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Review

Beyond Water Storage: The Multifaceted Role of Agricultural Ponds in Rural Socio-Ecological Landscapes

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Abstract

Agricultural ponds are often narrowly reduced to water storage units, purification systems, or biodiversity reservoirs, reflecting a dominant yet incomplete perspective that overlooks their role in rural landscapes. By moving beyond that, this study argues that they should be understood as multifunctional socio-ecological infrastructures embedded within rural territorial dynamics. Their functions extend beyond hydrological and ecological processes to include productive, social, cultural, and landscape-related dimensions. Both utilitarian and aesthetic, agricultural ponds contribute to territorial organisation, support agricultural productivity, sustain rural livelihoods, and shape local socio-ecological interactions. Based on a review of Scopus-indexed literature, this study proposes a reconceptualisation of agricultural ponds through a socio-ecological and landscape perspective. The analysis identifies the main research themes, their evolution, associated functions, and persistent knowledge gaps. Results reveal a fragmented literature, strongly dominated by biophysical approaches that focus on water quality, nutrient cycles, microbial dynamics, and ecosystem processes. Despite increasing methodological sophistication, social and territorial dimensions such as local perceptions, governance systems, practices, and spatial organisation remain marginal. Drawing on empirical illustrations from exploratory investigations of rural villages in Belgium and Poland, the study further highlights the role of agricultural ponds in shaping territorial organisation, identity, and community interactions. These examples demonstrate that pond-related systems are inherently multidimensional and have historically played an underappreciated role in shaping rural landscapes and mediating socio-ecological relationships across scales.

Keywords: agricultural ponds; multifunctionality; ecosystem services; socio-ecological system (SES); rural landscape

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1. Introduction

Across the world, from the Global North to the Global South, and from coastal lowlands to high-altitude regions, agricultural ponds occupy an important place within rural landscapes [1–3]. They are small bodies of standing water, generally not exceeding one hectare in surface area and less than one metre in depth [4,5]. They are typically located within agricultural holdings and farming areas. Historically designed for agricultural purposes such as livestock watering, irrigation during dry periods, and fire prevention, agricultural ponds are now increasingly recognised both as biodiversity refuges and as valuable agronomic tools [6–8].

Agricultural ponds differ from lakes and larger ponds in their small size and shallow depth [5]. Water within these systems is generally highly stagnant and may even partially dry out during summer without losing its biological functioning. Apart from the large proportion from rainfall, they are commonly supplied by surface runoff, groundwater recharge, or intermittent springs with little or no flow [9–11]. To improve agrosystem functioning, agricultural ponds are sometimes restored or newly created in response to environmental policy measures and ecological restoration programmes [4,12,13]. They should therefore be understood not only as natural ecosystems, but also as constructed infrastructures, frequently created and/or modified through human intervention. Increasingly recognised for their collective uses, particularly for recreational purposes, agricultural ponds are widely promoted as ecosystems providing multiple ecological functions, extending far beyond simple water storage [14,15]. Recent scientific publications have also highlighted their importance within natural processes, biodiversity conservation, and biological connectivity [16,17].

Furthermore, agricultural ponds constitute essential components of ecological networks, playing a crucial role in biodiversity conservation while delivering a wide range of ecosystem services (ES) to both humans and nature. Despite this growing recognition, they continued to be predominantly approached as isolated hydrological or ecological units [18–20], whereas in reality they operate as dynamic socio-ecological systems [21–23]. The prevailing functional and biophysical understanding of agricultural ponds remains incomplete. Indeed, these approaches often overlook the territorial, social, and landscape aspects associated with these infrastructures. In several rural areas (particularly in Europe and Asia), ponds historically contributed to the spatial organisation of villages, structured social interactions, and, in some cases, reinforced territorial identity [21,24].

Like other wetland ecosystems, they also provide cultural ecosystem services (ES), including aesthetic and recreational values, while supporting local beliefs and symbolic practices [24–26]. Water has historically played both utilitarian and aesthetic roles in shaping rural landscape [25,27–29]. Cities, villages, and settlements have long been established along rivers and near water bodies, thereby contributing to harmonious environmental configurations. The presence of ponds has likewise favoured the development of footbridges, small bridges, and numerous other landscape elements [25,30–32].

Nevertheless, these dimensions remain marginal within the available scientific literature. The available ones tend to fragment the functions of agricultural ponds and underestimate their role as multifunctional components of rural socio-ecological systems (SES). In other words, agricultural ponds, like many other water reservoirs, have traditionally been analysed from a narrow utilitarian perspective mainly as water storage systems for irrigation, hydropower abstraction, and limited domestic uses [13,24,31,33,34]. Such perspectives, unfortunately, underestimate their broader social, economic, and ecological importance [35,36]. Therefore, there is a need to develop a more comprehensive body of knowledge that goes beyond providing functions and incorporates supporting and cultural ES, including opportunities for recreation and spiritual enrichment. In fact, existing literature on agricultural ponds primarily focuses on issues related to water quality, their role in geochemical cycles, biodiversity, and hydrological processes underlying their functioning [13,20,27,31,33,37]. By contrast, relatively few studies address their role in territorial organisation, collective uses and social practices, or governance systems [28,35,36]. These gaps limit a comprehensive understanding of agricultural ponds within rural landscapes and increase their vulnerability to unsustainable exploitation and progressive degradation.

In response to these concerns, this study first proposes a review of the existing literature on agricultural ponds, with particular attention to dominant research themes, their evolution over time, and persistent knowledge gaps. The central research question can therefore be formulated as follows: (i) How does the scientific literature conceptualise agricultural ponds, and to what extent does it contribute to understanding their multifunctional role? This question is complemented by further inquiries into how these infrastructures contribute to the organisation of rural landscapes and socio-ecological interactions, and the extent to which they may be reconceptualised as multifunctional SES.

The overall objective of this paper is therefore to reconceptualise agricultural ponds through a socio-ecological and landscape-based approach. More specifically, the study aims to: (1) analyse the evolution of scientific research on agricultural ponds; (2) identify the principal themes and gaps within the literature; and (3) highlight the territorial and social dimensions of agricultural ponds through empirical examples from Belgium and Poland.

2. Materials and Methods

To address these research questions, a combination of three complementary approaches was employed: a literature review and bibliometric analysis, supplemented by field observations and historical map analysis. This interdisciplinary approach combines documentary analysis with empirical illustrations to better understand the multifunctional dimensions of agricultural ponds.

The literature review and bibliometric analysis were conducted using scientific publications collected from the Scopus database. To ensure the use of up-to-date data, only documents published after 2000 were considered. To ensure the transparency and reproducibility, bibliometric procedure was first adopted. Preliminary document searches were conducted to identify the most relevant keywords. We then used each word and combinations using Boolean operators. "*Agricultural ponds*", "*ponds*", "*farm ponds*", "*pondscape*", and "*small water bodies*" were used (Appendix A.2). The screening process involved three steps starting with duplicate removal, the title and abstract screening, and full-text assessment according to predefined inclusion criteria. After this data selection and cleaning, metadata (final corpus) were exported for bibliometric analysis. We considered variables such as year of publication, authors, study areas, and keywords to produce co-occurrence networks, thematic clusters, and temporal research evolution and bibliometric patterns using VOSviewer version 1.6.17 and Bibliometrix version 3.1 [38]. The word maps were interpreted based on node size, link strength, and composition. In fact, larger nodes indicate keywords, countries, authors, or references with higher frequencies of occurrence, while thicker links represent stronger associations or collaborations between elements. Colours identify clusters of closely related items, reflecting major thematic or intellectual structures within the research field [38,39]. This approach enabled the identification of dominant themes and relationships between scientific concepts and emerging research orientations [39].

To highlight the analytical dimensions of this study, we selected two European countries characterised by constraining agrarian, historical, and political contexts: Belgium and Poland. We considered municipalities in the province of Liège, Belgium (specifically along the Chaudfontaine-Trooz–Olne–Pepinster-Soumagne municipalities), as well as the Łódzkie and Mazowieckie regions in Poland. We passed through, Ninane, Beaufays, Gomzé, Forêt-Village, Hansez, Soumagne, Cerexhe and Heuseux (Belgium) and the municipality of Nowosolna, the village of Moskwa, Łódź–Mileszki, along Pomorska, Grabińska Roads, and all ponds located along (Poland).

The selection of agricultural ponds in Belgium and Poland was not based on a random sampling strategy, but rather on a purposive (theoretical) selection. These sites were selected as they represent landscapes where agricultural ponds are embedded in intensive agricultural systems, under different historical, institutional, and land-use trajectories. Field sites were identified along predefined travel routes rather than through random selection allowing us to document ponds encountered in situ across a variety of rural settings and landscape configurations.

They have different trajectories of agricultural development, policy and rural landscape management. Belgium represents a model of long-established intensive and highly industrialised agriculture [40,41], whereas Poland is characterised by more extensive farming systems and a more recent process of agricultural industrialisation. In more regions, Poland still preserves traditional landscape structures and small-scale farms [29,42,43].

By synthesising all the elements identified in the two countries and confronting them with the Scopus-derived literature, observations, and interpretations, thirteen comparative indicators were developed for both contexts, coupled with the interpretation of historical and topographic maps. Table 1 provides a summary of selected comparative elements used to analyse agricultural ponds. It highlights contrasting yet complementary trajectories of farm ponds. The table was created based on the authors' understanding and interpretation of the literature, theory, and fieldwork. Field visits were conducted in selected rural villages to illustrate the territorial and social dimensions of agricultural ponds. The triangulation of these sources enabled comparative insights into the two study areas [44]. Observations focused on the spatial position of ponds within villages, their integration into rural landscapes, and their collective uses. To enrich the analysis, qualitative and formal discussions were conducted with farmers and local inhabitants. These discussions also contributed to a better understanding of local perceptions of agricultural ponds, associated social practices, traditional uses, and their territorial significance. Historical and topographic maps (Appendix A.3.), combined with field observations, were further utilised to assess the relationships between agricultural ponds, village spatial organisation, and rural landscapes.

3. Conceptualizing Agricultural Ponds as Socio-Ecological Infrastructures

Agricultural ponds, like many other water reservoirs and wetland ecosystems, constitute "hybrid" socio-ecological systems (SES) situated at the interface between nature and society [21,22,24]. They result from continuous interactions among five major components: ecological, hydrological, agricultural, social, and landscape dimensions. These infrastructures represent spaces where human uses, agricultural practices, local governance, and ecological dynamics evolve simultaneously [24,41]. Biophysical processes constantly interact with human activities and management practices within these systems.

Agricultural ponds should therefore not be reduced to their hydrological or ecological functions. Rather, they can be conceptualised as SES, as far as they emerge from ongoing interactions between ecological processes and human activities. Based on the paper extracted from the database, focused on agricultural ponds and socio-ecological systems, the flowchart above (Figure 1) was created. Agricultural ponds simultaneously perform multiple functions related to biodiversity conservation, hydrological regulation, agricultural production, nutrient retention, and the support of local livelihoods [20,37,45–48], while also being shaped by agricultural practices, land-use dynamics, and governance arrangements. Their functioning is thus characterised by continuous feedback mechanisms between social and ecological components operating across multiple spatial and temporal scales. Indeed, rural landscapes are composed of interacting subsystems, including ecological components (biodiversity, soil and water), economic systems (markets, agriculture), social dimensions (populations and institutions), and spatial structures related to land use and land organisation. These subsystems are dynamic, interdependent, and cannot be understood in isolation from one another [23,45,49]. Rural landscapes are therefore produced and continuously reshaped over time through agricultural practices, resource use, and cultural traditions.

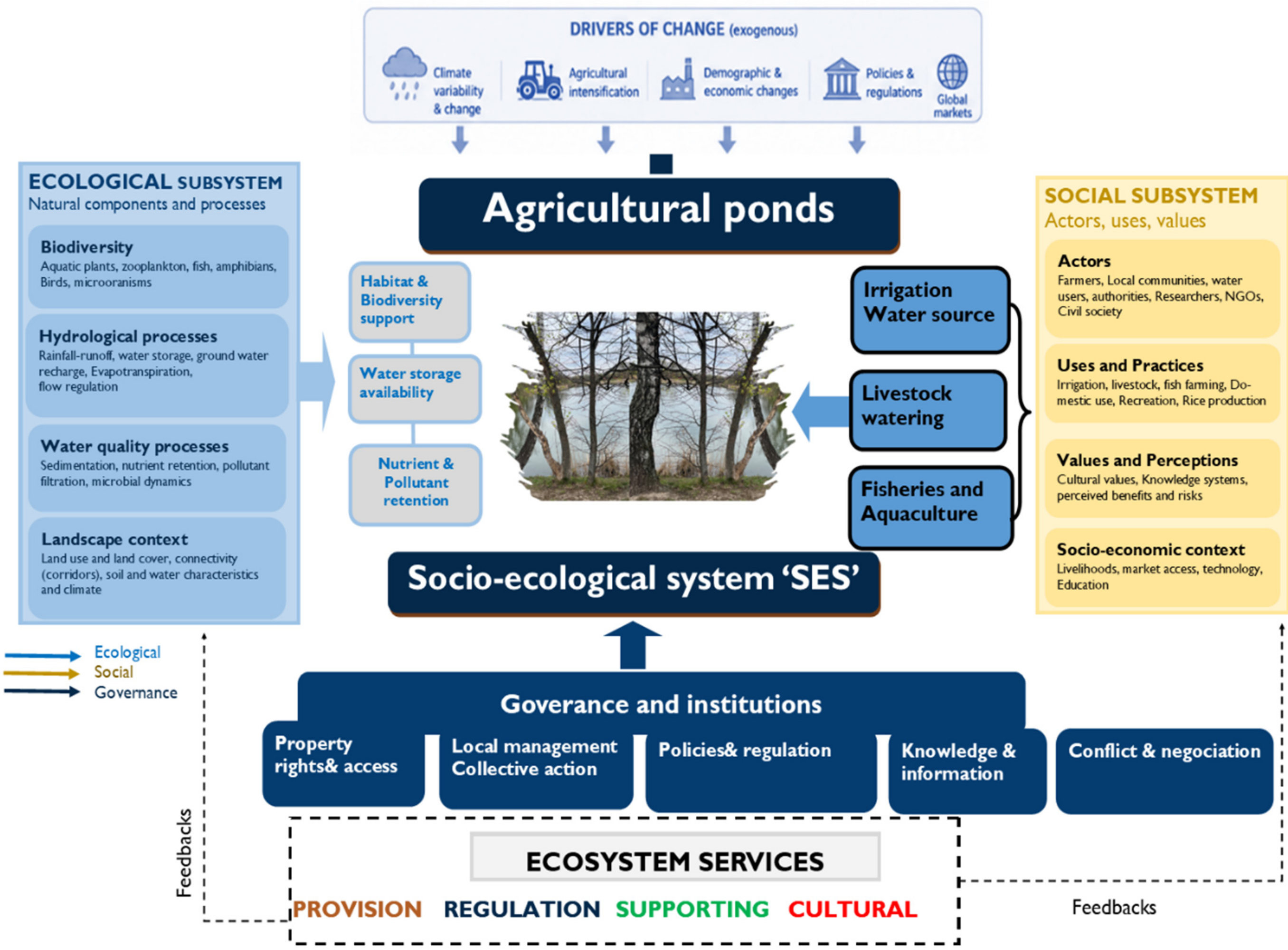


Figure 1. Socio-ecological system (SES) of agricultural ponds.

A central concept within the literature is that the socio-ecology of rural landscapes is inherently multifunctional. First, rural SES provide a wide range of ES, including food production, water provision, ecological regulation, and biodiversity conservation [37]. Second, they embody important cultural values linked to heritage, identity, and sense of place [50–52].

Rural socio-ecological landscapes are constantly evolving under the influence of processes such as urbanisation and climate change [34,52,53]. They are shaped by ongoing feedback between society and the environment, which may lead to resilience, transformation, or degradation depending on the nature and intensity of these interactions. Cultural dimensions also play a fundamental role in these dynamics, particularly through traditions, knowledge systems, territorial identity, and heritage values [28,44,54].

However, significant losses of agricultural ponds have been reported in the literature [34,55], particularly as a result of land artificialisation associated with roads, housing developments, and other infrastructures, as well as the decline in their practical use following the expansion of piped water distribution systems. In many cases, abandonment is also linked to rising maintenance and management costs. These trends are further reinforced by negative perceptions associated with the occurrence of diseases, insects, and local superstitions [25,52]. In addition, with the expansion of agricultural mechanisation and farm enlargement, they were progressively filled in (or totally drained) to facilitate tractor circulation and modern farming operations [56–58]. Furthermore, pits, hollows, or excavations associated with ice houses have subsequently evolved into agricultural ponds after abandonment through water accumulation. This phenomenon exists locally, although it is less well documented as an origin of agricultural ponds. Others are associated with the establishment of watermills in villages—some ponds located near watermills provided hydraulic energy. The work on the mill race, including sluice gates and channels, then required the installation of water retention points. These ponds were sometimes dammed and channelled to improve resistance and regulate flow [59,60]. In some cases, when the mill occupied a central location within the village, it was also used as a gathering place for village celebrations and other social activities, such as fishing or winter ice-skating events.

The ecological characteristics of agricultural ponds and other water reservoirs and wetlands are strongly influenced by community dynamics and local decision-making processes. Agricultural uses, management practices, community interactions, and local governance arrangements all contribute to shaping these ecosystems. Conversely, ecological transformations affect the ES provided, water use, and local practices. Permanent feedback mechanisms between society and the environment are therefore visible through these dynamic interactions. Despite these pressures, agricultural ponds continue to perform multiple functions (Figure 1), comprising hydrological, ecological, productive, social, cultural, and territorial functions. This multifunctionality justifies their integration within a socio-ecological and landscape-based framework that goes beyond strictly sectoral interpretations [61].

Like many other wetland ecosystems, agricultural ponds organise collective uses while connecting communities to the environment. Given their importance, they are increasingly recognised as structural elements of rural space that support territorial functions. They contribute to the territorial resilience of rural populations and play a structuring role in the functioning of rural territories [62,63].

Within rural landscapes, SES may therefore be understood as integrated systems in which ecological processes and human dynamics, including social, economic, and cultural dimensions, interact within a specific rural special context. These systems emerge from long-term interactions between human societies and nature, which co-evolve and collectively shape land use, ecosystem functions, and sustainability trajectories. Such a definition reflects the idea that rural systems constitute coupled human-nature systems, "material expressions of interactions between natural and cultural factors [63,64], and that rural landscapes themselves can be understood as SES linking nature and culture [54,65].

4. Evolution of Research on Agricultural Ponds

4.1. Trends and Global Overview of the Literature

The analysis of the database extracted from Scopus reveals a significant increase in the number of scientific publications over time. Research themes have progressively evolved from predominantly "productive" and "hydraulic" approaches towards more integrated perspectives that incorporate concepts such as ES and SES (Figures 2 and 3).

Chronologically, the literature can be divided into three main periods (Figure 2). First, before (<2000), research was mainly focused on irrigation, water management, agriculture, and fish production. Agricultural ponds were primarily perceived as hydraulic infrastructure intended to improve agricultural productivity. Consequently, much of the literature reduced agricultural ponds to their capacity for water storage and water quality improvement, while some studies also examined their contribution to biogeochemical cycles [1,66–69]. Second, during the intermediate period (from 2000 to 2020), research themes increasingly addressed biodiversity, conservation of pond and other wetland types, introduction to the ecological connectivity of farm ponds, and the ES provided. This period marked a progressive shift towards a broader ecological understanding of ponds within rural landscapes [7,70–72].

Finally, recent studies (>2020) demonstrate the emergence of more integrated approaches centred on concepts such as "*pondscape*", "*climate resilience*", "*Nature-based Solution: NbS*", and *SES*. Agricultural ponds increasingly began to be analysed as multifunctional spaces embedded within rural landscapes, simultaneously supporting ecological, hydrological, social, and territorial functions [40,45,52,61,62].

To analyse the documents in depth, we use the VOSviewer results. The keyword co-occurrence map reveals a strong thematic structure in the scientific literature on agricultural ponds, with several interconnected clusters, largely dominated by biophysical and environmental approaches.

The analysis highlights seven major thematic clusters structuring research on agricultural ponds (Figure 3a). Cluster 1 (red: 26%) is dominated by terms such as effect, pond, sediment, and assessment, reflecting studies primarily focused on the environmental impact of ponds within agricultural landscapes. Cluster 2 (blue: 22%) groups themes related to water quality, irrigation, catchments, environmental assessment, and contaminant removal. Cluster 3 (cyan: 18%) is more specifically associated with agricultural pollution, particularly pesticides, glyphosate, water flows, and transformation processes occurring within agricultural ponds. Cluster 4 (green: 16%) highlights microbiological and sanitary concerns, with terms such as bacteria, *Escherichia coli*, agricultural water, and risk assessment. Cluster 5 (yellow: 8%) emphasises the role of wetlands and ponds in treating, transforming, and reusing agricultural water. Cluster 6 (purple: 6%) is mainly related to nutrients, agricultural drainage, metals, and interconnected pond systems. Finally, Cluster 7 (brown: 4%) highlights the ecological importance of ponds as habitats for amphibians and aquatic plants, underscoring their role in biodiversity conservation within agricultural landscapes.

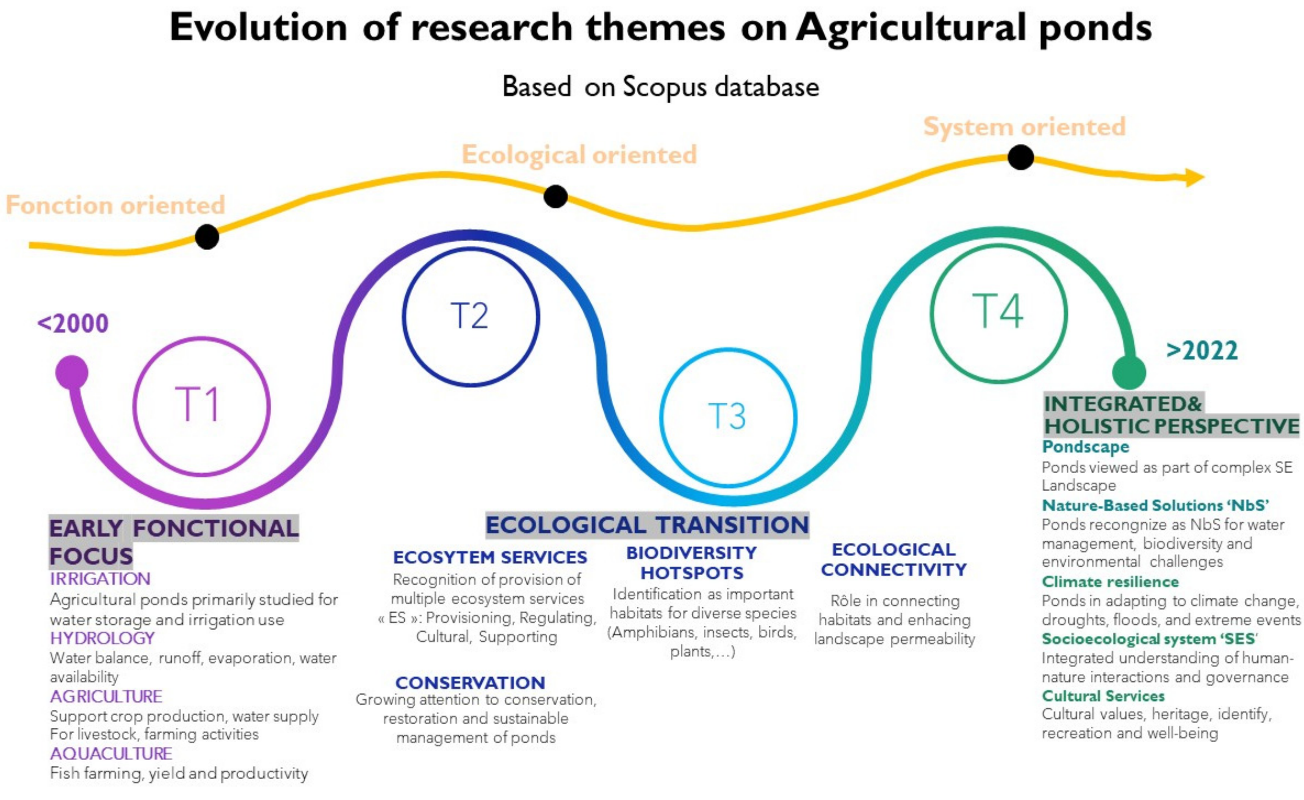
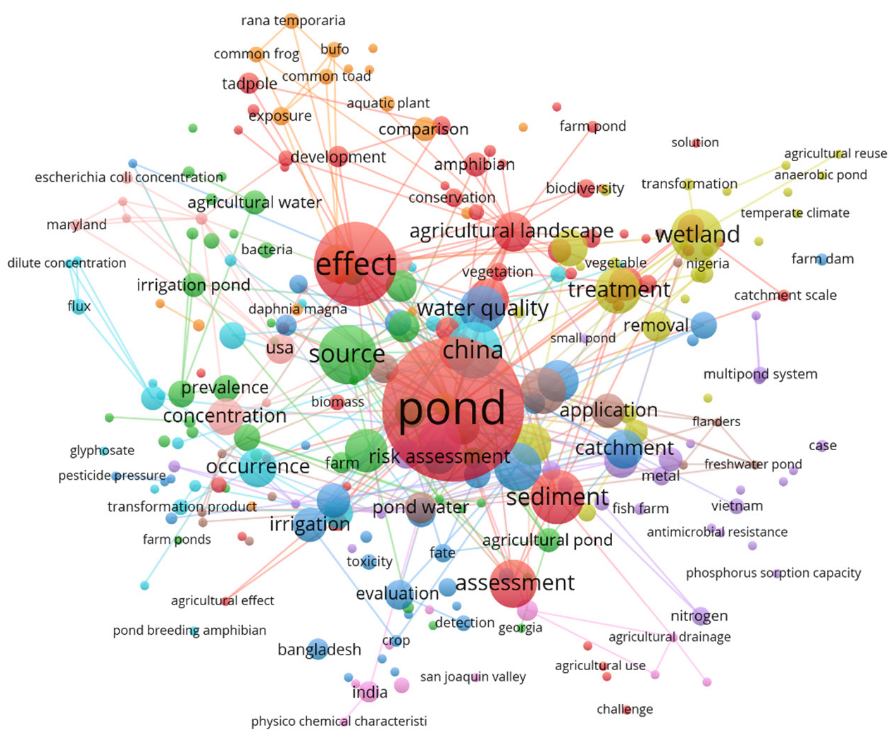
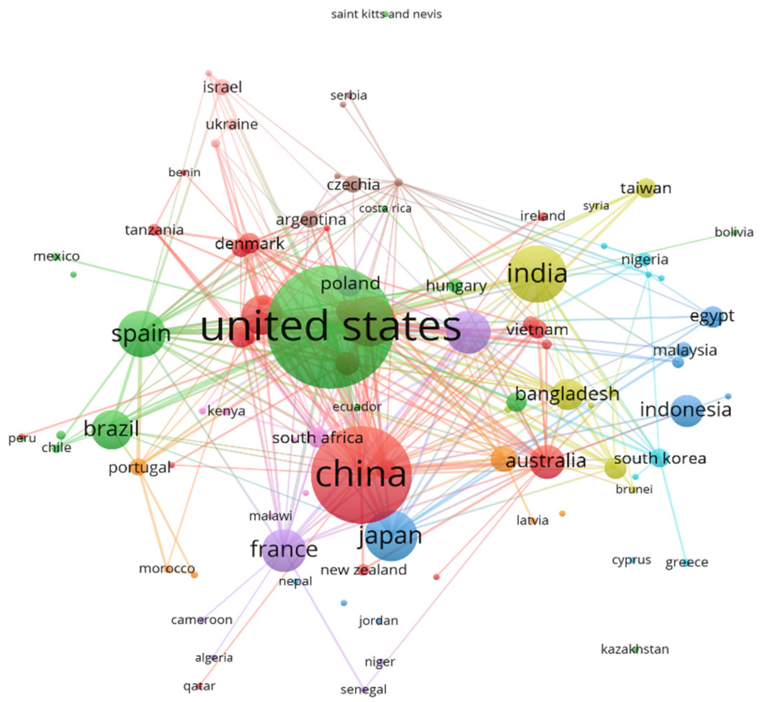


Figure 2. Evolution of research themes developed on agricultural ponds (this was created based on document analysis as extracted from the Scopus database).



(**a**)



(**b**)

Figure 3. Thematic structure of scientific literature on agricultural ponds based on keywords co-occurrence analysis (**a**) and connection map of countries working on agricultural ponds (**b**) using a database extracted from Scopus documents in VOSviewer software 1.6.21. The size of each circle corresponds to the weight of occurrence, while the intensity of connections between illustrates their relationships. Closer keywords on the map are more closely related than distant ones. The colours represent clusters of extracted terms organised by the software based on their relationships. Not all items are shown in the figure to avoid label overlap.

Some clusters also focus on agricultural management, drainage systems, farm reservoirs [73], and hydrological functions. The strong presence of terms such as analysis, application, management, and occurrence further indicates increasing methodological diversification and a growing effort to assess environmental effects across multiple spatial scales. Nevertheless, despite this thematic richness, the network clearly reveals the dominance of natural and environmental sciences, while social, cultural, territorial, and landscape dimensions remain largely marginal. Concepts related to rural identity, community interactions, local governance, and the spatial organisation of villages appear only weakly represented within the network, highlighting a significant imbalance in the current literature. This relative absence confirms that agricultural ponds are still approached mainly as ecological and hydrological entities rather than as multifunctional socio-ecological infrastructures structuring rural landscapes.

Figure 3a also demonstrates that despite this evolution and growing body of literature, the neglect of territorial organisation, social dimensions, governance systems, and the landscape identity associated with agricultural ponds persists. Overall, the available literature largely reduces ponds to their capacity for water storage, water quality improvement, biodiversity conservation, and contributions to biogeochemical cycles. Interactions between society and water remain significantly underrepresented in existing research. It is nevertheless important to acknowledge the limitations of using the Scopus database, which tends to favour natural and biomedical sciences comparatively to social sciences [74–76].

From these keywords, three main elements emerged:

(a) Centrality of water-agriculture-ecology interactions: the core structure of the work is organised around interactions among water, agriculture, biodiversity, land management, and ecological processes, demonstrating that agricultural ponds constitute major interfaces between hydrological systems, agricultural practices, and ecological dynamics. The network therefore suggests considering the multifunctional and interdisciplinary nature of agricultural ponds in contemporary rural landscapes.

(b) Limited visibility of social and territorial dimensions: One particularly important feature highlighted by Figure 3a is the very limited (or nearly absent) representation of concepts related to territorial identity, rural landscapes, governance, community interactions, and village spatial organisation. This relative absence reveals a major blind spot within the current scientific literature. Thus, despite their historical role in structuring rural landscapes, farm ponds continue to be studied from a biophysical perspective rather than a socio-territorial one.

(c) Thematic fragmentation of the literature: the analysis of keywords reveals a strong fragmentation of themes within scientific research on agricultural ponds. Several subgroups emerge clearly within the network, particularly those associated with certain clusters. This suggests that the literature remains largely structured around compartmentalised disciplinary approaches, with a strong emphasis on the dominance of natural science research. By contrast, social dimensions, local practices, governance systems, cultural representations, and territorial organisations remain absent or relatively marginal. This confirms the imbalance characterising the current scientific literature on agricultural ponds.

Furthermore, Figure 3b highlights an international network of scientific collaborations on agricultural ponds. The United States (USA) and China emerge as the main research hubs, exhibiting the most extensive and highly connected collaboration networks. Other countries, including India, Spain, Poland, Japan, France, Belgium, and the Netherlands, also play important roles in scientific exchanges. The numerous connections between countries reflect a high level of international research cooperation, underscoring the global nature of issues related to water management, biodiversity conservation, and broader environmental change. Research themes vary considerably across countries and over time (see Figure 2). Recent studies are particularly concentrated in India, China, and Spain, where scientific production on agricultural ponds has increased significantly in recent years.

We also found that these studies increasingly rely on sophisticated methodologies such as remote sensing, ecological modelling, molecular analyses, and geospatial approaches based on machine learning and deep learning. Such methodological sophistication reflects significant technical advances in research on agricultural ponds. However, this strong biophysical dominance tends to marginalise social dimensions. Issues related to local perceptions, collective uses, governance systems, and territorial dynamics remain only weakly represented.

4.2. Agricultural Ponds as Rural Landscape Structuring Elements

The available documentation concerning the role of agricultural ponds in landscape organisation, spatial structure, and recreation remains relatively limited. Nevertheless, an analysis of existing literature suggests that agricultural ponds could play a central role in the organisation of rural landscape [6,17,31,63–65]. To support these findings, field observations conducted in both study areas revealed that several villages display spatial configurations structured around central ponds.

Figures 4 and 5 illustrate how ponds historically influenced village morphology, the arrangement of dwellings, the organisation of community spaces, and broader rural practices. In European rural landscapes, the form of villages and spatial organisation generally result from a combination of factors such as topography (plains, valleys, slopes), the hydrological and road networks, land tenure systems, settlement history, etc. [73–75]. Other factors such as agricultural systems, water availability, and, in our context the presence of ponds, can also shape the village morphology. Agricultural ponds may influence these dynamics, but they are rarely the sole explanatory factor. Agricultural ponds, emerge as important structuring elements within rural territories. Such spatial configurations are not unique to these two countries, as similar patterns have been documented in other rural regions [77–79]. In Poland, for example, local inhabitants frequently associate ponds with local history, collective memory, and village identity [43,80,81]. These associations further highlight the role of ponds in shaping a sense of territorial belonging and place attachment [52,68,69,82,83]. Through activities such as fishing, visiting, and other recreational practices, agricultural ponds also function as spaces of social cohesion. Their collective use contributes to shared water practices, community interactions, and, in some cases, to local governance and collective management.

The spatial organisation of the villages of Długowola and Bzowiec (Figure 4) illustrates the structuring role of agricultural ponds within rural landscapes. The aerial photographs and land-use maps showed that ponds are not randomly distributed, but rather integrated into the settlement pattern, road networks, canals, and surrounding croplands (Appendix A.1). In several cases, houses and agricultural plots are organised around central ponds, suggesting that these infrastructures historically influenced village morphology and land-use planning. Beyond their agricultural functions, they contribute to landscape connectivity by linking built-up areas, waterways, and cultivated fields. Their distribution also reflects the multifunctional character of rural landscapes, where water management, farming activities, and settlement development are closely interconnected.

Figure 5 highlights the diversity and multifunctionality of agricultural ponds within rural landscapes. The photographs show ponds embedded in different environmental and socio-spatial contexts, including forested areas, cultivated lands, grasslands, and residential zones. Some remain permanently flooded and actively managed, while others are partially vegetated, temporarily dry, or undergoing natural succession. This variabil-

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ity reflects the dynamic interactions between agriculture practices, water management, and ecological processes. The images also demonstrate that agricultural ponds contribute significantly to the visual identity and heterogeneity of rural landscapes. They create aquatic habitats, transitional wetland zones, and open water features within predominantly agricultural environments.

In both Poland and Belgium, agricultural ponds historically constituted the visual and functional core around which houses, pathways, farms, and communal spaces were organised [25,29,58]. Agricultural ponds played a central role in shaping the traditional morphology of rural villages. Within open agricultural landscapes, ponds introduce significant spatial and ecological diversity by creating visual contrasts between cultivated fields, grasslands, wooded areas, and aquatic environments. Such a mosaic landscape contributes highly to the visual quality and territorial identity. Field observations indicate that agricultural ponds can be emblematic landscape features that break the spatial homogeneity characteristic of intensive agricultural systems.

In the most visited villages, ponds were surrounded by various semi-natural landscape elements, including tree alignments, hedgerows, wetlands, wet meadows, and microhabitats. These features enhance the complexity and visual heterogeneity of rural landscapes. Overall, agricultural ponds continue to contribute to the picturesque character of traditional villages, with landscape functions closely linked to local perceptions of territory, as they often serve as spatial landmarks, orientation points, places of contemplation, and transitional spaces between built-up and agricultural areas.

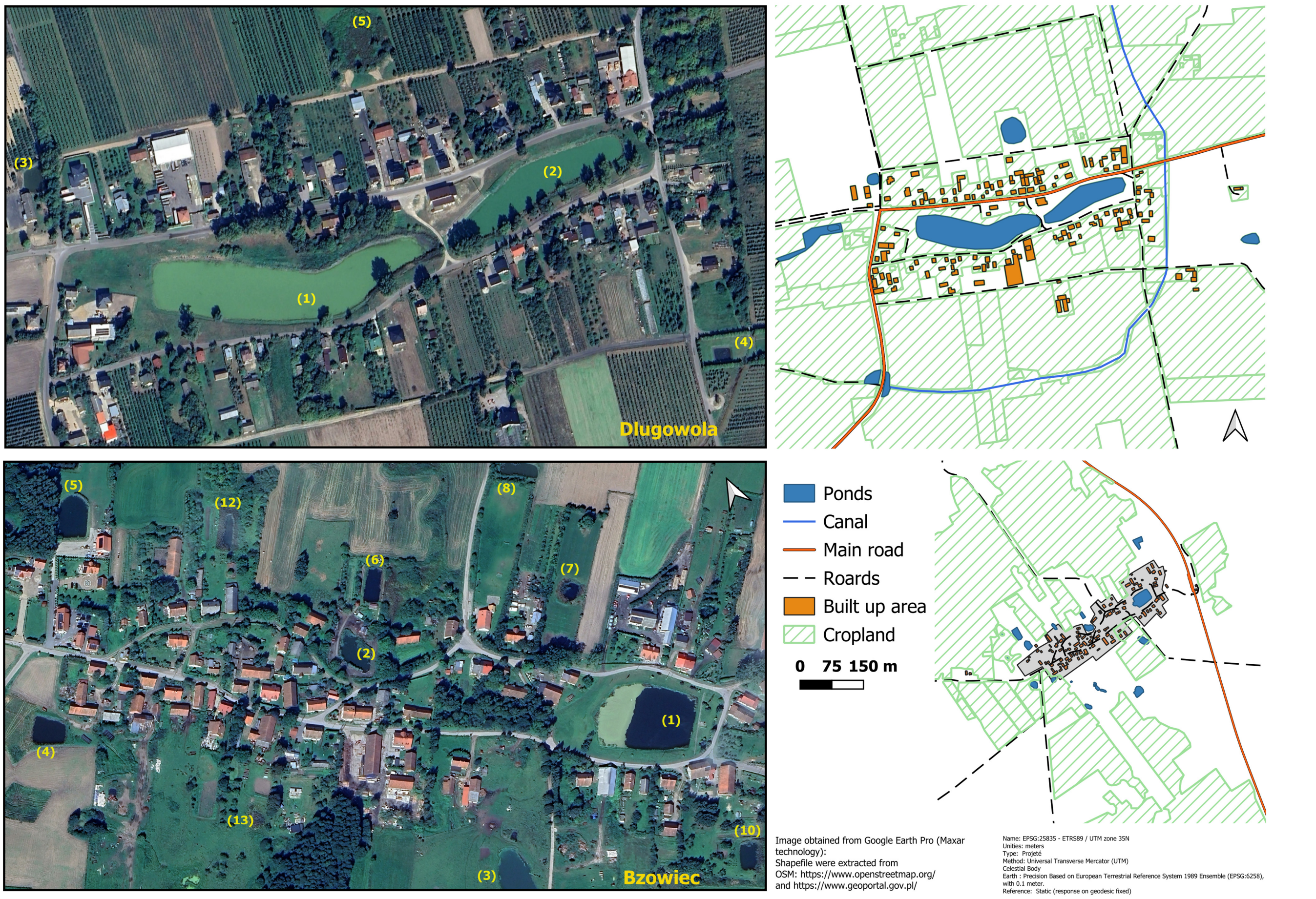

Figure 4. Villages in Poland with ponds as the centre element of the territory (September 2025 images, ponds are represented by numbers).

Figure 5. *Cont*.

Figure 5. *Cont*.

Figure 5. Images of agricultural ponds in rural landscapes visited during fieldwork conducted in April and May 2026 (legend: 1, 9 and 12: agricultural ponds mixed with fish ponds along the Moszczenica River in Nowosolna commune; 2 and 3: ponds formerly located in the center of a village, now converted into the Volunteer Fire Department site (Łódź–Mileszki) along Pomorska Road; 4: agricultural pond converted into an ecological wetland area along Pomorska Road; 7: agricultural pond in Moskwa village; 8: ponds along Grabińska Road, Łódź; 13: pond on Gomzé Street in front of the Fontain farm and Gomzé castle; 17: pond in Hansez; 20: agricultural ponds in Beaufays on the right side of Rue des Grosses Pierres; 15–16: ponds in Beaufays on Rue de Ninane; 18: agricultural pond behind a farm along Rue de la Heid; 14 and 19: agricultural ponds within a farm on Rue Forêt-Village, Forêt Trooz). Research is increasingly interdisciplinary, complementing traditional ecological and hydrological approaches. Farmers' perceptions remain mixed, ranging from constraints to valuable local resources shaped by environmental policies.

Discussions with rural communities further confirmed the findings from the landscape ecology literature, showing that these agricultural ponds, as other small water bodies and wetlands, contribute to the “readability” of rural landscapes, respectively, the capacity of inhabitants to recognise, interpret, and appropriate their environment.

From the heritage values, they constitute historical legacies reflecting former forms of rural spatial organisation and traditional water management practices. In established villages, ponds may date back several centuries, bearing witness to ancient techniques of water collection and storage, traditional agropastoral systems, historical patterns of land occupation, and rural ways of life. In this sense, agricultural ponds can be understood as elements of both tangible and intangible rural heritage. Agricultural ponds’ heritage value extends beyond their physical form to include collective memory, local narratives, traditions, customary uses, and the knowledge systems associated with their maintenance and use. In most regions, local communities associate agricultural ponds with village history, events, intergenerational memories, and longstanding cultural practices, thereby reinforcing their symbolic and identity-building role within rural landscapes.

4.3. Lesson Learned

In Poland, agricultural ponds remain more closely associated with traditional village structures and former agropastoral landscapes, where they historically played a central role in the spatial organisation of settlements, water retention, and community functions. Despite a marked decline since the second half of the 20th century due to agricultural intensification, land drainage, and post-socialist transformations, some relic pond networks persist and continue to provide important ecological and hydrological functions. In Belgium, rural landscapes were transformed earlier and more intensively through agricultural intensification, urban expansion, and increasing landscape artificialisation, leading to an earlier and continuous reduction. Nevertheless, these features still function as important ecological refuges with highly anthropised landscapes and are currently the focus of ecological, landscape, and educational initiatives. In both contexts, agricultural ponds emerge as multifunctional landscape elements at the interface of territorial heritage, agricultural dynamics, and contemporary challenges related to climate resilience and ecological conservation.

Territorial and institutional trajectories of agricultural ponds differ across many rural contexts, especially in governance, conservation, and heritage recognition. Governance is often fragmented among agricultural, environmental, and territorial actors, although some regions show stronger institutional coordination through local authorities and public policies. Overall, farm ponds reflect broader rural transformations, including agricultural intensification, land consolidation, and post-socialist change. While tensions persist between production-oriented agriculture and pond conservation, some compromises are emerging that integrate biodiversity, farming, and landscape management.

We finally developed an analytical framework based on a set of guiding questions to compare the two selected study sites, followed by explanatory elements and primary responses. In total, thirteen questions were formulated and presented in Table 1.

Table 1. Analytical framework and comparative criteria for the study of agricultural ponds.

ID	Question	Elements of Comparison/Guide
1	**What is the historical agrarian organisation?**	*Influence of political regime, socio-economic transformations, traditions, and land restructuration*
2	**What is the heritage value**	*Strong, neutral, emerging or limited.*
3	**What is the relationship between villages and agricultural ponds?**	*Integration into the spatial organisation of villages and communal areas, association with livestock systems, dispersed farms, or hedgerow networks*

Table 1. *Cont.*

ID	Question	Elements of Comparison/Guide
4	**What is the landscape morphology?**	*Open, closed, highly fragmented or strongly anthropised landscapes*
5	**How did agricultural pond density evolve?**	*Historically high but declining, with remnant networks, continuous reduction, and new creation*
6	**How has agriculture intensified?**	*Major transformation after xxx years, rapid modernisation, longstanding, highly mechanised*
7	**Hydrological functions of agricultural ponds**	*Local water retention, maintenance of wet agricultural landscapes, water filtration, irrigation and domestic uses...*
8	**What are the ecological functions?**	*Biodiversity reservoirs, ecological refuges, habitat connectivity, and support for ecosystem services...*
9	**What are the social and community functions?**	*Heritage value still perceived in some rural villages, historically limited social functions, and opportunities of revalorisation through local initiatives*
10	**What are the main anthropogenic pressures?**	*Agricultural intensification, abandonment, drainage, pollution, urbanisation, land artificialisation, other human-induced pressures*, etc.
11	**What are the contemporary uses of agricultural ponds?**	*Residual agricultural functions, ecological conservation, aesthetic appreciation, environmental educational, and recreational functions*
12	**What is the climate resilience potential?**	*Significant in rural regions where dense agricultural pond networks, depending on restoration policies and ecological connectivity*
13	**What are the futures challenges?**	*Preservation of remnant agricultural ponds networks, integration into rural development policies, functional restoration, and ecological reconnection of landscapes*

5. An Integrated Pondscape Approach

The observation made led to two important implications, both theoretical and operational. First, they highlight the limits of sector-based approaches, which tend to separate hydrology, ecology, and the social sciences in the study of ponds. In contrast, several authors propose the concept of "*pondscape*" as an integrated framework for analysing ponds within rural landscapes and socio-ecological systems [52,62,76,84]. This perspective supports more holistic approaches to rural planning, landscape conservation, climate adaptation, and interdisciplinary research. Second, ongoing environmental changes—particularly climate-induced hydrological shifts, biodiversity loss, and the spread of invasive species—underscore emerging research priorities that remain underexplored. In addition, limited global scientific collaboration constrains a comprehensive understanding of how pond systems respond to global change [36,52]. Strengthening comparative and transdisciplinary studies is therefore essential for improving future management and conservation strategies.

6. Conclusions

This study shows that agricultural ponds go far beyond their traditional role as simple water storage or biodiversity reservoirs. They should be understood as multifunctional SES that structure rural landscapes and actively shape territorial dynamics. This multifunctionality is central to agroecological transitions, as ponds simultaneously act as solutions (e.g., water filtration, storage, habitat provision) and as potential risk zones (e.g., pollution accumulation, greenhouse gas emissions). Although the current literature remains largely dominated by biophysical approaches, more integrated perspectives are emerging, highlighting the need for interdisciplinary research. This imbalance reveals a major blind spot in existing studies: the limited consideration of human and social dimensions, which constrains a full understanding of ponds as SES. This work therefore aligns with a growing body of research calling for stronger integration of social, territorial, and landscape perspectives into agricultural pond management and research.

Future research should adopt more integrated socio-ecological frameworks that combine local perceptions, governance processes, and ecological connectivity. Particular attention should be given to multi-actor governance systems, hydrological and landscape connectivity, and changing community perceptions under pressures from climate and land-use change. Interdisciplinary approaches combining remote sensing, historical documents analysis, participatory methods, and landscape ecology would significantly improve understanding of the resilience and long-term sustainability of agricultural pond networks.

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Abbreviations

The following abbreviations are used in this manuscript:

SES	Socioecological system
ES	Ecosystem services
USA	United States of America
VOSviewer	Visualization of Similarities viewer

Appendix A.

Appendix A.1. Location of Agricultural Ponds in the Rural Landscape of Poland

Appendix A.2. Document Screening Process on Scopus

Keyword	Nb. Documents	Script
Pond *	23,539	*TITLE (pond *) AND PUBYEAR > 1999 AND PUBYEAR < 2027*
Pond	5717	*TITLE (pond) AND (LIMIT-TO (EXACTKEYWORD, "Agriculture")) AND PUBYEAR > 1999 AND PUBYEAR < 2027*
Ponds	2742	*TITLE (ponds) AND (LIMIT-TO (EXACTKEYWORD, "Agriculture")) AND PUBYEAR > 1999 AND PUBYEAR < 2027*
Small lakes	4437	*TITLE (small lakes) AND PUBYEAR > 1999 AND PUBYEAR < 2027*
Agricultural ponds	373	*TITLE (pond *) AND (LIMIT-TO (EXACTKEYWORD, "Agriculture")) AND PUBYEAR > 1999 AND PUBYEAR < 2027*
Pondscape	18	*TITLE (pondscape) AND PUBYEAR > 1999 AND PUBYEAR < 2027*
Farm pond *	277	*TITLE (farm pond *) AND PUBYEAR > 1999 AND PUBYEAR < 2027*
Small water bodies	340	*TITLE (small water body) AND PUBYEAR > 1999 AND PUBYEAR < 2027 23, 539*

Appendix A.3. Historical Maps Used (Belgium and Poland)

Information	Belgium	Poland
Website	https://geoportail.wallonie.be/carte#ADD%7CMETADATAID=b8b9e555-a4d1-49bf-940d-31bbbf7613fc (accessed on 6 July 2026)	ATLAS HISTORYCZNY WSI W POLSCE Website: www.geoportal.gov.pl
Accessibility	Free	Free
WMS	https://geoservices.wallonie.be/arcgis/services/CARTES_ANCIENNES/FERRARIS/MapServer/WMSServer?request=GetCapabilities&service=WMS (accessed on 6 July 2026)	https://www.geoportal.gov.pl/en/services/view-services-wms-and-wmts/ (accessed on 6 July 2026)
Period	1770–1778	19th Century (1803, 1820–1840)
Scale	1/11,520	1/5000 and 1/30,000

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