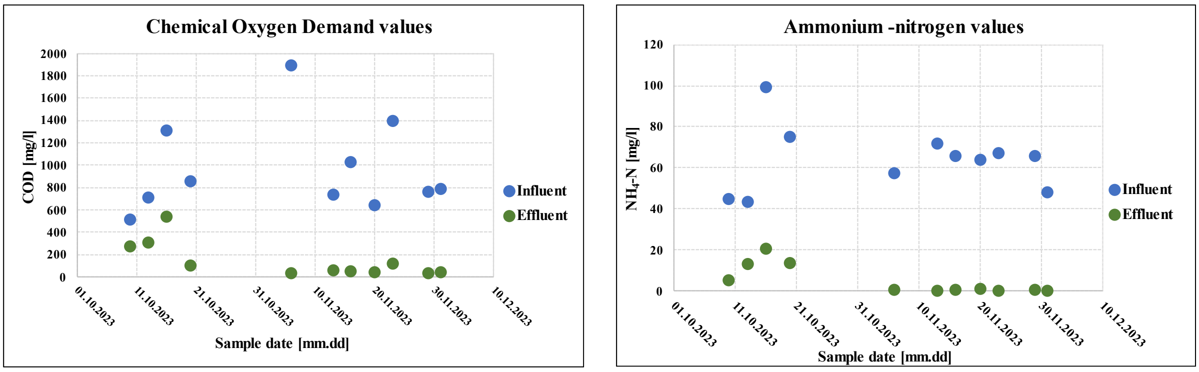

Figure 3. COD and NH_4-N concentration of inflow and effluent during the biofilm development process
3. ábra. A KOI és NH_4-N koncentráció változása a be- és elfolyóban a betelepedés során

The average concentration of chemical oxygen demand of the influent was 580 mg/l; however, the maximum was 1 893 mg/l showing great variability and relatively concentrated wastewater characteristics. Low COD values were reached in the effluent in the first ten days.

The ammonium-nitrogen concentration of the influent shows somewhat less, but still high variability having an average of 36.1 mg/l and a maximum concentration of 99.2 mg/l. The decrease of ammonium-nitrogen concentration to a low level took 4 weeks due to the decreasing wastewater temperatures, and the lower growing rate of autotrophic nitrifying bacteria.

During the biofilm colonisation period, nitrite-nitrogen appeared as an intermediate product of nitrification. The final product is nitrate-nitrogen. The second step of denitrification requires nitrate-nitrogen, anoxic conditions, and easily accessible organic matter for the facultative heterotrophic microorganisms. *Figure 4* shows the nitrite-N and nitrate-N values over the experiment.

Nitrite-nitrogen appeared in the effluent at the beginning of the colonization process at a high (1-9 mg/l) in the first ten days, after that, its value remained zero, or slightly more than that. Nitrate-nitrogen started to increase after the initial period; it reached its maximum value on 13.11.2023. After that, the settings of the technology were changed significantly: aeration of the first reactor was cut, and the recycling rate was raised. These changes led to decreasing nitrate-nitrogen concentrations in the effluent, however a significant amount (26-36 mg/l) appeared in the effluent through the measurement period. Results suggest that the recycling capacity of the system needs to be further upgraded in the future.

After the startup period (when all necessary types of bacteria could be developed on the surface of the carriers) we set the continuous measurement device in the upper region of the preliminary clarifier. Effluent samples were taken from the carrier separator. In *Figure 5* we show the results of COD and ammonium-nitrogen measurements.

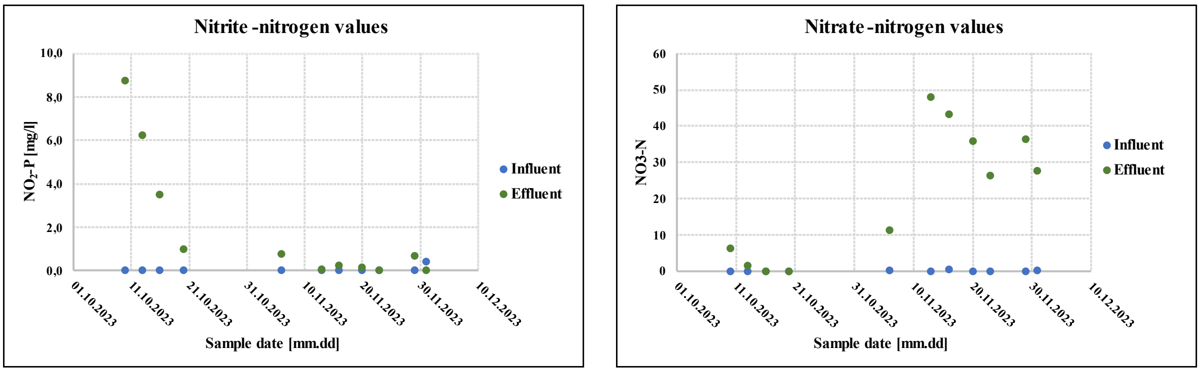

Figure 4. NO_2-N and NO_3-N values over the experiment
4. ábra. A NO_2-N és NO_3-N értékek változása a kísérlet során

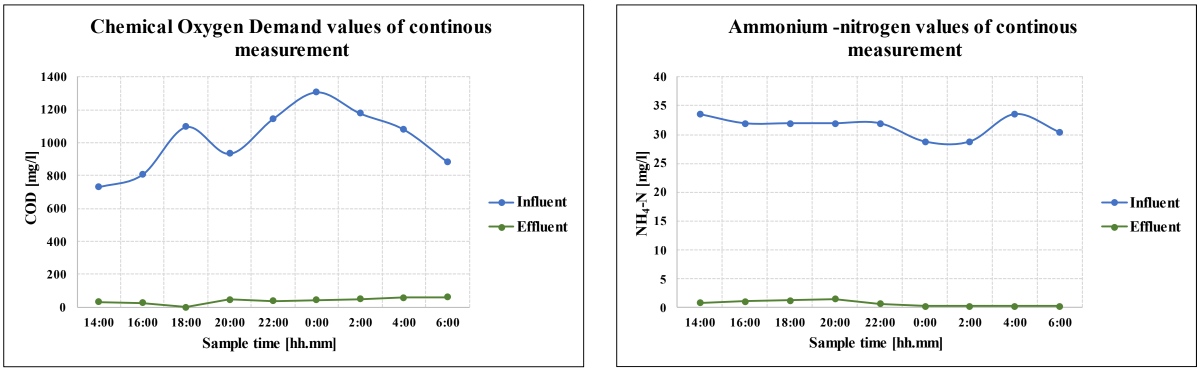

Figure 5. COD and NH_4-N values over the continuous measurements
5. *ábra. A KOI és NH_4-N értékek változása az automata mintavevővel történt mérés során*

Influent COD values varied between 729 mg/l and 1 308 mg/l and the average COD removal rate was 94.3%. The organic removal efficiency was slightly greater than the efficiency by *Goswami and Mazumdar (2016)* who reached (90%) in MBBR, but less than reported by *Erkan et al. (2020)* (98.5%). Ammonium-nitrogen of the influent was more stable, with values remaining in a narrow range (28.8-33.6 mg/l). The average ammonium removal rate was 99.4%, which is much higher than *Chu and Wang (2011)*'s 52% having similar HRT (14 h). *Ashkanani et al. (2019)* reached an 87.3% ammonium-nitrogen removal rate at 20 °C, which is still lower than in our technology. However, *Shitu et al. (2020)* reached 91.65% ammonium removal by using only a 6 h retention time.

Nitrate-nitrogen shows the denitrifying capacity of the system, and total nitrogen is important to calculate the overall nitrogen removal capacity. *Figure 6* shows the continuous measurements of nitrate-nitrogen and total nitrogen results.

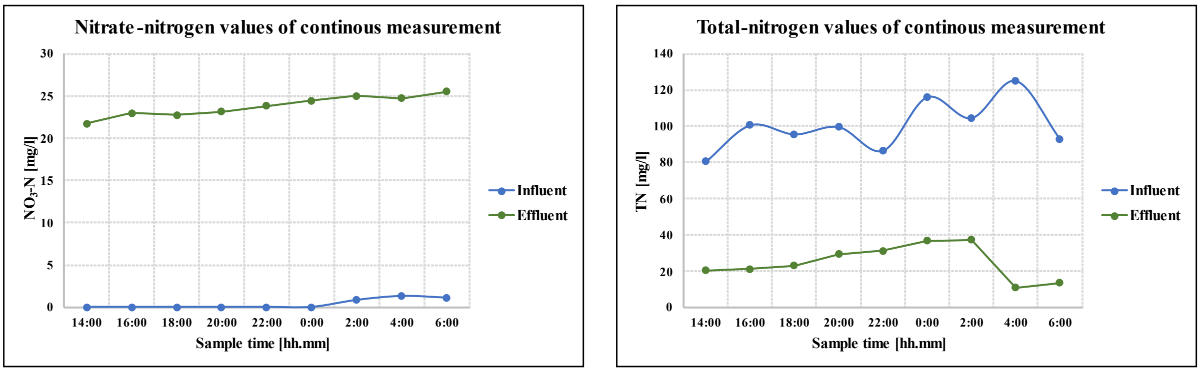

Figure 6. NO_3 and TN values over the continuous measurement
6. ábra. A NO_3 és ÖN értékek változása az automata mintavevővel történt mérés során

Treated wastewater had a nitrate-nitrogen concentration between 21.8 mg/l and 25.5 mg/l. This shows that a recycling rate would be required to optimize the treatment process. Increasing the recirculation rate is expected to allow quick adaptation of the denitrifying heterotrophic bacteria causing higher nitrate removal rates.

The total-nitrogen content of the inflow was relatively high (80.5-125.0 mg/l; average: 102 mg/l). The average TN removal rate was 75.0%, which is behind *Kermani et al. (2008)*'s results, however they had 24 h HRT and 28 °C. *Phanwilai et al. (2020)* showed 64% and 77% TN removal, with an HRT of 5-11 hours, which is similar to our results, however they had shorter retention time.

Sauer et al. (2002) stated that there are five major stages of biofilm development, the initial reversible and irreversible attachment of microbes, the formation of microcolonies, maturation of the biofilm, and dispersion or detachment of biofilm. It is difficult to determine/measure the quantity of the attached biomass. In our study, biofilm formation was followed based on microscopic measurements applying Image Pro software. The method was found suitable to determine the diameter (mean, max, min) and the surface area of the carriers, as well as the colonisation rate (%). Colonisation rate was defined by the percentage of the carrier surface covered by biofilm over the total surface. *Figure 7* shows that the average colonisation rate follows the change in the mean diameter of the carriers.

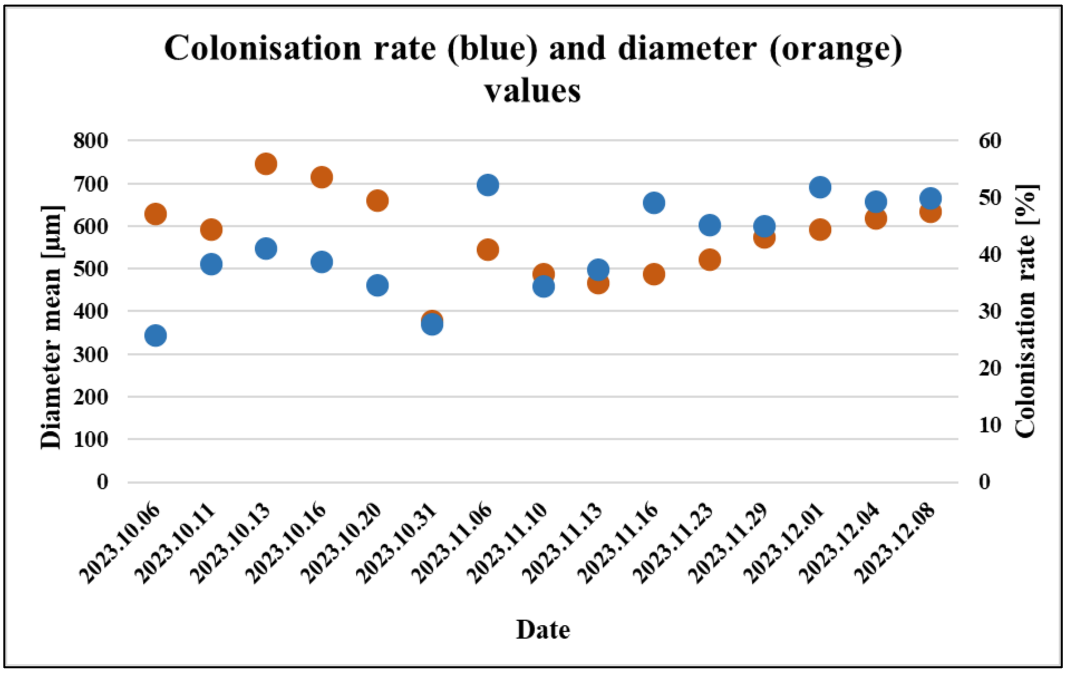

Figure 7. Colonisation rate and diameter values of the carriers over the experiment
7. ábra. A mikrohordozók betelepedettségi arányának és az átmérőjének változása a kísérlet alatt

Colonisation rate quickly rose over 50%, then fell back to around 30%, which is because fresh carriers were loaded into the reactors. After 06.11.2023. colonisation rate values slowly began to rise around 50%. *Barwal et al. (2014)* observed a 70% colonisation rate over the whole carrier surface, and *Bjornberg et al. (2009)* discovered 30-50% on the outer and 100% on the inside of the carriers. It is important to consider that our new micro-carriers are about 100 times smaller than those used in other studies, therefore we reach a higher specific surface area overall. The measured diameter of the inoculated carriers also changes due the biofilm development. It varies between 400 µm and 750 µm. The diagram shows that there is a correlation between the two values, increasing the colonisation rate means increasing measured diameter values.

Figure 8 shows that with different colonisation rates (above 50 and 75 percent, below 15 and 20 percent) the changes of diameter (max – blue, mean – orange, min – grey) values over the experiment.

The first two diagrams (below 15 and 20 percent colonisation rate) show, that the carriers have low interaction with the microorganisms. It is like a control sample, which shows how the carrier's diameter changes due to pumping, mixing, aeration, etc. The first diagram (below 15%) shows a large variation in the values, which makes it harder to analyse trends. The second diagram shows that the carriers have a slight decrease in diameter, which may be caused by mechanical loads like the pumps, or the mixing. However, the carriers have starch and PVA inside them, that can diffuse from the inside and may cause a decrease in size.

The colonisation rate above 75% has similar diagram trends like the below 15%, which is caused by low sample numbers visible in *Figure 9*. The 50% colonisation rate diagram however shows less variability and more sample numbers. It has an increasing-decreasing tendency, which is due to the microorganism flocs depart and rebuilt on the surface area.

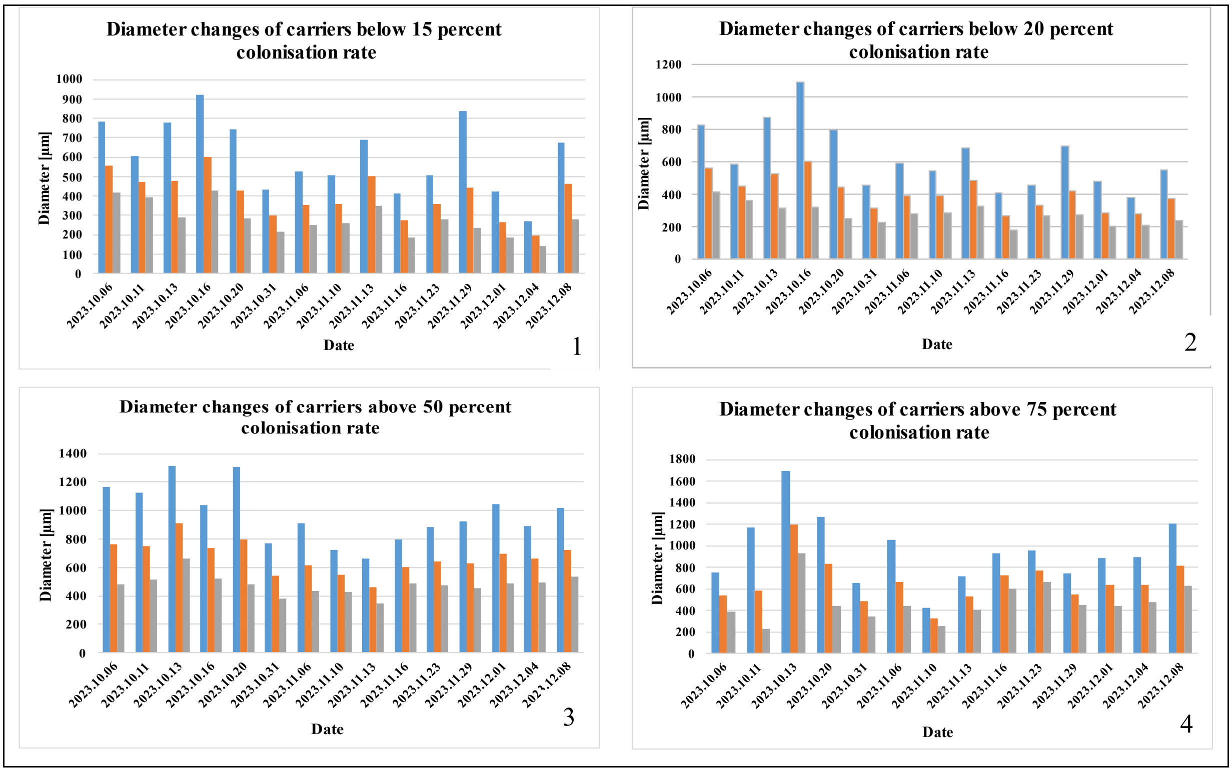

Figure 8. Diameter changes according to the colonisation rate
8. ábra. Átmérő változás a betelepültség függvényében

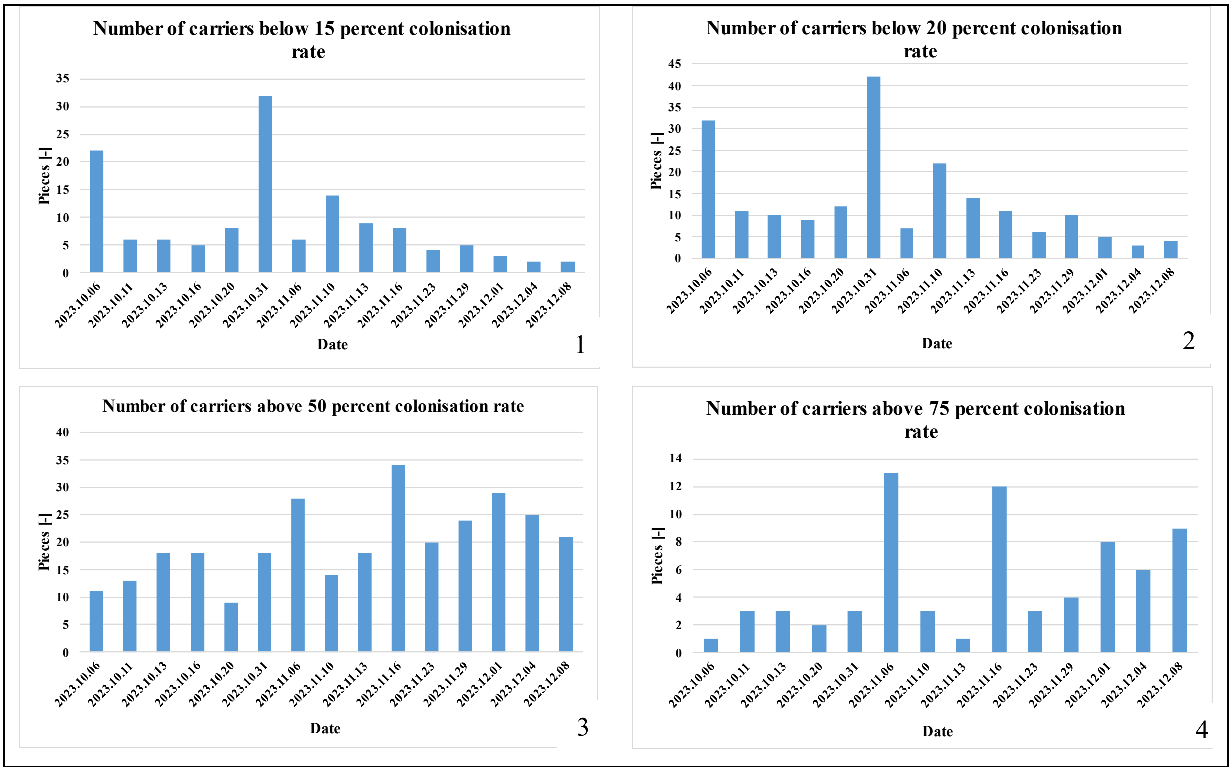

Figure 9. Number of carriers according to the colonisation rate
9. ábra. Mikrohordozók száma betelepültség függvényében

Figure 9 shows the number of carriers equivalent to a certain colonisation rate (15-20-50-75%). Higher numbers mean more accurate analysis in terms of the amount of biomass. Most data belong to a 50% colonisation rate (minimum 9 – on 20.10.2023.), while there are sampling dates when only 1 data belong to 15 and 75% colonisation rate. This suggests that below 20 percent and above 50 percent is preferable for biofilm analysis.

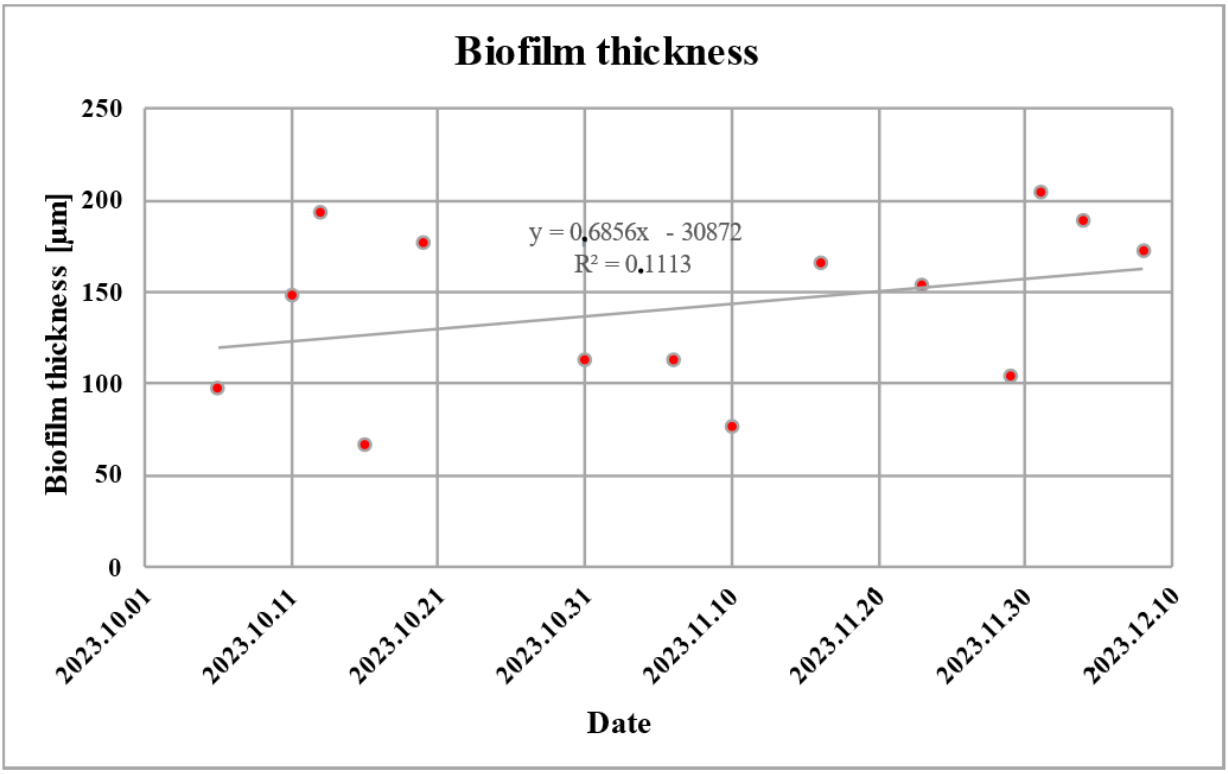

Figure 10. Biofilm thickness through the experiment
10. ábra. A biofilm vastagságának változásai a kísérlet során

Biofilm thickness was calculated by subtraction of the mean diameter values of carriers below 20 percent colonisation rate from the mean diameter of carriers above 50 percent colonisation rate and dividing by 2. *Figure 10* shows the changes and the values of biofilm thickness over the measured period. It shows a maximum biofilm thickness of 200 µm, with an average of 140 µm. According to *Barwal et al. (2014)* for a full substrate penetration, 100 µm biofilm thickness is ideal, and *Torresi et al. (2016)* claims that above 200 µm biofilm thickness there is no significant nitrification increase.

CONCLUSIONS

MBBR systems have been a well-studied area in wastewater treatment, there is a lot of information about the biofilm carriers, their specific surface area, and biomass. Also, a lot of knowledge about different types of experiment setups, and their capabilities in terms of ammonium, total nitrogen, or COD removal rate. In conclusion, MBBR is a promising and well-working technology, that has a wide variety of base knowledge. However, with the new micro-carrier developed in the MICROBI R&D project, we can have a significantly more specific surface area, as this carrier is in the size range of micrometres, instead of the traditional carrier's millimetre size. With this monitoring program, which contains the method to paint the living biomass, take many pictures of it, and analyses it with software we can monitor and measure the primal parameters of new carriers, which is going to be useful in calculations required for modelling. This study shows that:

- the biofilm on the carrier's surface is between 60 and 200 micrometres, which is optimal according to literature data,
- the biofilm grows and detaches on the surface of the carriers, but overall shows an increasing tendency,
- for biofilm thickness monitoring, the carriers with over 50 percent colonization rate are most suitable,
- the containerized technology can clean communal wastewater up to 28 m^3/day in cold weather (12 °C influent) and
- has above 90% of COD and ammonium-nitrogen removal rate,
- also, above 70% of nitrate-nitrogen removal rate.

Further improvements still need to be made, like upgrading the recirculation rate or controlling the DO levels to a minimum for energetic optimization. The results however show that even in these pilot conditions with cold influent, the technology can reach the efficiency found in the literature. With further optimization, it is possible to reach a stable, highly efficient system, thanks to the new type of micro-carriers.

The statistical analysis of microscopic pictures shows promising results about the carrier's diameter changes over time, both in terms of biomass growth and material properties. According to the literature, the examined biofilm developed in our experiments has an ideal thickness and a slightly low colonisation rate.

ACKNOWLEDGEMENT

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The effect of expanded perlite and metakaolin on the physicochemical properties of collapsible soils

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Abstract

Collapsible soils, such as loess, are a kind of problematic soil that is naturally unsaturated and withstands high loads at their natural moisture content, but unexpectedly collapses when wet and saturated, creating a risk to buildings constructed on it. This study highlights the effect of chemical stabilizers, including perlite and metakaolin, on the physicochemical behavior of collapsible soils, especially Zeta potential measurement, and the soil's morphology. The properties of natural soil were compared to those of treated soil using a set of Zeta potential measurement tests. Furthermore, scanning electron microscopy (SEM) analysis was used to validate the results. According to the results, perlite and metakaolin changed the loess soil properties. The results showed that the absolute Zeta potential of soils increased after adding perlite and metakaolin, which indicated a higher dispersity of soils mixed with perlite or metakaolin. The scanning electron microscope (SEM) indicated that untreated samples had a loose structure with extensive pores, whereas treated samples had a dense and uniform structure with particle rearrangement. The flocculation and agglomerations in the soil matrix, which are a significant contributing factor to the mechanical property enhancement of the metakaolin-stabilized samples, were confirmed by SEM images. According to the microstructure and product composition analyses, the calcium-aluminate-silicate hydrate (CASH) generated by the metakaolin enhanced cementation between the flake units of the plain soil, and the soil structure of the plain soil stabilized by the metakaolin was denser.

Keywords

Collapsible soil, stabilization, Zeta potential, perlite, metakaolin.

Roskadásveszélyes talajok tulajdonságainak vizsgálata perlittel és metakaolinnal történő talajkezelés hatására

Kivonat

A roskadásveszélyes talajok, mint például a lösz, olyan problémás talajok, amelyek természetes állapotban telítetlenek, és természetes nedvességtartalmuk mellett jó teherbíró képességűek, de telítve váratlanul összeomlanak, és veszélyt jelentenek a ráépült épületekre. A tanulmány vizsgálja a kémiai stabilizátorok, köztük a perlit és a metakaolin hatását az összeomló talajok fizikai-kémiai viselkedésére, különösen a Zéta-potenciál értékére és a talaj morfológiájára. A természetes talaj és a kezelt talaj tulajdonságai összevethetők a Zéta-potenciál mérési tesztsorozat segítségével, az eredmények validálására pedig pásztázó elektronmikroszkópos (SEM) vizsgálatok szolgáltak. Az eredmények szerint a perlit és a metakaolin megváltoztatta a löszös talaj tulajdonságait. Az eredmények azt mutatták, hogy a talajok abszolút Zéta-potenciálja megnőtt perlit és metakaolin hozzáadása után, ami a perlittel vagy metakaolinnal kevert talajok nagyobb diszperzitását jelzi. A pásztázó elektronmikroszkóp (SEM) azt mutatta, hogy a kezeletlen minták laza szerkezetűek, kiterjedt pórusokkal, míg a kezelt minták sűrű és egyenletes szerkezetűek, részecskék átrendeződésével. SEM felvételek igazolták a geopolimer gél kialakulását a talajmátrixban, amely jelentős mértékben hozzájárul a metakaolinnal stabilizált minták mechanikai tulajdonságainak javításához. A mikroszerkezeti- és termékösszetétel-elemzések szerint a metakaolin által generált szilikát-aluminát kolloid fokozta a sima talaj pelyhes egységei közötti cementációt, a metakaolin által stabilizált sima talaj talajszerkezete pedig sűrűbb volt.

Kulcsszavak

Roskadásveszélyes talaj, stabilizáció, Zéta-potenciál, perlit, metakaolin.

INTRODUCTION

Collapsible soils are meta-stable soils that can experience significant deformation and a complete change in particle structure after being wetted, either with or without stress (*Khodabandeh et al. 2020*). Loess is considered as one of the most widespread collapsible soils in arid and semi-arid areas, covering 10% of the world's land surface (*Khodabandeh and Nagy 2022*). Loess soils are known for their open structure, which is produced by sharp-edged grains and has a low dry density, water content and plasticity (*Nokande et al. 2020, Nokande et al. 2022*).

In recent years, researchers have focused on the treatment of loess soils with cost-effective and environmentally friendly materials. Various types of materials, including nanomaterials, polymers, fibers, biological materials, and industrial waste materials, have been widely used to stabilize loess soils (*Khodabandeh et al. 2023a*). Chemical soil stabilization improves soil cohesion and hence shear strength and structural stability by forming interparticle chemical interactions that bond the soil particles (*Khodabandeh et al. 2023b*).

Geopolymers are clinker-free binding materials that provide for building materials good mechanical properties

(*Bakriet al. 2012*), high thermal resistance (*Zhang et al. 2016*) and great chemical resistance (*Mehta and Siddique 2017*). The influence of metakaolin-based geopolymers on dust control and the tensile strength of loess soils was evaluated by *Hanegbi and Katra (2020)*. The geopolymer utilized by *Hanegbi* and *Katra (2020)* behaved remarkably well in terms of dust control and tensile testing. The most successful geopolymer composition, which produced the most soil strength after 28 days, was a sodium silicate and sodium hydroxide (NaOH) activation solution with a 30% metakaolin addition. For the stabilization of sulfate-rich soil, a calcium-free geopolymer synthesized using metakaolin (MK) as an aluminosilicate precursor showed improved strength with no reduction in volumetric expansion in specimens cured for 7 days, based on *Zhang et al. (2015)*. Metakaolin has been examined for its influence on the geotechnical qualities of cohesive soils. The addition of 2% to 12% metakaolin resulted in a decrease in soil-specific gravity and optimal compaction water content. Metakaolin's pozzolanic reaction influenced soil grain size disruption. More than 90% of the swelling was decreased by adding 10% metakaolin (*Ahmad and Hamza 2015*). Further research utilizing metakaolin revealed that the optimal percent of metakaolin in expansive soil stabilization is 6%; at this concentration, the strength and durability values were raised (*Muhammad et al. 2020*). *Calik and Sadoglu (2014a)* investigated the geotechnical properties of soils stabilized with perlite. The results showed that with an increasing amount of perlite up to 10%, the Unconfined Compressive Strength (UCS) of soils increased, and further increases resulted in a decrease in UCS. In a similar study, a reduction in cohesion and an increase in friction angle were observed in soils stabilized with perlite (*Calik and Sadoglu 2014b*).

In the present study, the treatment of soil with perlite and metakaolin was examined to determine their effectiveness in improving the physicochemical properties of collapsible loess soils. The experimental program of this paper includes Zeta potential measurements, and Scanning Electron Microscopic (SEM) observations.

MATERIALS AND METHODS

Properties of the soils

The loess soils utilized in the present study were provided from two sites in Hungary; the first site was in Balatonakarattya, Koppány sor with 47°1'14.93"N 18°8'38.64"E coordinates, and the second site was in Vál in Fejér county with 47°21'25.6"N 18°40'15.7"E coordinates. *Table 1* presents the basic properties of loess soils. Grain size distribution curves for the soil samples are presented in *Figure 1.* X-ray diffractogram (XRD) of soils is presented in *Figure 2.* Quartz, muscovite, and calcite were the main mineral components of soils.

Table 1. The basic properties of loess soils
1. táblázat. A vizsgált talajok tulajdonságai

Parameter	Soil 1 (Balatonakarattya)	Soil 2 (Vál)	Method Used
Liquid limit (LL), Plasticity limit (PL), Plasticity index (PI) (%)	30, 23, 7	26, 23, 3	AST* D4318
Natural water content (%)	5,5	4,5	ASTM D2216
Specific gravity (G_s)	2,70	2,67	ASTM D854
Void ratio (e)	0,9	0,9	ASTM D7263
Dry density (γ_{dry}) (kN/m^3)	14,2	14,2	ASTM D7263
Soil classification (USCS)	CL-ML	ML	ASTM D2487
Soil classification (Euro code)	SiCL	SaSi	EN ISO 14688-2

* *American Society for Testing and Materials*

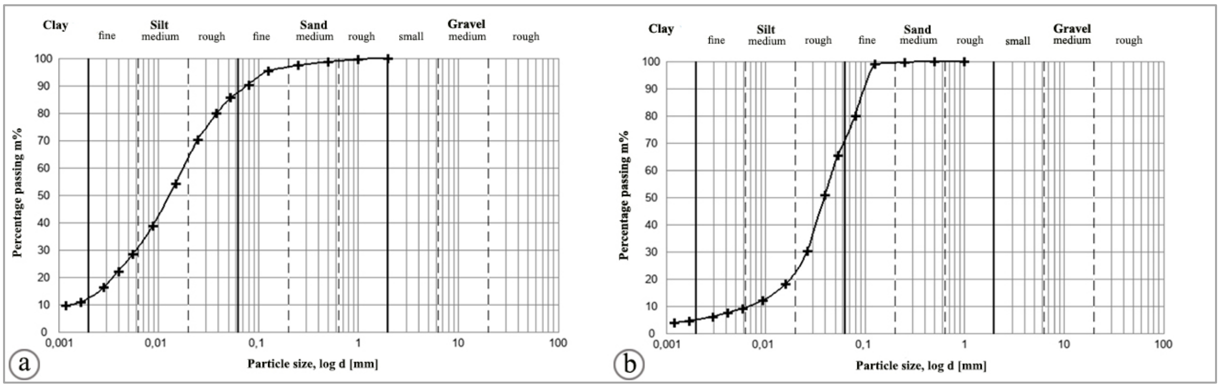

Figure 1. Grain size distribution curves for the soil samples a) Soil 1 b) Soil 2
1. ábra. A talajminták szemeloszlási görbéi, a) Talaj 1, b) Talaj 2 esetére

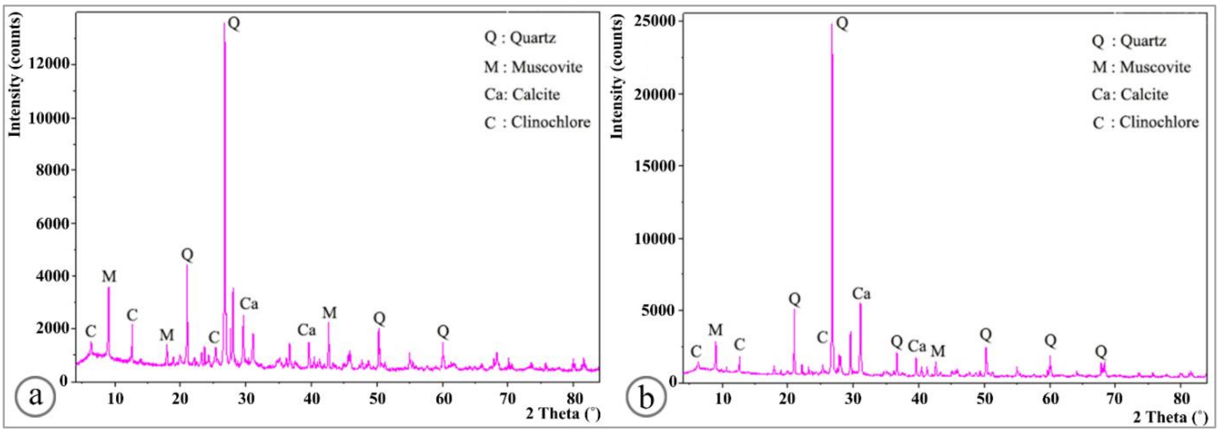

Figure 2. XRD patterns of soils, a) Soil 1 b) Soil 2
2. ábra. A talajminták XRD vizsgálatának eredménye, a) Talaj 1, b) Talaj 2 esetére

Properties of the stabilizing agents

Expanded perlite powder and calcined clay (metakaolin) were chosen as stabilizing agents. The geologic occurrence of perlite is in Pálháza, Tokaj mountain area, Hungary. The expanded perlite powder (Expanded perlite P2) used in this research is a product of ANZO Ltd., Hungary, and was prepared according to *MSZ EN 14316-1*. The main ingredients are SiO_2, Al_2O_3, and Fe_2O_3, which influence the natural pozzolana's activity. Perlite has a siliceous nature based on chemical composition. Metaver N-type metakaolin was produced by Newchem GmbH, Austria. *Table 2* represents the properties of perlite and metakaolin.

Table 2. Chemical composition and particle size of perlite and metakaolin
2. táblázat. A perlit és metakaolin oxidos összetétele és szemcsemérete

Oxide compounds	Perlite	Metakaolin
SiO_2 (%)	68-75%	52-54%
Al_2O_3 (%)	10-14%	40-43%
Fe_2O_3 (%)	<2%	<2.5%
CaO (%)	<2%	<0.5%
MgO (%)	<1%	<0.4%
K_2O (%)	3.2-4.5%	<2.0%
SO_3 (%)	<1.0%	<1.0%
Na_2O (%)	2.8-4.5%	<0.1%
Particle size	0-2 mm	<2 μm

Figure 3 shows the results of XRD patterns for perlite and metakaolin. Both materials show an amorphous nature, and the major crystalline phases of perlite and metakaolin are α-quartz and muscovite.

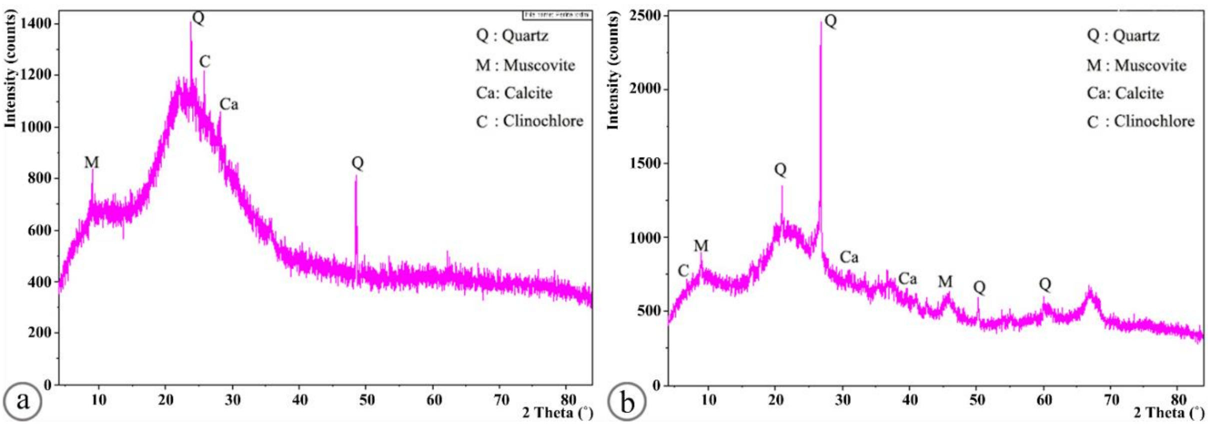

Figure 3. XRD patterns of stabilizing agents, a) perlite b) metakaolin
3. ábra. A stabilizátor anyagok röntgen-diffraktogramjai, a) perlit, b) metakaolin esetére

Sample preparation and experimental plan

At first, the remolded samples were placed into oven at 105 °C temperature for 24 hours to ensure that the soils were totally dry. To remove large particles and achieve a homogeneous distribution of the soil, the oven-dried sample was hand-ground and passed through sieve No. 10 (2 mm) based on ASTM standards. To evaluate the influence of the stabilizing agents on the physicochemical properties of soils, different dosages of perlite and metakaolin were added to the remolded and ground soil at percentages of 2, 4, 6, and 8 by dry weight of the soil. During the hand-mixing of the soil with stabilizing agents, special care was taken to ensure a homogenous mixture. Then, the treated samples were mixed with water to obtain the in-situ moisture content of the soil (5%), according to the previous research (*Khodabandeh et al. 2023b, Nokande et al. 2020, Siddiqua and Bigdeli 2022).* To achieve equilibrium conditions and allow for possible interactions between soil and stabilizing agents, the samples were placed in insulated plastic containers for 7 days for curing based on the literature review (*Ogila and Eldamarawy 2022, Zamani and Badv 2019*). Tests were performed just after this 7-day cure. Treated soil samples with perlite or metakaolin were examined by Zeta potential measurements, and due to Scanning Electron Microscopic (SEM) observations.

Zeta potential measurement

The Zeta potential is an electrokinetic characteristic of dispersed particles in a dispersant (e.g., water) that is used to measure the thickness of the diffuse double layer (DDL) and to understand the physicochemical interactions between instant clay particles and water (*Farahani et al. 2019*). In the present study, Zeta potentials were measured to analyze the electrochemical characteristics of soil samples. At first, hydrometer tests were performed on untreated soil samples in two conditions, including without Calgon solution (Sodium hexametaphosphate) and with Calgon solution. Then, hydrometer tests were performed on soils treated with different percentages of metakaolin and perlite, without and with Calgon solution. After sedimentation of soil samples for 4 hours, the soil solutions were extracted from the top of the hydrometric container and were placed into oven at 60 ºC for 48 hours. Zeta potential was examined in the extracted samples dispersed in distilled water. Before each Zeta measurement, the Zeta cuvette was washed three times with distilled water. The Zeta potentials of every sample were measured three times, and the average was used as the final test value. A Zeta potential analyzer (Zetasizer Nano ZS, Malvern, Germany) was used to test the Zeta potential.

Scanning Electron Microscopic (SEM) observations

Scanning Electron Microscopic (SEM) images are one of the best methods to observe and analyze materials' microstructure. Soil samples were studied by scanning electron microscopic method. SEM pictures were scaled to 200 μm, 100 μm, 80 μm, and 30 μm to demonstrate how the microstructure of the soils changed after 8 mass% of stabilizing agents (perlite, and metakaolin) were added to the soil samples. For the SEM observation, a Phenom XL (Thermo Fisher Scientific) desktop scanning electron microscope was used.

RESULTS

The results of Zeta potential measurement

Table 3 presents the results of the Zeta potential measurements. The results show that the Zeta potentials of both soils in the condition without Calgon (Sodium hexametaphosphate) were -17.6 mV and -12.5 mV for Soil 1 and Soil 2, respectively. However, both soils had smaller negative Zeta potentials after adding Calgon to the solutions (-33.1 mV for Soil 1 and -37.7 mV for Soil 2). Because increased electric potential near the soil surface caused a repulsive electric force among the soil particles, the soil became more dispersive at higher absolute Zeta potential levels. Therefore, it can be concluded that with the increase of Calgon, soil particles became more dispersed, and the absolute Zeta potential increased. The Zeta potential of perlite and metakaolin without Calgon were -23.4 and -20.6 mV, respectively, and their absolute values were higher than the absolute Zeta potentials of both soils without Calgon.

Table 3. The results of Zeta potential tests
3. táblázat. A Zéta-potenciál mérések eredményei

Sample	Hydrometer tests condition	Saturation fluid	Zeta potential (mV)
Perlite	without Calgon	water	-23.4
Perlite	with Calgon	water	-
Metakaolin	without Calgon	water	-20.6
Metakaolin	with Calgon	water	-
Clean soil 1	without Calgon	water	-17.6
Clean soil 1	with Calgon	water	-33.1
Clean soil 2	without Calgon	water	-12.5
Clean soil 2	with Calgon	water	-37.7

Figure 4 represents the results of Zeta potential for soils mixed with different percentages of perlite and metakaolin. As shown in *Figure 4,* with increasing perlite and metakaolin the absolute Zeta potential of treated soils increased. However, for soils containing Calgon the rising trend was more evident.

A conceptual model of a diffuse double layer in a water-soil system before and after treatment with perlite or metakaolin is presented in *Figure 5*. As shown in *Figure 5*, by increasing dosages of perlite or metakaolin, the thickness of the diffuse double layer increased. The pore water outside the diffuse double layer is free, but the water inside the diffuse double layer has a certain flow viscosity and is weakly fluid. Lower free layer thickness results in less free water flow space, which can decrease the loess sample's permeability (*Xu et al. 2021*). In other words, the actual cross-sectional area of gravitational water moving through decreases as the double layer's thickness rises. Its permeability thus decreases as the seepage time increases (*Xu et al. 2021*).

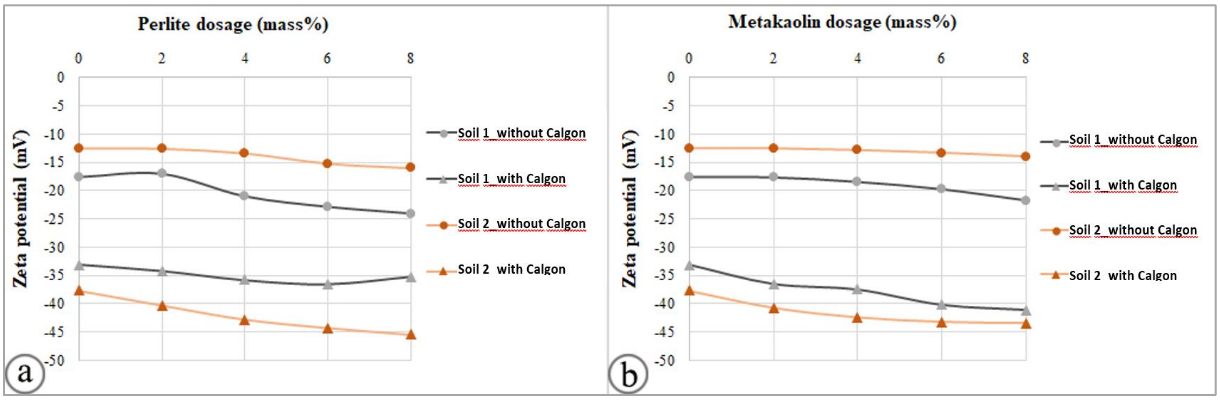

Figure 4. The results of Zeta potential tests, soil samples a) mixed with perlite b) mixed with metakaolin
4. ábra. A Zéta-potenciál mérés eredményei a) perlittel kezelt talaj b) metakaolinnal kezelt talaj esetén

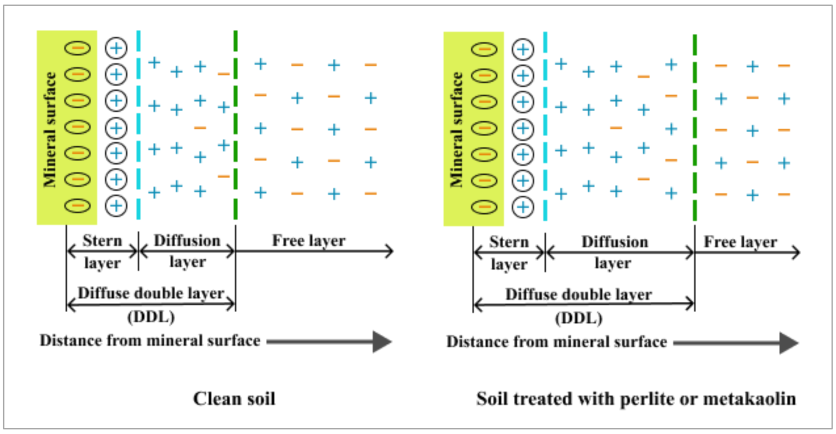

Figure 5. Conceptual model of diffuse double layer in water-soil system before and after treatment with perlite or metakaolin (modified after: Xu et al. 2021)
5. ábra. A víz-talaj rendszer diffúz kettős rétegének koncepcionális modellje, perlittel vagy metakaolinnal végzett kezelés előtt és után (Xu et al. 2021 alapján)

Effect of stabilization on the soil morphology

The results of scanning electron microscopy (SEM) are represented in *Figure 6*. The SEM images of soils treated with perlite are demonstrated in *Figures 6a* to *6d*. As shown in *Figures 6a* to *6d*, with the help of friction and interlocking force, a three-dimensional network of randomly dispersed expanded perlite particles connects soil particle surfaces. Consequently, perlite prevents soil particles from slipping on each other and increases the soil's strength. The spongy structure of expanded perlite particles has been ripped because of the applied axial stress. The failure surface of perlite-treated soil can be seen in *Figure 6c.*

As shown in *Figures 6e* to *6h*, with the addition of 8 mass% metakaolin to the soil, the microstructure of the mixture became denser and more uniform, and the number of cracks and pores decreased significantly. The presence of physicochemical reactions can be responsible for changes in the soil structure. Furthermore, several calcium-aluminate-silicate hydrate (CASH) compounds emerged in the soil structure because of the long-term presence of pozzolanic interactions between soil and metakaolin. CASH phases can fill both macro- and micropores, enhancing cohesion and macro-mechanical parameters.

DISCUSSION

As discussed in the article of Khodabandeh (*Khodabandeh et al. 2023b*) the expanded perlite had a significant influence on the mechanical properties of loess soils (*Khodabandeh et al. 2023b*). With adding perlite, soil became granular, because perlite is mainly composed of sand and gravel-size particles. In soils treated with perlite, a three-dimensional network of randomly dispersed perlite particles binds soil particle surfaces with the help of friction and interlocking forces. This can improve the strength properties of the soil/perlite mixture by preventing slippage of the perlite and soil particles in the matrix.

Metakaolin, which contains 52-54% silica and 40-43% alumina and is considered an aluminosilicate mineral, caused a change in the physical texture of the soil and an increase in the fine-grain content. The chemical interactions between MK and small particles in loess soils (consisting of SiO_2 and Al_2O_3) generated an interparticle bond that made the stabilized soils stiffer. The large surface-to-volume ratio of MK improved particle-soil interaction at the nanoscale. As a result, even a small percentage of the MK changed the physiochemical properties of the soil. It caused flocculation in loess particles, as well as increased particle bond and cohesion. The flocculation and agglomerations in the soil matrix, which are significant contributing factors to the mechanical property enhancement of the metakaolin-stabilized samples, were confirmed by SEM images.

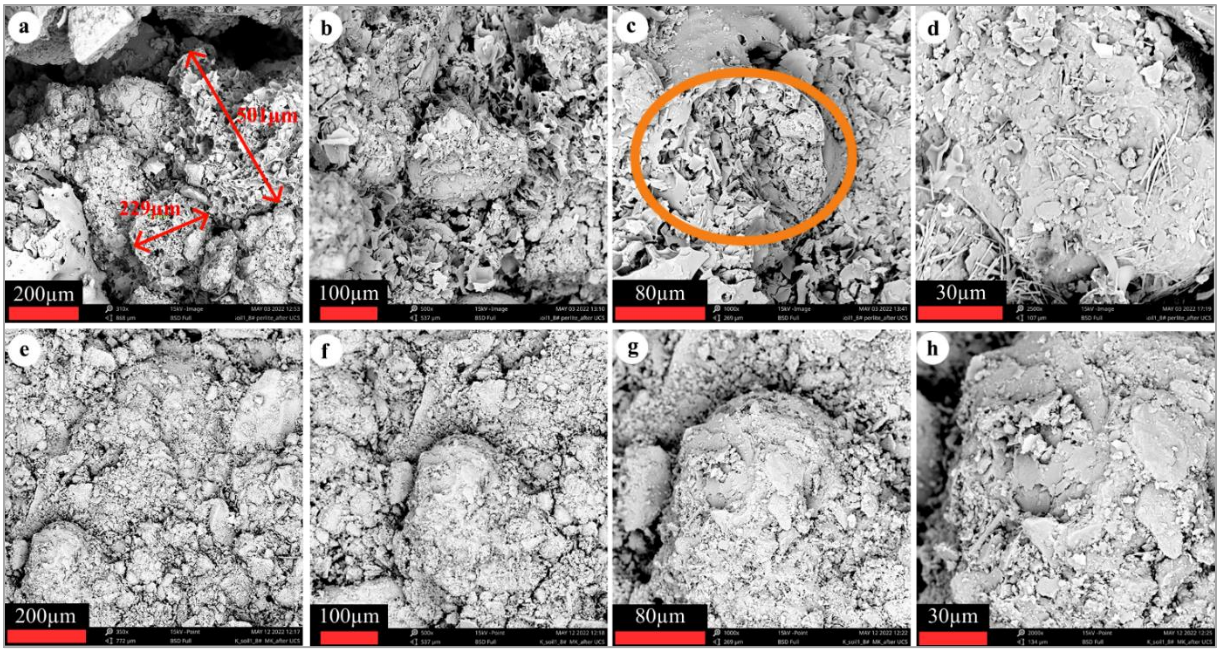

Figure 6. SEM images of soil 1 treated with 8% perlite (a, b, c, d) and soil 1 treated with 8% metakaolin (e, f, g, h)
6. ábra. SEM felvételek 8% perlittel kezelt talaj esetén (a, b, c, d) és 8% metakaolinnal kezelt talajok esetén (e, f, g, h)

The addition of metakaolin to the soil resulted in considerable improvements in the mixture's microstructural properties, such as higher density and improved homogeneity, and a notable decrease in the number of cracks and pores. The presence of metakaolin has caused a few complicated physicochemical reactions that are responsible for the observed modifications in the soil's structure. A variety of calcium-aluminate-silicate hydrate (CASH) compounds emerged within the soil matrix because of the metakaolin's interactions with the soil as a pozzolanic material. Filling macro- and micropores and improving the soil's overall cohesion were shown to be facilitated by the creation of CASH phases. Microstructure and product composition analyses revealed that the CASH colloid generated by metakaolin enhanced cementation between flake units in the plain soil, resulting in a denser soil structure when stabilized by metakaolin. In similar research (*Tabarsa et al. 2018*), soil stabilization was assessed in the field with 1, 1.5, and 2% nano clay. The extent of improvement achieved was evaluated by the flow of irrigation water in the channel. It was concluded that with increasing the percentage of nano clay, less erosion and scouring occurred. A similar behaviour can be predicted for soils stabilized with metakaolin when facing the flow of irrigation water in the channel.

The results of the Zeta potential measurement show that with increasing the percentage of expanded perlite or metakaolin, the values of the absolute Zeta potential increased (which means that the Zeta potential became a smaller negative value); this indicated a higher dispersity of soil. Based on previous research (*Parameswaran 2017*), the dispersity of soils and their Zeta potential has been discovered to be highly correlated. Also, the electrostatic repulsive pressure between soil particles increases as the Zeta potential increases (*Li et al. 2018*).

According to the article of *Khodabandeh et al. (2023b)*, by increasing the percentage of perlite and metakaolin by up to 8%, the highest improvement can be achieved. Perlite stabilization can be suggested when high compaction is not possible, for instance, around the pipelines and the edge of the excavation. However, metakaolin had better functionality after curing time due to the chemical interaction of metakaolin with soil particles during that time. Therefore, when long-term stabilization is considered, metakaolin will have a better effect due to its chemical reactions with soil particles.

CONCLUSIONS

In the present study, soil treatment by two stabilizing agents, with expanded perlite and metakaolin was examined. Our goal was to determine their effectiveness in enhancing the physicochemical properties of collapsible loess soils. The experimental program of this paper includes Zeta potential measurements and Scanning Electron Microscopic (SEM) observations.

The following conclusions may be drawn from the results of this study:

- With the aid of friction and interlocking force, expanded perlite particles connected soil particle surfaces. Metakaolin acted as a filler for honeycomb voids in the collapsible soil, increasing cementation between the grains.
- Perlite-treated soils became more granular in terms of particle size, as soil grains aggregated due to treatment. Perlite particles kept the soil grains from sliding on top of each other. In terms of metakaolin, the calcium-aluminate-silicate hydrate (CASH) colloid generated by the metakaolin enhanced cementation between the flake units of the plain soil, consequently, the metakaolin-stabilized plain soil had a denser soil structure.

- The absolute Zeta potential increased as the dosages of expanded perlite and metakaolin increased, indicating higher dispersity for soils mixed with applied stabilizing agents.
- Scanning electron microscopic observations indicated that untreated samples had a loose structure with extensive pores, whereas treated samples had a dense and uniform structure with particle rearrangement.

Finally, it is obvious that soil improvement with expanded perlite and metakaolin can improve soil engineering characteristics in any construction application. However, expanded perlite is a more cost-effective material than metakaolin.

ACKNOWLEDGEMENTS

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GÁBOR NAGY was born in 1988 in Szombathely, he completed his secondary school studies at the Jurisich Miklós High School in Kőszeg. Graduated from the Budapest University of Technology and Economics with a degree in civil engineering at the BSc level in 2011 and an MSc degree in 2013. Since 2013 he has been working at BME's Department of Geotechnics, then the Department of Engineering Geology and Geotechnics, where he performs both teaching and research tasks. In 2017 he defended his PhD thesis entitled "Dispersive clays in flood protection structures". Civil engineer, geotechnical designer, member of the Hungarian Chamber of Engineers, and the Hungarian Geotechnical Association. Member of the Hungarian Hydrological Society since 2016.

Life path

The Hungarian Hydrological Society (MHT) acknowledged the lifetime achievement of Professor Hans Wessel and honoured him with an honorary foreign membership award. On this occasion we respectfully publish salute of Prof. Ijjas and Prof. Bogárdi on behalf of friends and former students of Prof. Wessel.

The Hungarian Hydrological Society (Magyar Hidrológiai Társaság – MHT) is one of the oldest professional-scientifical organisations in Hungary. In 2017 was the 100th anniversary of its foundation. It is an association established to deal with water sciences. It has three thousand individual members as well as 150 institutional and company members. The honorary foreign member title is one of the highest honours of the MHT. Those foreign persons who were awarded with this title this century:

2000 Wolfram Dirksen (Germany) and János Szolgay (Slovakia); 2001 Janus Kindler (Poland); 2005 Arnd Böhme (Germany); 2009 Marcello Benedini (Italy) and Pavol Miklánek (Slovakia); 2013 Vladimir Zabcic (Croatia); 2017 János Bogárdi (Germany) and Charles J Vörösmarty (USA); 2019 Mitja Brilly (Slovenia) and Franz Nobilis (Austria); 2021 László Hayde (Netherlands); and 2024 Hans Wessel (Netherlands).

In 2024, on the occasion of founding the River Basin Administration (RBA) Centre and establishing close and fruitful cooperation with Hungarian scholars and researchers 35 years ago, the MHT acknowledged the achievements of Hans Wessel and honoured him with a foreign honorary membership award. With this acknowledgement, the MHT expresses its honour and thanks for what Professor Wessel has done to promote the international and European integration of Hungarian water management.

Professor Wessel is a retired professor of public law and public administration from Delft University of Technology (DUT), with main responsibility for law and administration in the field of physical planning, the environment and water management.

In 1989, with the help of prof. J. H. Kop and prof. J.C. van Dam, professors of water sciences, he founded the Centre for Comparative Studies on River Basin Administration (RBA) at DUT. In the early 1990th, within the framework of the existing cooperation of the DUT and the Budapest University of Technology (BUT), he visited the Department of Water Resources Engineering of BUT. Recognizing the common interests he initiated to start the Rhine-Danube comparative research and education programme that became the start of a more than 30 years long cooperation, the RBA partnership and friendship. This cooperation was strongly supported by prof. Kozák and prof. Józsa at BUT and prof. Bándi at Eötvös Lóránd University of Budapest.

The first main action of the Rhine-Danube cooperation was the Environmentally Sound River Basin Development ESRBD) EC supported TEMPUS Joint European Project (Ijjas-Kardoss: ESRBD TEMPUS JEP0266, Final Report, 1990-1993). The project plan has been prepared by prof. Wessel and prof Ijjas with the help of ass. prof Kardoss (BUT). The JEP, approved at the end of 1990, was among the first EC supported JEPs that have begun their activities. In the first year three universities were participating in the project: DUT, BUT and the University of Karlsruhe. From the second phase of the JEP other universities were also involved: Agricultural University of Wageningen, Eötvös Lóránd University of Budapest, Pollack Mihály College (Baja), University of Belgrade, University of Novi Sad, University of Sarajevo, University of Timisoara and Technical University of Vienna.

In the period of 1990-93 six Rhine-Danube Workshops, five TEMPUS JEP Workshops (one of them together with the Equipe Cousteau) and three intensive short courses were organised. 26 study reports were completed, 46 mobility grants have been provided, 18 for MSc, 9 for PhD students and 19 for the university staff members.

In spring of 1993 the RBA's group of foreign guest researchers included six Hungarians from BUT: prof. Ijjas, Ferenc Kiss Guba and Anna Csiti associate professors, Edina Pinczés and Gábor Dávid MSc students and Károly Pálovits PhD student (see 1. photo).

The success of the first TEMPUS Joint European Project led to a larger scale cooperation and exchange of Duch and Hungarian professors and MSc and PhD students. The impact of Professor Wessel's work and DUT is evident in the successful careers of many Hungarian water scientists who participated in the RBA's programs.

Professor Wessel and the RBA engaged in numerous collaborative projects with Hungarian experts. These collaborations included hosting Hungarian researchers and students in Delft, organizing joint workshops and conferences, and co-publishing research findings. These efforts significantly contributed to the international recognition of Hungarian water management achievements.

Photo 1. Prof. Wessel with the regular staff and with the foreign guest researchers of the RBA in the spring of 1993
Sitting in the middle of the middle row: Hans Wessel professor, director of RBA, and István Ijjas, guest professor (BUT). Guest researchers in the back row from left to right: Ferenc Kiss Guba and Anna Csiti associate professors (BUT), and in the back row from right to left: Edina Pinczés and Gábor Dávid MSc students (BUT), P. Boeriu guest professor (University of Timisoara) and Károly Pálovits PhD student (BUT)

1. kép. Wessel professzor az RBA állandó dolgozóival és vendég-kutatóival 1993 tavaszán
Középső sor közepén ülve: Hans Wessel professzor (Delfti Műszaki Egyetem) és Ijjas István vendégprofesszor (Budapesti Műszaki Egyetem- BME). Vendég kutatók a hátsó sorban balról jobbra: Kiss Guba Ferenc és Csiti Anna adjunktus (BME), a hátsó sorban jobbról balra: Pinczés Edina, Dávid Gábor MSc hallgató (BME), P. Boeriu vendég professzor (Temesvári Műszaki Egyetem) és Pálovits Károly PhD hallgató (BME)

The adoption of the DUT's International Project Education system in BUT was a key action in the early 90s. Prof. Dijk (DUT) and Prof Wessel had a leading role establishing this Dutch-Hungarian Project Education cooperation. Thank to prof. Wessel with whom the first DUT-BUT Summer Project Work was organised in 1990. In the period 1990-1995 the cooperation resulted 13 international summer projects (joint project teams of students from the Netherlands and from Hungary), 7 projects in the DUT and 6 in the BUT, for a total number of 116 students. 41 students from Hungary participated in the joint projects, eight of those students made their final thesis works later in RBA.

Professor Wessel and the RBA partnership supported the Hungarian experts and institutions in joining European research and education organisations, networks and projects, such as the TECHWARE, ETNET-ENVIRONMENT, EUROWATER, EUROWATER-CEC, EUWATERMAN, EWA Ring, ICER, the HARMONICOP, the HYDROWET, ERASMUS, and many others. His support enabled Hungarian researchers to contribute to and benefit from global and European advancements in water sciences.

Looking back to the significance of prof. Wessel's activities, on 19th September 2008 he was awarded with the Memorial Plaque of "Vásárhelyi Pál" by prof. Lovas, the Dean of the Faculty of Civil Engineering of BUT.

For his international scientific activities in 2002 he was awarded the International Cannes Water Prize. Two Hungarians, prof. Mosonyi and prof. Bogárdi were honoured with similar Cannes Prize.

István Ijjas
former president of MHT

Veronika Major
Editor-in-Chief

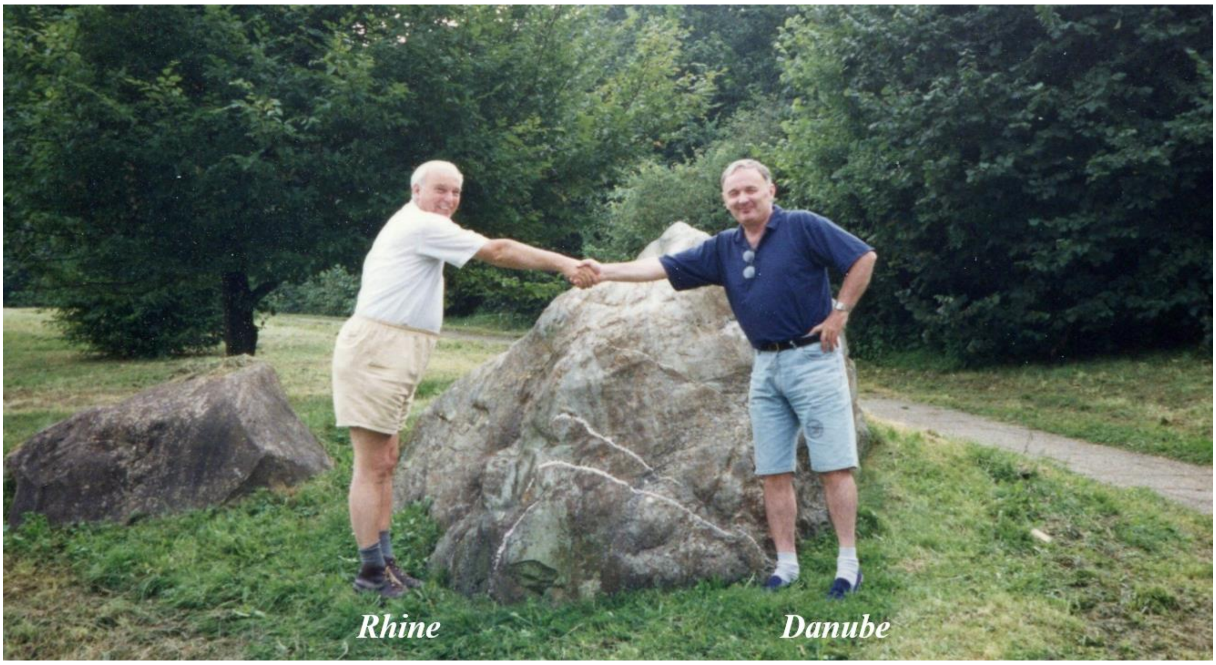

Photo 2. Professor Wessel standing in the catchment of the Rhine and Professor Ijjas in the catchment of the Danube, in the Black Forest, in front of the stone marking the border of the watershed of the two rivers (Photo by Ijjas)
2. kép. Wessel professzor a Rajna, Ijjas professzor pedig a Duna vízgyűjtő területén állva a Fekete Erdőben, a két folyó vízgyűjtőjének határát jelölő kőtömb előtt (Fotó:Ijja)

Tribute to Prof. Wessel by Prof. Bogárdi on behalf of friends and former students

The recent award of the foreign honorary member of the Hungarian Hydrological Society to Professor Hans Wessel is a well-deserved recognition of his long-term engagement as scientist to interdisciplinarity, river basin management, administration and scientific collaboration.

Prof Wessel established an interdisciplinary centre for river basin management at the Delft University of Technology. Irrespective of his academic background in law, he was a well esteemed professor at a technical university.

Obviously if your concern is the management of transboundary river basins, then the Rhine and Danube rivers are automatically the top priorities on your scientific agenda. We may call Hungary as the heart of the Danube basin. Hence his interest in Hungary and its water resources problems emanates from this coincidence. His engagement in Hungary shows on the other hand that scientific collaboration can be the root of friendship as amply documented in the books of Prof. Ijjas and myself (volumes 3 and 6 of the series "Building the future in water resources management", 2019 and 2022).

Thus, beyond praising Prof Wessel for his scientific ideas and achievements as well as his dedication to introduce interdisciplinary thinking in engineering curricula, we must also acknowledge his human virtues and warm personality.

I met Professor Wessel in 1989, shortly after having started my tenure as professor for hydrology, hydraulics, and water resources management at the Wageningen Agricultural University. He was the first Dutch colleague who invited me to attend a water resources management workshop in Groningen. This was the start of a more than thirty year-long friendship and collaboration. We participated in the then ongoing ERASMUS cooperation network masterminded by Prof André van der Beken (see *3. photo*). Spirit and principles of this collaborative platform was transferred to the then emerging TEMPUS-PHARE programs targeting the cooperation with Central European candidate states to join the EU. Prof Wessel and I participated in each other's initiatives.

Friends and former students of Prof. Wessel congratulate him for receiving this important award. Our thanks are accompanied with our best wishes of good health and pleasant memories of our collaboration.

János J. Bogárdi
Ludovika University of Public Service
Faculty of Water Sciences
Department of Water and Environmental Policy
Institute of Advanced Studies Kőszeg (iASK)

Photo 3. Meeting of the professors of water resources management participating in the European Community ERASMUS cooperation scheme, Brussels 1989.

In the first row from left to right: André van der Beken (coordinator), János Bogárdi, Hans Wessel, Ronny Verhoeven

3. kép. Az Európai Közösség ERASMUS együttműködési programjában részt vevő vízkészlet-gazdálkodási professzorok találkozója. Brüsszel 1989.

Az első sorban balról jobbra: André van der Beken (koordinátor), Bogárdi János, Hans Wessel, Ronny Verhoeven

HUNGARIAN JOURNAL OF HYDROLOGY

Guide for the preparation of professional articles in English January 2024 (excerpt)

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