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THE CHALLENGES OF CLIMATE CHANGE ADAPTATION IN ROMANIA'S LAND RECLAMATION SYSTEMS: BETWEEN GREY INFRASTRUCTURE AND NATURE-BASED SOLUTIONS

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Abstract

Climate change is placing increasing pressure on Romania's agricultural sector through intensified drought, greater precipitation variability, and more frequent hydrometeorological extremes. In this context, land reclamation systems, including irrigation, drainage and dewatering works, and anti-erosion measures, are becoming essential for reducing vulnerability and strengthening agroecosystem resilience. This article analyzes the main challenges in adapting these systems to climate change from an integrated technical, ecological, economic, and institutional perspective. It highlights outdated infrastructure, limited modernization, high water and energy demands, and environmental impacts, especially on hydrological regimes and biodiversity. At the same time, it examines economic and institutional barriers, and the gap between stated policies and practical implementation. The paper also explores the potential of Nature-based Solutions, and integrated green infrastructure, as viable complements or alternatives to traditional grey infrastructure. The findings emphasize the need for adaptive management, combining technological modernization, effîcient water use, and green solutions, to support climate resilience, food security, and territorial sustainability. In addition, the paper includes a case study of the Comlod polder project (Bistrița-Năsăud County, Romania), illustrating how flood retention infrastructure can function as a hybrid grey-green system contributing to climate adaptation and integrated water management.

Key words*: adaptation, climate change, environmental impacts, nature-based solutions.*

INTRODUCTION

Climate change represents one of the most significant challenges for agricultural systems worldwide, affecting crop productivity, water resource availability, and the stability of agroecosystems (Yuan et al., 2024). The intensification of extreme events such as droughts, floods, and heatwaves leads to significant changes in hydrological regimes and plant growth cycles. Recent studies indicate that these processes directly influence land suitability for agriculture and may lead to the degradation of productive potential in many regions of the world (Shevchenko et al., 2023). In this context, European agriculture is considered one of the sectors most vulnerable to climate change, particularly in southern and eastern regions where water deficits and precipitation variability are intensifying (Florea et al., 2025). Consequently, the adaptation of agricultural infrastructure and water management systems becomes essential for maintaining productivity and food security. Land reclamation systems -including irrigation, drainage and dewatering works, and anti-erosion measures - represent fundamental components of this adaptation, as they enable the regulation of soil water regimes and reduce the risks associated with drought or excess water (OECD, 2025). In Romania, the effects of climate change are manifested through the intensification of water deficits, the aridification of certain agricultural regions, and increased precipitation variability (Nițu et al., 2023). Climatic and agronomic analyses highlight the high vulnerability of Romanian agriculture to hydrological imbalances, particularly in the Romanian Plain, Dobrogea, and southern Moldova (Frone et al., 2021).

These findings underline the sensitivity of the agricultural sector to climate variability and water scarcity, with direct effects on agricultural production and the stability of agri-food systems. At the same time, Romania's land reclamation infrastructure faces structural problems related to technical degradation, low efficiency, and the incomplete use of existing capacities. Although large areas have been equipped for irrigation, the actual functioning of these systems remains limited, and water losses are significant (Corcheș, 2025). These conditions indicate that the main issue is not only the availability of water resources, but also the low efficiency of the systems designed to manage water deficits.

In this context, recent literature emphasizes the need to move beyond a paradigm based exclusively on technical infrastructure ("grey infrastructure") and to shift toward integrated water management approaches (Castañeda Rodriguez et al., 2026). Nature-based Solutions (NbS) use ecosystem processes to support water retention, soil stabilization, erosion reduction, and biodiversity conservation (Santos, 2025). However, these solutions should not be viewed as alternatives to technical infrastructure, but rather as complementary elements within an integrated water management system. The concept of hybrid ("grey-green") infrastructure involves combining hydrotechnical structures with natural elements that can perform part of the system's hydrological functions (Bujak et al., 2025). For example, irrigation systems can be complemented by shelterbelts, wetlands, or vegetative anti-erosion measures, which help reduce pressure on water resources and increase the resilience of agricultural systems to climate variability (Pourmohammad & Hajirad, 2025). Against this background, the present study analyzes the challenges of adapting Romania's land reclamation systems to climate change, highlighting the interdependencies between technical, ecological, economic, and institutional dimensions. At the same time, it explores the potential and limitations of integrating Nature-based Solutions into the modernization of existing infrastructure, as well as the role of hybrid infrastructures in increasing the resilience of agricultural systems. To illustrate the practical application of these concepts, the paper also includes a case study analysis of the Comlod Polder project in Bistrița-Năsăud County. This project represents an example of hybrid hydrotechnical infrastructure designed for flood retention and flood risk reduction, integrating both engineering solutions and elements with ecological functions. The case study highlights how such arrangements can simultaneously contribute to hydrological risk management, water retention in the landscape, and the enhancement of water management system resilience in the context of climate change.

MATERIALS AND METHODS

The preparation of this article was based on an interdisciplinary approach that combined the analysis of scientific literature with the examination of strategic and legislative documents relevant to water resource management and the adaptation of agriculture to climate change. The research methodology aimed to identify the main challenges associated with the adaptation of land reclamation systems in Romania and to evaluate the potential of Nature-based Solutions (NbS) to complement existing technical infrastructure.

The first methodological step consisted of a critical review of the scientific literature, including national and international journal articles addressing the impacts of climate change on agriculture, the functioning of irrigation and drainage systems, and the role of Nature-based Solutions in water management within agricultural landscapes.

In parallel, an analysis of relevant strategic documents and public policies related to land reclamation and climate change adaptation was conducted. Based on the information derived from the literature and policy analysis, the challenges of adapting land reclamation systems were structured into four main dimensions: technical, ecological, economic, and institutional. This approach made it possible to highlight the interdependencies between infrastructure condition, ecosystem functioning, the economic viability of investments, and the institutional capacity to implement adaptation policies. To complement

the theoretical analysis, the study also includes an applied case study represented by the Comlod Polder project, located in Bistrița-Năsăud County. The case study was used to illustrate how hydrotechnical infrastructure can integrate elements of hybrid ("grey-green") infrastructure and contribute to adaptive water management in the context of climate change. The analysis was based on the technical documentation prepared for obtaining the environmental permit for the project, as well as on information regarding the construction solutions, hydrological functioning, and environmental constraints associated with the development of the polder. The principal author of the article participated, as an environmental expert, in the environmental permitting procedure for the Comlod Polder project. This direct involvement provided access to the technical documentation and to the environmental impact assessment process, enabling a detailed understanding of the interaction between the project's technical requirements, environmental constraints, and biodiversity protection measures. It also allowed the author to contribute to the identification of mitigation measures during the project planning phase.

By combining literature review, analysis of public policy documents, and the applied case study, the methodology provides an integrated perspective on the challenges and opportunities associated with the adaptation of land reclamation systems to climate change in Romania.

RESULTS AND DISCUSSIONS

In Europe, agriculture is one of the sectors most vulnerable to climate change, particularly in southern and eastern regions where droughts are becoming increasingly frequent and severe. European adaptation policies highlight the need to adapt agricultural infrastructure and water management systems, including their integration into the Common Agricultural Policy, in order to maintain productivity and food security (Naumann et al., 2020). At the global level, national adaptation plans frequently identify agriculture as a priority sector, and the integration of ecosystem-based solutions and green infrastructure is increasingly promoted to reduce vulnerability and enhance the resilience of agricultural systems (Terton et al., 2024).

In this context, land reclamation systems - such as irrigation, drainage and dewatering works, and anti-erosion measures - represent essential infrastructures for water management in agriculture and for stabilizing agricultural production. By regulating the soil water regime, these systems reduce risks associated with drought or excess water and contribute to increasing crop productivity while limiting soil and nutrient losses (Pistocchi et al., 2022). Under climate change conditions, the role of these infrastructures becomes even more important. Increasing precipitation variability and prolonged droughts raise dependence on irrigation, while intense rainfall events increase the need for drainage systems and anti-erosion works. At the same time, inefficient water management in irrigation systems can generate hydrological imbalances and additional pressure on water resources (Junquera et al., 2024). From a food security perspective, land reclamation infrastructure contributes to stabilizing agricultural production and reducing the vulnerability of agri-food systems. In many regions, these systems enable agriculture to be practiced in areas with water deficits or erosion-prone soils, thereby supporting agricultural production and rural economies (Polo-Ballinas et al., 2022).

In recent decades, climate change adaptation strategies have been dominated by technical solutions based on grey infrastructure, such as dams, irrigation canals, drainage systems, and river regulation works. Although these measures reduce hydrological risks associated with climate variability, their high maintenance costs and ecological impacts have led to reconsideration of their exclusive use in adaptation policies (Naumann et al., 2020; Pistocchi et al., 2022). As an alternative or complement to grey infrastructure, the concept of Nature-based Solutions (NbS) has gained increasing importance, as it uses natural ecosystem processes to address challenges such as climate change adaptation, water management, and biodiversity conservation. In agriculture, NbS include measures such as artificial wetlands, natural water retention in

the landscape, agroforestry, and the restoration of riparian ecosystems (Pistocchi et al., 2022).
Recent studies show that NbS can generate multiple co-benefits, including flood risk reduction, increased biodiversity, and enhanced ecosystem carbon storage capacity (Santos, 2025). However, their large-scale implementation remains limited by institutional, financial, and planning barriers, which maintains grey infrastructure as the dominant solution in many sectors (Ryfisch et al., 2023). Although the literature on agricultural adaptation to climate change is expanding, significant gaps remain in integrating water management infrastructure with Nature-based Solutions. Most studies analyze technical infrastructures or ecological solutions separately, without addressing their interactions within complex agricultural systems (Polo-Ballinas et al., 2022). In many European countries, including those in Eastern Europe, land reclamation infrastructure was designed for the climatic conditions of the twentieth century and does not reflect current climate realities. This situation highlights the need to integrate Nature-based Solutions into the modernization of existing agricultural infrastructure, using ecosystem processes to provide similar or complementary services such as natural water retention, wetland restoration or conservation, and afforestation or reforestation (Pistocchi et al., 2022).

1. Romania's Context in Relation to Climate Change

In Romania, climate change is manifested through the intensification of water deficits, the aridification of southern and eastern regions, and increasing precipitation variability, with direct effects on agriculture. Recurrent droughts have led to the degradation of extensive areas and are associated with the decline of agricultural systems and the abandonment of irrigation infrastructure (Prăvălie et al., 2013). A national-scale analysis based on the Normalized Difference Drought Index (NDDI) for the period 2001-2020 shows that these regions remain consistently the most affected, even in relatively wetter years, indicating a structural vulnerability of agriculture in the Romanian Plain, Dobrogea, and southern Moldova, where water availability becomes critical during the growing season (Dobri et al., 2021). Dobrogea shows a high vulnerability to drought. Analyses for the period 2001-2021, based on the CDI, SPI, and SPEI indices, indicate an increasing frequency of drought episodes associated with high temperatures and reduced precipitation. Severe droughts were recorded particularly in 2011, 2012, and 2020, while between 2018 and 2020 a prolonged drought episode affected more than 70% of the region (Șerban et al., 2025). Climatological analyses for Constanța County also indicate a frequent transition between slightly arid and semiarid conditions, with more pronounced aridity episodes especially after 2000 (Maftei et al., 2024). From an agricultural perspective, this variability reduces soil water reserves and increases uncertainty regarding crop selection and the timing of agricultural operations. At the same time, the precipitation regime is changing, with intense rainfall events occurring more frequently as isolated episodes with large amounts of water. The analysis of pluviometric indices for the period 1961-2013 shows an increase in days with very intense precipitation (R10, R20, R30), with regional differences between northern and southern Romania (Croitoru et al., 2016). For agriculture, this pattern increases both the risk of soil drought between rainfall events and the risk of erosion or waterlogging during intense precipitation. The impact on production is particularly evident in Dobrogea, where maize productivity depends on climatic conditions by approximately 40%, and each additional 1 mm of water deficit can reduce yields by 7.1-11.0 kg/ha, reaching up to about 1.1 t/ha for a deficit of 100 mm (Prăvălie et al., 2014).
In this context, drought monitoring becomes essential for adaptation strategies. Studies conducted in southeastern Romania show an intensification of drought conditions in recent decades, reflected by SPI and SPEI indices, and emphasize the need to expand climate monitoring networks (Venturi et al., 2024).

2. Current State of Land Reclamation Infrastructure in Romania

Romania has approximately 15 million hectares of agricultural land, of which about 7 million hectares are potentially irrigable, while around

3.2 million hectares have been equipped for irrigation. However, the area actually irrigated each year is significantly smaller than the equipped area, highlighting a major gap between the existing infrastructure and its real use (Beilicci et al., 2019). A key factor is the poor technical condition of irrigation infrastructure. Before rehabilitation works, pumping stations operated at about 50% efficiency, the degradation level of canals and hydrotechnical structures reached 72%, and water losses along conveyance canals were estimated at 52% (Cojocinescu et al., 2017; Stanciu et al., 2024).

Similar difficulties occur in drainage and dewatering systems, where temporary excess water, sedimentation, and infrastructure wear reduce the operational capacity of existing arrangements, highlighting the need for strategies adapted to new hydrological conditions (Ilca et al., 2024). At the same time, recent literature indicates that a large part of Romania's irrigation infrastructure is technologically outdated and requires modernization, as the lack of investment and maintenance has led to network deterioration in many agricultural areas (Stanciu et al., 2024). These aspects suggest that simple physical rehabilitation of infrastructure is insufficient without technological and managerial reconfiguration adapted to current climatic conditions. Although some studies highlight local examples of modernization - such as the introduction of modern irrigation techniques in western Romania that can increase yields and reduce vulnerability to water deficits - these initiatives remain isolated and are not yet widely implemented at the national level (Șmuleac et al., 2024).

3. **The Role of Public Policies and European and National Funding**

Public policies have significantly influenced the modernization of land reclamation systems in Romania, although the results have been uneven. While the National Strategy for Reducing the Effects of Drought represents an important reference framework, recent analyses indicate limited progress and a gap between strategic planning and actual implementation (Stanciu et al., 2024).

From a financing perspective, the National Program for the Rehabilitation of the Main Irrigation Infrastructure has been one of the main public interventions, with investments of approximately €1.015 billion. In parallel, the National Rural Development Programme (NRDP) 2014-2020, through sub-measure 4.3, allocated around €435 million for the modernization of secondary irrigation infrastructure managed by Water Users Organizations (Cojocinescu et al., 2017). The program aimed to increase the share of economically viable functional irrigated areas from about 50% to 70% by 2020 and to 90% by 2030. However, the literature shows that funding policies in Romania have focused mainly on the technical rehabilitation of existing infrastructure, while the integration of Nature-based Solutions remains limited. Although climate change is increasing pressure on agriculture, current infrastructure still faces significant problems related to functionality and incomplete modernization, highlighting the need for an integrated approach that combines technical modernization, efficient water management, and Nature-based Solutions.

4. **Challenges of Adaptation in Land Reclamation Systems**

Adapting land reclamation systems to climate change goes beyond the simple rehabilitation of existing infrastructure and requires viewing them as socio-technical-ecological systems, in which infrastructure, ecosystems, and management practices are closely interconnected. In Romania and across the Danube region, increasing climatic pressure highlights the limitations of the traditional model based on grey infrastructure and emphasizes the need for more flexible and integrated solutions grounded in adaptive water management (Dogaru et al., 2019; Chitu et al., 2020).

4.1. ***Technical Challenges***

One of the main technical challenges is the outdated irrigation infrastructure and the rigidity of water distribution systems. In many irrigation schemes in Romania, systems still operate according to design principles developed for more stable climatic conditions, which limits their ability to adapt to current variability. Studies show that irrigation

scheduling is often influenced more by infrastructure characteristics than by the actual water needs of crops, while efficiency assessment is complicated by the lack of reliable data and by losses through evaporation, infiltration, or runoff (Dogaru et al., 2019; Chitu et al., 2020). With the intensification of drought conditions, existing infrastructure is increasingly insufficient to meet current agronomic requirements. Simulations using the CROPWAT model for wheat cultivation in southwestern Romania indicate the need for up to four additional irrigation events per year, while insufficient water supply may reduce yields by 17.9-43.3%, highlighting the growing inflexibility of traditional irrigation schemes under new climatic conditions (Constantin et al., 2025). The increasing frequency of droughts, the alternation between very dry periods and intense rainfall events, and rising temperatures exert additional pressure on irrigation systems. Under these conditions, existing infrastructure is often under-dimensioned and operationally rigid, reducing the efficiency of water distribution and increasing the vulnerability of agricultural production. Consequently, adaptation requires not only the technical rehabilitation of infrastructure but also more flexible and integrated water management solutions.

Water losses represent not only a technical problem but also an issue related to monitoring and institutional organization. The lack of efficient measurement and coordination systems makes it difficult to identify losses and optimize water distribution, meaning that even rehabilitated infrastructure may operate below optimal parameters. In addition, many existing drainage systems are rigid and designed primarily for rapid water evacuation, which becomes problematic under the increasing alternation between intense rainfall and drought. This situation requires more flexible water management approaches capable of addressing both water excess and deficit simultaneously (Bogdan et al., 2024; Petruța et al., 2025).

Excess soil moisture also represents a major pedological limitation, often caused by precipitation, high groundwater levels, or insufficient drainage, which negatively affects soil aeration and biological processes (Lațo et al., 2022). Although drainage systems can mitigate these effects, interventions based exclusively on rapid water evacuation may simplify hydrological regimes and reduce the ecological functions of agricultural landscapes.

4.2. *Ecological Challenges*

Ecological challenges associated with land reclamation systems arise because grey infrastructure modifies natural water regimes and reduces ecological connectivity, thereby affecting biodiversity. River regulation and declining groundwater levels have contributed to the degradation of floodplain ecosystems and to the reduction of ecosystem services (Constandache et al., 2022). At the same time, environmentally friendly practices such as shelterbelts and small water retention structures have been abandoned or degraded, although they previously played an important role in water and soil conservation (Hălbac-Cotoară-Zamfir et al., 2019). The tension between agricultural productivity and environmental conservation therefore has not only a biogeophysical dimension but also a historical and institutional one, as infrastructure and land-use patterns have been shaped by changing economic priorities. In this context, drainage works may negatively affect wetlands and aquatic biodiversity by reducing floodable areas and simplifying hydrological regimes. Consequently, drainage interventions should be evaluated in a broader perspective that considers the role of wetlands in maintaining biodiversity and supporting the natural regulation of water within agricultural landscapes.

4.3. *Economic Challenges*

The economic dimension of adaptation is strongly influenced by the high costs of modernizing irrigation infrastructure, which involve not only physical rehabilitation but also investments in monitoring systems, digitalization, and energy efficiency (Corcheș, 2025). At the same time, the uneven agrarian structure of Romanian agriculture makes such investments more accessible to large farms, while small farms often face difficulties in securing financing and covering operational costs (Burja et al., 2020). Studies on family farms in Central and Eastern Europe show that

production scale and market integration are key factors influencing economic resilience, placing small farms at a structural disadvantage in the adaptation process (Borychowski et al., 2020). In addition, the high dependence on subsidies and the limited impact of eco-schemes in reducing inequalities make the transition difficult without substantial public support (Borychowski et al., 2020; Toma et al., 2023). As a result, the modernization of water infrastructure risks increasing agricultural polarization, as large farms are able to adopt new technologies more rapidly, while smaller farms remain more vulnerable due to constraints related to access to technology, professional training, and the productivity of production factors (Florea et al., 2021).

4.4. *Institutional and Governance Challenges*

Institutional and governance challenges represent an important barrier to the adaptation of land reclamation systems, as they involve numerous actors and administrative levels, making the coordination of investments and decisions more difficult. In Romania, climate services are still at an early stage, and the lack of a dedicated platform limits the operational use of climate information in decision-making processes (Falcescu et al., 2024). Although agriculture, water resources, biodiversity, and the forestry sector are recognized as highly vulnerable to climate change, the implementation of adaptation measures remains fragmented, and the transition from strategic planning to integrated territorial interventions is still limited (Dumitrașcu et al., 2025).

At the river basin level, there is a gap between the need for integrated water management and current administrative practice. Studies emphasize the importance of a basin-based approach and the use of forecasting and decision-support tools to optimize water distribution (Dogaru et al., 2019; Chitu et al., 2020). However, their application is constrained by limited institutional capacity for data collection, intersectoral cooperation, and the integration of scientific knowledge into routine management. Overall, the literature indicates that technical, ecological, economic, and institutional challenges are strongly interconnected. Outdated infrastructure generates water losses and high operating costs, hydrological rigidity may negatively affect ecosystems, and structural inequalities within agriculture limit the ability of many farms to participate in modernization processes. Without adaptive governance capable of integrating grey infrastructure with Nature-based Solutions and territorially differentiated policies, the adaptation of land reclamation systems risks remaining incomplete and largely reactive rather than transformative (Hălbac-Cotoară-Zamfir et al., 2019; Burja et al., 2020; Falcescu et al., 2024).

5. **The Role and Potential of Nature-based Solutions (NbS)**

The integration of Nature-based Solutions (NbS) into the management of land reclamation systems represents an emerging direction in the adaptation of agriculture to climate change. Unlike approaches based exclusively on engineering solutions, NbS rely on natural ecosystem processes to provide services such as water retention, soil stabilization, and erosion reduction. These solutions do not replace hydrotechnical infrastructure but rather complement it, contributing to improved water management efficiency within agricultural landscapes (Ion et al., 2024).

In Romania, Nature-based Solutions are becoming increasingly relevant because much of the land reclamation infrastructure was designed within a rigid technical model focused on artificial hydrological control. Under current climate change conditions, the integration of NbS can support the natural regulation of hydrological flows, increased soil water retention, and the strengthening of ecosystem functions, thereby contributing to the development of more resilient and sustainable agricultural systems.

5.1. *Examples of Nature-based Solutions*

- Shelterbelts (Protective Forest Belts)

Shelterbelts represent effective Nature-based Solutions in agricultural areas vulnerable to drought and wind erosion. By reducing wind speed and evapotranspiration, they protect crops, favor snow accumulation, and limit soil losses. In Romania, the reintroduction of shelterbelts is considered an important measure for reducing land degradation and supporting

agricultural adaptation to climate change (Hălbac-Cotoară-Zamfir et al., 2019).

- Wetland Buffers and Wetland Restoration
Wetlands and riparian buffer zones represent important Nature-based Solutions for water management in agriculture, as they retain and filter water, reduce nutrient runoff, and help stabilize local hydrological regimes. At the same time, they provide valuable habitats for biodiversity and can reduce flood risk by absorbing excess water. In Romania, the degradation of these ecosystems through drainage and river regulation has negatively affected biodiversity, and their restoration is considered an effective solution for restoring ecosystem functions and increasing the resilience of agricultural landscapes (Constandache et al., 2022).

- Green Anti-Erosion Measures
Green anti-erosion measures include practices such as vegetative soil cover, strip cropping, and the use of perennial plants, which reduce surface runoff, limit soil erosion, and enhance water infiltration into the soil (Ion et al., 2024). Soil stabilization can also be optimized through laboratory methods and geotechnical modeling to identify effective solutions for reducing the degradation of agricultural land (Olinic et al., 2023).

- Natural Water Retention in the Landscape
An increasingly discussed concept in the European literature on Nature-based Solutions is that of Natural Water Retention Measures (NWRM). These measures include the restoration of floodplains, the creation of micro-depressions, the restoration of wetlands, and the use of vegetation to increase water infiltration into the soil.

5.2. *Benefits of Nature-based Solutions*

A major advantage of Nature-based Solutions lies in their ability to generate multiple benefits for socio-ecological systems. They contribute to climate adaptation by increasing the capacity of agricultural landscapes to manage hydrological variability and by reducing risks associated with drought or extreme precipitation. At the same time, NbS improve soil quality, reduce erosion, and support biodiversity. They also provide essential ecosystem services such as water purification, carbon sequestration, and microclimate regulation, thereby contributing to the development of more resilient agricultural systems (Hălbac-Cotoară-Zamfir et al., 2019; Ion et al., 2024).

6. **Case Study: The Comlod Polder - Hybrid Infrastructure for Flood Management and Climate Adaptation**

To illustrate the transition of land reclamation infrastructure toward adaptive water management models, the Comlod Polder project, located in Bistrița-Năsăud County and promoted by the Mureș River Basin Administration, can be analyzed (Figure 1).

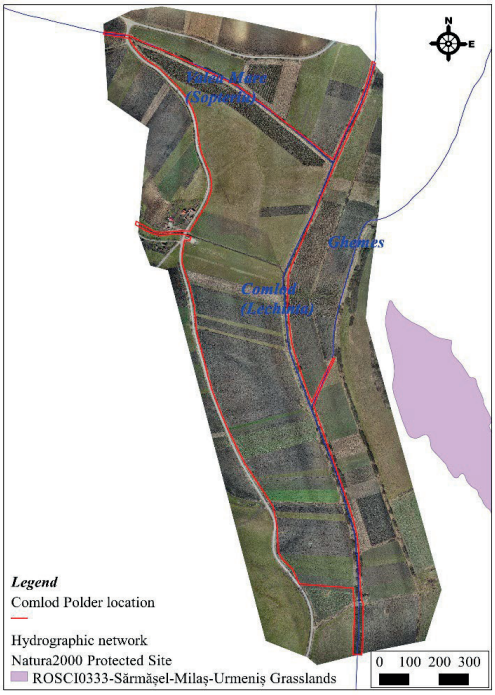


Figure 1. Comlod Polder Location (original)

The project is designed as a hybrid flood-retention infrastructure within the catchment of the Valea Mare and Comlod rivers, integrating the Fânațe tributary. The technical solution involves the construction of a compartmentalized polder with a single water intake threshold, while Fânațe river is channelized and functions as an internal

spillway separating the two compartments of the polder (SC 4C Project Consulting SRL, 2023). The concept of the project is based on the temporary retention of flood waves by storing excess water volumes inside the polder and releasing them in a controlled manner through a spillway and a bottom outlet. Through this mechanism, the polder reduces peak downstream flows and mitigates flood risk, functioning as a local hydrological regulation system. From a technical perspective, the polder covers an area of approximately 43.04 ha and has a total retention capacity of about 1.75 million m³, divided into two functional compartments: 17.93 ha (0.62 million m³) and 25.11 ha (1.13 million m³). The hydrological supply is ensured by Valea Mare and Comlod rivers, while Fânațe river is integrated through a reinforced concrete channelization of 370 m, designed to convey flows with a 1% exceedance probability (Q1%) (SC 4C Project Consulting SRL, 2023). Water intake into the polder is controlled through a system of hydraulic thresholds: a broad-crested intake weir with a length of 24 m and a downstream diversion weir measuring 7.5 m in length and 1 m in height. To maintain hydrological connectivity during non-flood periods, the structure includes a low-flow slot (1.0 m × 0.50 m) that ensures the continuity of the watercourse and the movement of aquatic biodiversity. Downstream works include energy dissipation and riverbed stabilization structures, such as concrete lining, an energy dissipator, and a mobile stilling basin (SC 4C Project Consulting SRL, 2023). The containment and guidance of water volumes are achieved through a system of embankments with a total length of 5,715 m, of which 4,000 m are perimeter embankments and 1,715 m are guiding embankments. The embankments have 1:2 slopes and a crest stabilized with crushed stone to allow maintenance access. Slope stabilization is achieved through grassing, while areas exposed to higher hydraulic stress are protected with concrete lining. Controlled water evacuation is performed through a 24 m spillway and a bottom outlet consisting of two gated openings, with a maximum discharge capacity of approximately 24.6 m³/s.

In the context of current climatic trends characterized by the increasing frequency of extreme hydrological events, including intense rainfall and flash floods alternating with drought periods, the Comlod polder highlights the role of such infrastructure as a climate adaptation measure, capable of temporarily storing significant water volumes and reducing flood peaks. Beyond its flood protection function, the polder also presents characteristics similar to Nature-based Solutions. During non-flood periods, its surface can function as a temporary wetland, promoting water retention in the landscape, infiltration, and groundwater recharge. Vegetation established on the embankment slopes and within the polder also contributes to soil stabilization, erosion reduction, and the enhancement of local biodiversity.

The project also raised several challenges during the environmental permitting process. Near the project site lies the Natura 2000 site ROSCI0333 - Sărmășel - Milaș - Urmeniș Grasslands, covering 1,127.10 ha, designated for the protection of habitats and species of community interest. The environmental assessment analyzed the potential impact on amphibian species such as *Bombina bombina*, *Bombina variegata*, and *Triturus cristatus*. As a result, specific measures were required to maintain the longitudinal connectivity of the watercourse, ensured through the low-flow slot integrated into the diversion weir structure.

The case study analysis shows that the Comlod polder represents an example of hybrid hydrotechnical infrastructure, combining engineering solutions with natural stabilization elements and potential ecological functions. Through temporary water retention, flood peak reduction, and the potential formation of seasonal wetland habitats, the project contributes both to reducing hydrological risks and enhancing local ecosystem services. In the context of climate change, such integrated solutions become increasingly important for strengthening the resilience of water management systems.

CONCLUSIONS

The analysis highlights that the adaptation of land reclamation systems to climate change represents a complex challenge that goes beyond the strictly technical dimension of

hydrotechnical infrastructure. The increasing frequency of droughts, the growing variability of precipitation, and the occurrence of extreme hydrological events intensify pressures on agriculture, emphasizing the dependence of agricultural systems on efficient water resource management. In the case of Romania, the results show that land reclamation infrastructure continues to play an essential role in stabilizing agricultural production; however, its functioning is limited by technical degradation, high water losses, and the rigidity of operational schemes. These aspects indicate that the adaptation challenge is not related solely to water availability, but also to technical efficiency, institutional capacity, and the organization of water management.

The study also demonstrates that the challenges associated with adaptation should be analyzed from an integrated perspective that simultaneously considers the technical, ecological, economic, and institutional dimensions of land reclamation systems. In this context, the literature and the present analysis suggest that Nature-based Solutions can play an important role in increasing the resilience of agricultural systems by improving water retention in the landscape, reducing erosion, and strengthening ecosystem functions.

The results further indicate that integrating grey infrastructure with Nature-based Solutions may represent a promising direction for adapting water management systems. The concept of hybrid ("grey-green") infrastructure allows the combination of hydrotechnical control of water resources with natural hydrological regulation processes, thereby reducing the vulnerability of agricultural systems to climate variability.

The case study analysis of the Comlod Polder illustrates how hydrotechnical infrastructure can integrate multiple functions, contributing both to flood risk reduction and to water retention and the development of temporary wetland habitats. In this sense, retention structures can be interpreted as hybrid infrastructures capable of combining hydrological protection objectives with ecosystem conservation goals. At the same time, adapting land reclamation systems to climate change requires a paradigm shift, in which the modernization of technical infrastructure is correlated with the integration of Nature-based Solutions, the development of institutional capacity for adaptive management, and public policies focused on the sustainable management of water resources in agriculture. Such an approach can contribute to strengthening the resilience of agricultural systems and enhancing food security in an increasingly uncertain climatic context.

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