







Bibliometric Analysis of Efficiency and Sustainability in Research on Tidal Flat Rice Farming (2000–2025)

Dina Omayani Dewi^{1*}, Rita Nurmalina², Netti Tinaprilla², Saptana¹

¹ National Research and Innovation Agency (BRIN), Jakarta 12710, Indonesia

² Department of Agribusiness, Faculty of Economics and Management, IPB University, Bogor 16680, Indonesia

Corresponding Author Email: dina021@brin.go.id

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ABSTRACT

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Global challenges such as population growth, climate change, and limited land availability are increasing the need for agricultural systems that are both efficient and sustainable. Although tidal wetlands are constrained by flooding, salinity, and soil acidity, they have strong potential for rice production when managed appropriately. This study uses bibliometric analysis to map global research on the efficiency and sustainability of rice farming in tidal wetlands. Data were retrieved from the Scopus database in January 2026 using a search strategy applied to the TITLE-ABS-KEY field, with keywords related to efficiency, productivity, rice, sustainability, and tidal land. The analysis was restricted to English-language publications and included articles, reviews, conference papers, and book chapters published between 2000 and 2025. In total, 1,501 documents were analyzed using the bibliometrix package in R and the Biblioshiny interface to assess publication trends, collaboration networks, and thematic evolution. The results show an annual publication growth rate of 12.4%, indicating increasing scholarly attention. The literature is dominated by Asian countries, particularly Indonesia, China, India, and Bangladesh. Thematic evolution suggests a shift from primarily agronomy-focused studies toward more integrated approaches that emphasize efficiency, sustainability, and climate resilience. Overall, these findings highlight the growing importance of tidal rice farming in global discussions of sustainability and food security.

1. INTRODUCTION

Global food systems are facing increasing pressure due to population growth, climate change, and the declining availability of arable land and freshwater resources. By 2050, global food demand is projected to rise by nearly 50%, necessitating the expansion of agricultural production into non-conventional areas [1, 2]. In this context, marginal lands, including arid regions, degraded soils, and coastal ecosystems, are increasingly considered as strategic resources to support future food security.

Among these, tidal wetlands (tidal flats) represent a particularly important yet underutilized agricultural frontier. Extensive tidal lowlands are distributed across Asia, Africa, and Latin America, with significant potential for rice cultivation under improved management practices [3]. These areas are increasingly incorporated into national and global food security strategies, especially in countries experiencing land scarcity and high population pressure. In addition to their production potential, tidal wetlands contribute to environmental functions such as carbon sequestration, water regulation, and coastal protection, reinforcing their relevance within sustainable agriculture and climate adaptation frameworks.

Rice is a staple food for more than half of the global population, particularly in Asia, making its production central to food security efforts [4-6]. Expanding rice cultivation into tidal wetlands offers a viable pathway to increase production; however, these systems are characterized by significant constraints, including flooding, salinity intrusion, soil acidity, and complex hydrological conditions [7, 8]. Addressing these challenges requires efficient resource management and sustainable production practices.

Research on tidal rice farming has grown over the past two decades, encompassing agronomic, environmental, and socio-economic aspects [9]. However, the literature remains fragmented, with limited integration of efficiency and sustainability perspectives at the global level. A comprehensive understanding of research trends, key contributors, and thematic developments is therefore needed to support evidence-based policy and research planning.

Bibliometric analysis provides a systematic approach to map the structure and evolution of scientific knowledge within a field [10-12]. This study applies bibliometric techniques to map and analyze global research on the efficiency and sustainability of rice farming in tidal lowlands, focusing on publication trends, leading contributors, and emerging themes. Specifically, the study addresses the following research

questions:

RQ1: How has scientific research on the efficiency and sustainability of rice farming in tidal lands evolved over time?

RQ2: Which authors, institutions, and countries have contributed most significantly to this research field?

RQ3: What thematic clusters and knowledge gaps can be identified to guide future research on tidal rice farming efficiency and sustainability?

Conceptual framework of the study showing the linkages between global challenges, the tidal land context, and rice farming efficiency and sustainability (Figure 1). The framework emphasizes how bibliometric analysis (publication trends, collaboration networks, and thematic clusters) provides insights into research gaps, policy directions, and strategies for sustainable rice farming in tidal ecosystems.

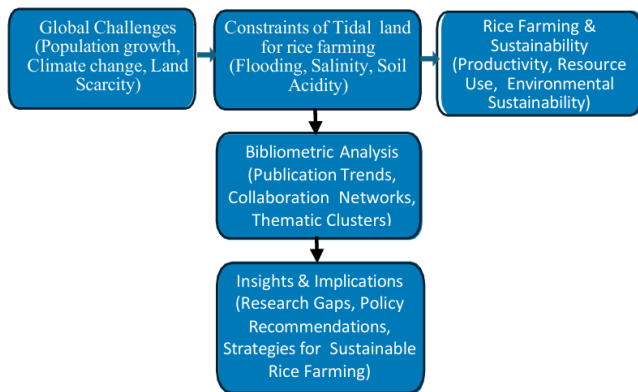


Figure 1. Conceptual framework: Efficiency and sustainability of rice farming

2. MATERIALS AND METHODS

2.1 Data source and search strategy

This study employed a bibliometric approach using the Scopus database as the primary data source due to its broad coverage of peer-reviewed literature. To ensure transparency and reproducibility, a structured search query was developed using Boolean operators and field qualifiers.

The search was conducted on January 2026 using the following Boolean query applied to the TITLE-ABS-KEY fields: ("rice" OR "paddy") AND ("efficiency" OR "productivity") AND ("sustainability" OR "sustainable development") AND ("tidal land" OR "tidal wetland" OR "swamp land" OR "coastal agriculture").

The use of the TITLE-ABS-KEY field ensures that the retrieved documents are directly relevant to the core topics, as these fields capture the main focus of each publication.

To refine the dataset, several inclusion criteria were applied:

- Time span: 2000–2025
- Language: English only
- Document types: articles, review papers, conference papers, and book chapters

The initial search results were further screened to remove duplicate records and irrelevant studies that did not specifically address rice farming in tidal or coastal wetland environments.

2.2 Data cleaning and preparation

The retrieved dataset was exported in BibTeX format for compatibility with bibliometric software. Data cleaning involved the removal of duplicates, non-English documents, and irrelevant records that did not directly address rice farming or tidal land systems. Author names and institutional affiliations were standardized to minimize inconsistencies arising from spelling variations or database errors.

2.3 Analytical tools and techniques

The analysis was conducted using the *Bibliometrix R-package* and its web-based interface *Biblioshiny* [10]. These tools enabled descriptive and inferential bibliometric analyses, including: (1) Performance analysis, focusing on publication trends, prolific authors, institutions, and countries, (2) Science mapping, using co-authorship, co-citation, and keyword co-occurrence networks to reveal intellectual structures and collaboration patterns, (3) Thematic evolution analysis, identifying Tidal Lands how research topics have emerged and shifted over time, (4) Collaboration network analysis, highlighting linkages among global researchers, institutions, and regions.

2.4 Indicators of analysis

In this study, several bibliometric indicators were used to evaluate the scientific performance and impact of publications, authors, and institutions. Among these, the h-index and g-index were applied as key metrics to assess scholarly influence.

The h-index measures both productivity and citation impact. It is defined as the maximum value h such that a given author (or set of publications) has published h papers, each of which has received at least h citations. For example, an h-index of 10 indicates that an author has 10 publications that have each been cited at least 10 times. This metric balances quantity and impact, but it does not account for highly cited outliers.

The g-index, proposed as an extension of the h-index, gives more weight to highly cited publications. It is defined as the largest number g such that the top g publications have collectively received at least g^2 citations. In other words, the cumulative citations of the most cited articles must be equal to or greater than the square of the number of those articles. This allows the g-index to better capture the influence of highly cited works compared to the h-index. Both indices were computed using the *Bibliometrix R-package*, which automatically ranks publications in descending order of citations and applies the respective calculation algorithms. By combining h-index and g-index, this study provides a more comprehensive assessment of research performance, capturing both consistent scholarly productivity and the impact of highly influential publications. The co-authorship index (CAI) was used to measure the degree of collaboration among authors in the dataset. In this study, the CAI is operationalized as the average number of authors per document, which reflects the intensity of research collaboration.

2.5 Research questions alignment

The methodological approach was directly aligned with the study's objectives and research questions:

RQ1 (Evolution of research): Addressed through performance analysis and thematic evolution.

RQ2 (Contributors): Examined using productivity and impact indicators of authors, institutions, and countries.

RQ3 (Thematic clusters and gaps): Explored via keyword co-occurrence and thematic mapping.

Through this approach, the methodology provides a comprehensive basis for mapping knowledge structures, identifying research gaps, and offering strategic insights into the efficiency and sustainability of rice farming in tidal lands. The process begins with data retrieval from the Scopus database covering the period 2000–2025 (Figure 2). The dataset was then cleaned by removing duplicate entries, non-English publications, and irrelevant records. Data preparation involved standardizing author names and institutional affiliations to ensure consistency and exporting files in BibTeX formats for compatibility with bibliometric software. Bibliometric analysis was conducted using the *Bibliometrix R-package* and its web interface *Biblioshiny*, enabling performance analysis, science mapping, and thematic exploration.

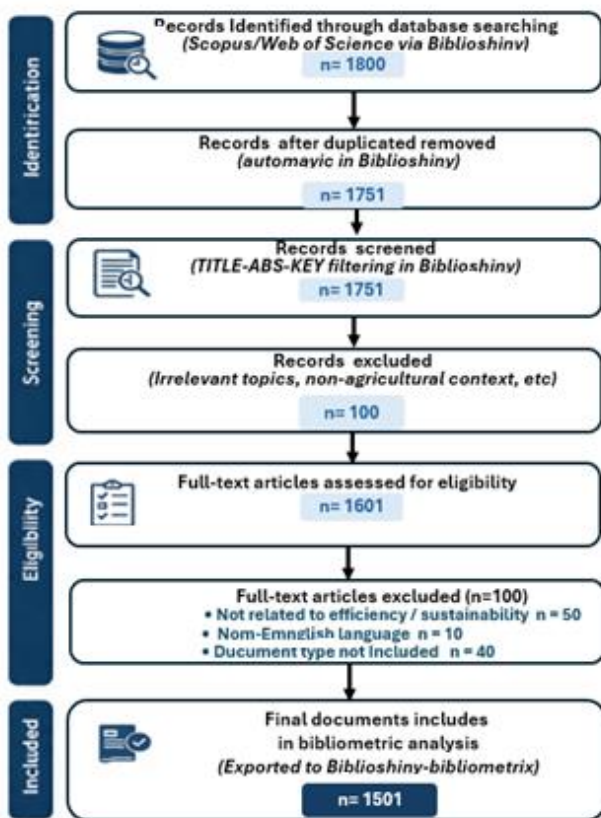


Figure 2. PRISMA diagram: Bibliometric analysis of efficiency and sustainability of rice farming on tidal lands

The final stage generated insights in terms of publication trends, collaboration networks, thematic clusters, and research gaps, directly aligned with the study’s research questions. This bibliometric analysis visualizes the knowledge network in the field of rice farming efficiency and sustainability in tidal wetlands by using bibliographic mapping that illustrates the relationships among documents based on shared references [11].

The study maps the literature to obtain accurate data on trends and developments in research related to the efficiency and sustainability of rice farming in tidal areas, while also identifying research gaps that remain underexplored. The

results of this analysis are expected to provide a foundation for future studies, particularly in advancing strategies to enhance resource-use efficiency and sustainable productivity in tidal rice farming systems.

3. RESULTS AND DISCUSSION

3.1 Result

The bibliometric performance indicators provide an overview of research development on efficiency and sustainability in rice farming systems within tidal wetlands. Over the period 2000–2025, a total of 1,501 documents were published across 604 sources, demonstrating a strong annual growth rate of 12.4%, which indicates increasing scholarly interest in this field (Figure 3).



Figure 3. Main information

The literature is supported by contributions from 5483 authors, with a collaboration intensity reflected in an average of 4.39 co-authors per document and 27.58% international co-authorship, underscoring the global relevance of sustainability and efficiency issues in rice farming. The relatively high number of 11,063 author keywords shows the diversity of research themes, while the average citation per document (19.29) suggests a strong impact within the academic community.

With an average document age of 6 years, the literature demonstrates both continuity and novelty, highlighting that the field remains dynamic and continues to expand. Collectively, these indicators confirm that the topic of efficiency and sustainability in tidal rice farming is emerging as a critical research domain within the broader discourse on sustainable agriculture and food security. Sustainable development in tidal lowlands requires balancing crop production with ecosystem preservation, focusing on productive cultivation methods, effective waste control, and efficient input use to achieve SDGs by 2030 [12, 13].

The annual scientific production graph illustrates the temporal growth of publications in the field of rice farming efficiency and sustainability within tidal wetlands from 2000 to 2025 (Figure 4). In the early 2000s, research output was relatively limited, with fewer than 20 articles published per year. A gradual increase began around 2010–2015, reflecting growing recognition of sustainability challenges in agriculture, particularly concerning water management, salinity, and climate change impacts on tidal rice systems.

From 2016 onward, the number of publications rose more sharply, surpassing 100 articles annually by 2020. The most significant surge occurred after 2021, peaking at more than 200 articles in 2025, which reflects the increasing global

urgency to address food security, resource-use efficiency, and sustainable development in vulnerable coastal and tidal ecosystems. This trend confirms that the field is not only expanding but also becoming an important research frontier within the broader context of agricultural sustainability and climate resilience [14].

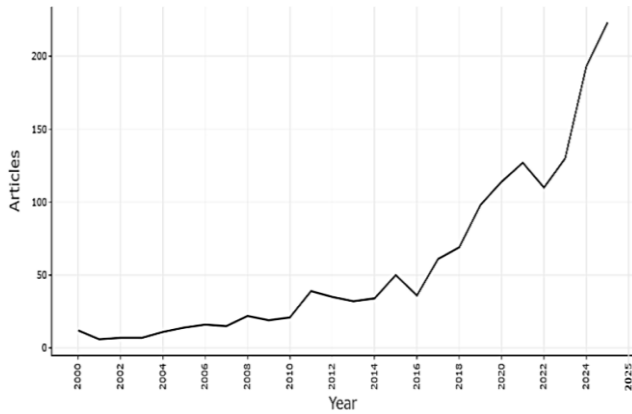


Figure 4. Annual scientific production (Year 2000-2025)

The citation trend graph shows fluctuations in the impact of publications on rice farming efficiency and sustainability in tidal wetlands from 2000 to 2025 (Figure 5). In the early 2000s, citations were relatively low and unstable, reflecting the limited number of publications and the emerging nature of this research area. Peaks in citations occurred around 2002, 2007, 2012, and 2014, indicating that certain influential studies during these periods became highly referenced within the scholarly community.

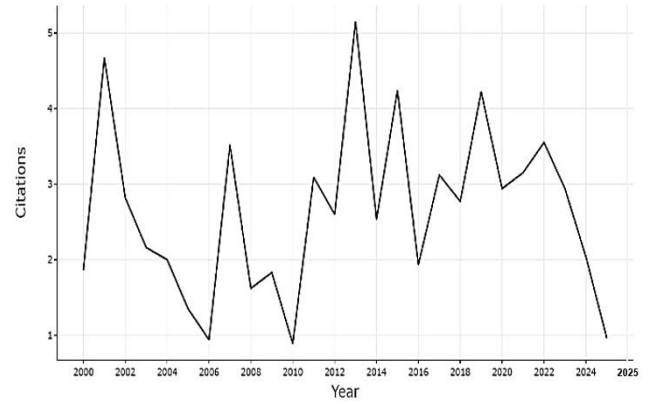


Figure 5. Average citation per year (2000-2025)

From 2015 to 2021, the trend stabilized at an average of 2–4 citations per year, suggesting steady integration of this research into broader discourses on sustainable agriculture and climate resilience. The decline after 2022 does not necessarily indicate reduced relevance but may instead reflect a time-lag effect, as newer publications require more time to accumulate citations. Overall, the citation dynamics confirm that while the field is relatively young, it has produced several key contributions that have shaped ongoing debates on sustainability, efficiency, and productivity in tidal rice systems.

The three-field plot (Figure 6) provides a more nuanced understanding of the relationships among countries, keywords, and institutions, not only in terms of their presence but also their interaction intensity and structural roles within the research network.

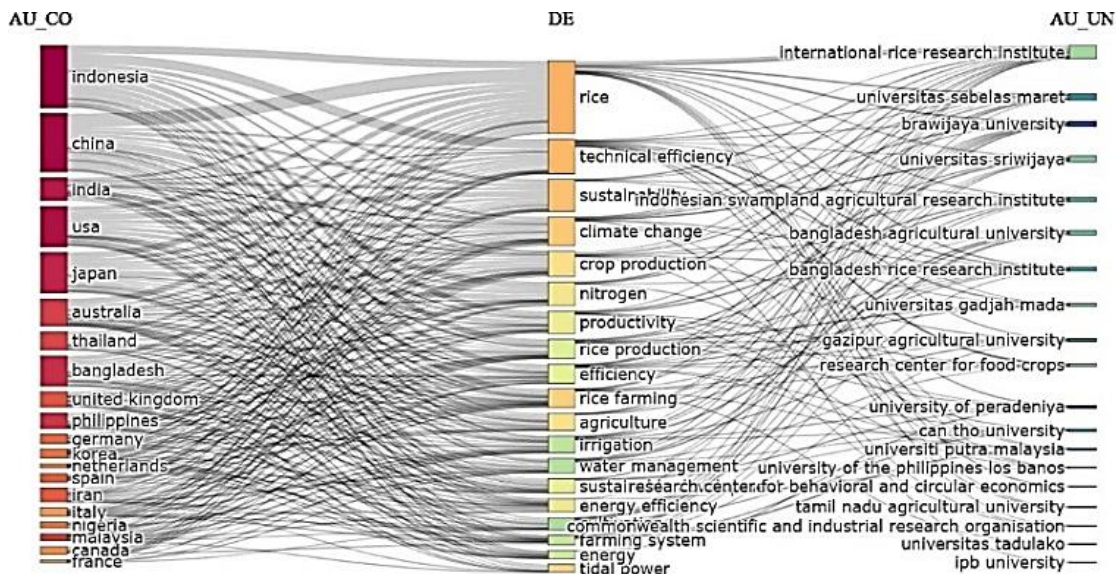


Figure 6. Three-field plot (countries, keywords, and affiliations)

The thickness of the connecting lines represents the strength of the relationships between nodes, indicating the frequency of co-occurrence or collaboration. Thicker links between countries (e.g., Indonesia, China, India, and Bangladesh) and key research themes such as *technical efficiency*, *sustainability*, and *rice production* suggest that these countries are not only highly productive but also strongly engaged in core research topics. This reflects a high level of thematic concentration and specialization within these regions.

At the institutional level, certain organizations—most

notably the International Rice Research Institute (IRRI) emerge as central nodes within the network. These nodes play a mediating (bridging) role, connecting multiple countries and thematic areas. The central position of IRRI indicates that it acts as a key hub facilitating knowledge exchange, collaboration, and dissemination across different geographical regions and research domains. Such institutions enhance network cohesion by linking otherwise fragmented research clusters.

Furthermore, the network structure reveals that

collaboration is not evenly distributed. A small number of countries and institutions dominate the core of the network, as indicated by dense and thick interconnections, while others remain more peripheral with thinner links. This suggests the presence of a core–periphery structure, where leading actors drive knowledge production and collaboration, whereas less-connected regions may face limitations in research integration.

Overall, the three-field analysis demonstrates that research on tidal rice farming is characterized by strong thematic linkages and centralized collaboration patterns, with key institutions such as IRRI playing a crucial role in bridging global research efforts. This highlights the importance of strengthening international collaboration networks, particularly by integrating underrepresented regions into the global research system.

Analysis of the most relevant sources shows that research on tidal wetlands and rice farming efficiency is widely disseminated across multidisciplinary journals (Figure 7). The *IOP Conference Series: Earth and Environmental Science* (67 documents) and *Sustainability* (Switzerland) (49 documents) dominate, reflecting the strong integration of environmental

sciences and sustainability perspectives in this field. Substantial contributions also appear in *Science of the Total Environment* (27 documents), emphasizing ecosystem interactions and climate impacts, and in *Marine Policy* (20 documents), highlighting the governance dimension of coastal and wetland management. Meanwhile, agronomic outlets such as the *Indian Journal of Agronomy* (17 documents) and *Field Crops Research* (14 documents) provide evidence of crop-specific and technical studies related to rice productivity in marginal lands. Journals such as *Ecological Indicators* (16 documents), *Ocean and Coastal Management* (15 documents), *Aquaculture* (14 documents), and *Frontiers in Marine Science* (14 documents) further demonstrate the cross-sectoral nature of the topic, linking agricultural practices with ecological monitoring, integrated aquaculture systems, and marine sciences. This pattern confirms that tidal rice farming research is positioned at the intersection of agricultural innovation, environmental sustainability, and policy frameworks, aligning with global priorities on food security and climate resilience [15].

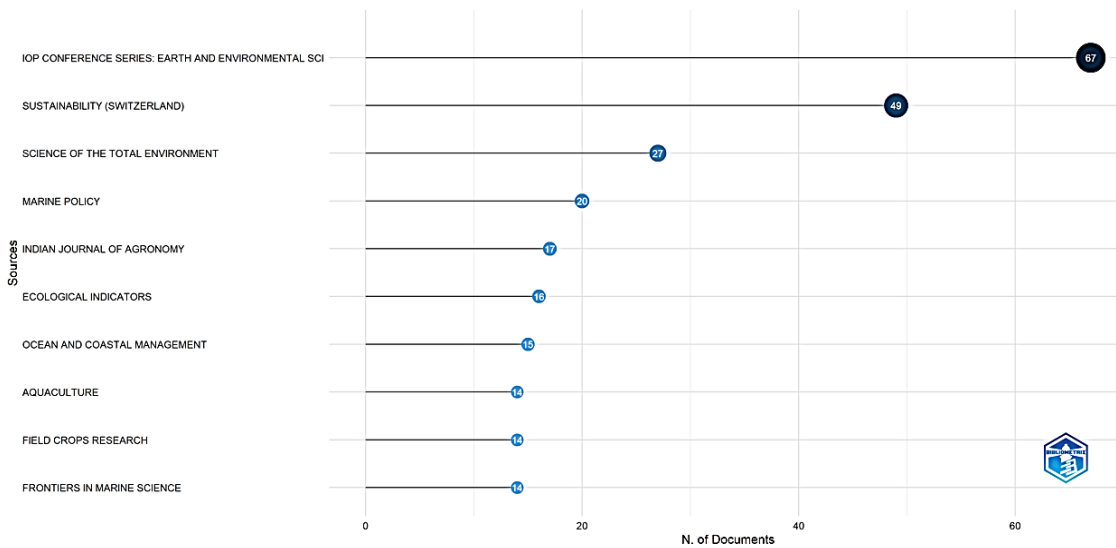


Figure 7. Most relevant sources

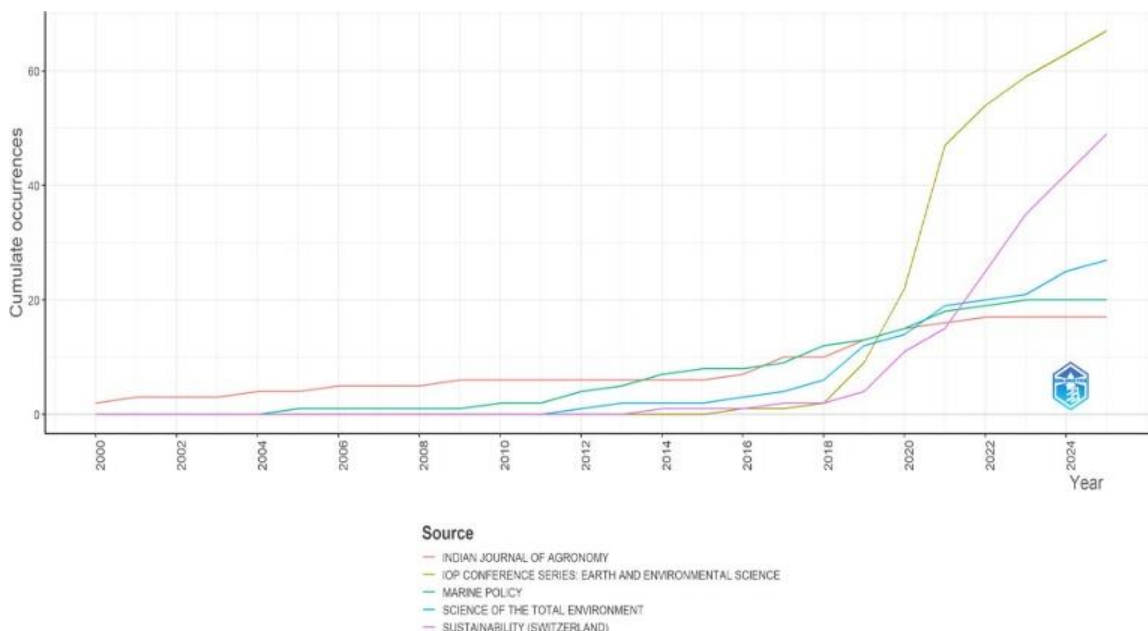


Figure 8. Sources of production over time

Figure 8 indicates that research on tidal wetlands, rice farming, and sustainability has shifted from being localized and agronomic (pre-2010) to multidisciplinary and sustainability-driven (post-2018).

The sharp rise in *Sustainability* and *IOP Conference Series* suggests that scholars increasingly frame tidal wetland rice farming within global sustainability and environmental change discourses, rather than only within crop science. Integration [16, 17]. This reflects a broader transition in agricultural research toward climate-smart practices, ecosystem services, and policy.

The cumulative occurrence of publications indicates a significant shift in research dynamics from 2000 to 2024. In the early years (2000–2015), contributions were relatively modest, with the *Indian Journal of Agronomy* maintaining a steady but limited output, reflecting the crop-specific orientation of agronomic studies in tidal wetlands. From 2015 onwards, a gradual rise was observed in *Marine Policy* and

Science of the Total Environment, aligning with the global agenda of the Sustainable Development Goals (SDGs), particularly food security and climate action [18]. A sharp acceleration is evident after 2018, with *Sustainability (Switzerland)* and the *IOP Conference Series: Earth and Environmental Science* emerging as the dominant outlets. This surge reflects the increasing integration of tidal rice farming within global sustainability debates, including climate change mitigation, carbon management, and sustainable agricultural intensification [19, 20]. In contrast, *Marine Policy* and *Science of the Total Environment* exhibit more moderate growth after 2021, while the *Indian Journal of Agronomy* shows a plateau trend, highlighting a relative decline in localized agronomic publishing. These patterns confirm a paradigm shift in the literature, from a predominantly agronomic perspective toward multidisciplinary approaches that emphasize sustainability, ecosystem services, and policy frameworks [17, 21].

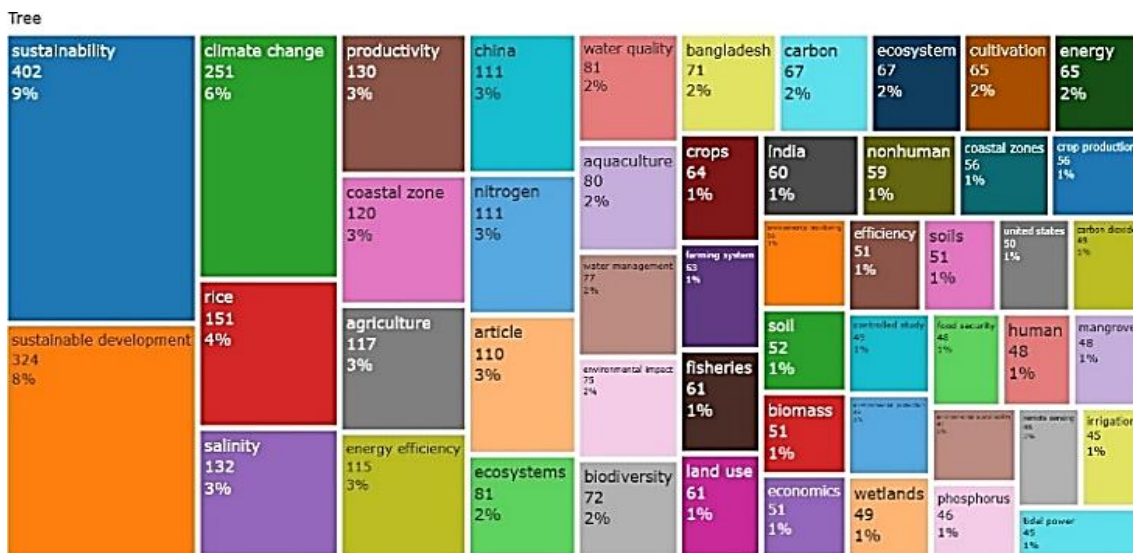


Figure 9. Tree map

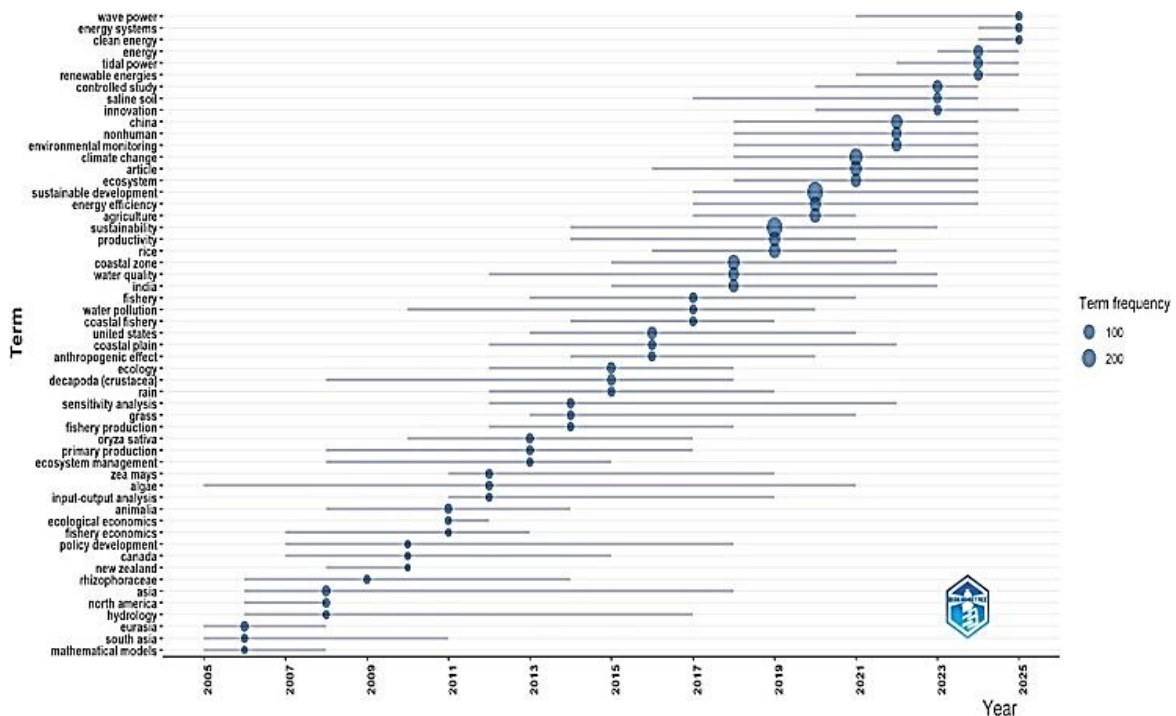


Figure 10. Trend topic

The tree map analysis highlights that research on tidal wetlands and rice farming is framed within broader global discourses of sustainability and climate change (Figure 9). The most dominant keywords are *sustainability* (402 occurrences) and *sustainable development* (324 occurrences), underscoring the alignment of this field with the SDGs, particularly those related to food security and climate action [19].

The prominence of *climate change* (251) and *salinity* (132) reflects growing concerns over sea-level rise, saline intrusion, and their impacts on rice productivity in tidal environments, consistent with findings from coastal Asia [22]. Agronomic terms such as *rice* (151), *productivity* (130), *agriculture* (117), and *efficiency* (51) confirm that yield optimization and resource-use efficiency remain central research priorities [23]. Simultaneously, environmental dimensions emerge strongly, with keywords including *water quality* (81), *nitrogen* (111), *ecosystem* (67), *biodiversity* (72), and *wetlands* (49), reflecting the role of tidal rice systems in ecosystem functioning and service provision [16]. The appearance of *carbon* (67), *biomass* (51), and *mangrove* (48) further points to the importance of tidal wetlands in climate mitigation through carbon storage and landscape resilience [17]. Geographically, the prominence of *China* (111), *Bangladesh* (71), and *India* (60) highlights their leadership in tidal rice research, while Indonesia's tidal swamplands are increasingly represented in applied studies on productivity and efficiency [24]. Overall, the keyword structure demonstrates that tidal rice farming research has evolved into a multidisciplinary agenda that integrates agronomic efficiency, environmental sustainability, and socio-ecological resilience, aligning directly with your research focus on enhancing both the efficiency and sustainability of tidal rice farming. This dynamic is further supported by the shift in dominant sources (Figure 8) and thematic development (Figure 10).

In the early phase (2000–2010), research was predominantly agronomic and biophysical in nature, focusing on constraints such as hydrology, soil acidity, salinity, and crop productivity. Studies during this period relied heavily on field experiments and biophysical modeling, with efficiency implicitly treated as yield optimization. As shown in Figure 10, themes such as hydrology, fishery production, and mathematical models dominated, reflecting a productivity-oriented paradigm.

Between 2011 and 2016, the research focus began to expand toward efficiency and environmental concerns. This period marked the introduction of more rigorous quantitative approaches, including efficiency measurement techniques such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). At the same time, growing attention to water management, nutrient use, and environmental impacts signaled a transition toward a resource-use efficiency paradigm. This shift is consistent with the emergence of sustainability-related themes in Figure 10 and the gradual diversification of publication outlets observed in Figure 8.

From 2017 to 2019, the field entered a more integrative phase, characterized by multidisciplinary approaches combining agronomic, environmental, and socio-economic perspectives. Research increasingly incorporates sustainability indicators, climate-related variables, and ecosystem-based approaches. Thematic evolution during this period highlights the rise of concepts such as climate change, ecosystem services, and sustainable development, indicating a shift toward a systems-oriented perspective in evaluating both efficiency and sustainability.

In the most recent phase (2020–2025), research has evolved into a highly interdisciplinary and systemic domain. As illustrated in Figures 8 and 10, there is a clear transition toward themes such as ecological economics, renewable energy, environmental monitoring, and policy development. Methodologically, studies increasingly employ integrated modeling, spatial analysis, and bibliometric techniques to capture the complex interactions between environmental, economic, and social dimensions. This phase reflects a socio-ecological systems paradigm, in which efficiency and sustainability are treated as interconnected components within broader food–water–energy–climate systems. Overall, these findings demonstrate that the evolution of research has progressed from productivity-focused agronomic studies to efficiency-oriented analyses, and ultimately toward integrated, multidisciplinary sustainability frameworks. This trajectory confirms that tidal rice farming is no longer viewed solely as a technical agricultural issue, but as a complex socio-ecological system central to global food security and climate resilience.

The emergence of themes such as *renewable energy* and *fishery production* in the thematic evolution analysis (Figure 10) does not necessarily indicate the inclusion of irrelevant studies, but rather reflects the interdisciplinary nature of research on tidal wetland systems. Tidal lands are complex socio-ecological environments where rice farming is often integrated with other activities, including aquaculture (e.g., rice–fish systems) and energy-related innovations such as biomass utilization and renewable energy for water management.

Specifically, the appearance of *fishery production* is closely associated with integrated rice–fish farming systems, which are widely practiced in tidal and wetland environments to enhance productivity and resource-use efficiency. These systems have been recognized as sustainable approaches that combine crop production with aquatic resource management.

Similarly, the theme of *renewable energy* is linked to the increasing adoption of energy-efficient and climate-smart technologies in tidal rice farming, such as solar-powered irrigation systems, biomass utilization, and low-emission agricultural practices. These innovations are particularly relevant in the context of sustainable intensification and climate resilience.

Furthermore, to ensure dataset relevance, a rigorous screening process was applied during data cleaning, including the removal of records that did not explicitly relate to rice farming in tidal or coastal wetland systems. Therefore, the presence of these themes reflects the expansion of research toward integrated and multidisciplinary approaches, rather than the inclusion of unrelated studies.

The combined tree map and timeline analyses reveal the evolving research landscape on tidal wetlands and rice farming systems. Early studies (2005–2012) were dominated by themes such as *hydrology*, *mathematical models*, and *fishery production*, reflecting a focus on biophysical foundations.

From 2013 onward, research shifted toward broader sustainability concerns, with growing emphasis on *climate change*, *ecosystem services*, and *sustainable development*, consistent with the global SDG agenda [25]. In recent years (2020–2025), new clusters such as *renewable energy*, *ecological economics*, *policy development*, and *environmental monitoring* have emerged, highlighting the integration of governance and socio-economic perspectives into tidal farming studies [19].

researchers are recognizing the complexity of these environments, where hydrological dynamics, soil constraints, and socio-economic conditions interact in ways that require cross-border knowledge exchange. Similar patterns have been observed in other areas of sustainability science, where collaboration enhances both innovation and the practical relevance of research outcomes [28, 29].

The prominence of sustainability as a central research theme further reflects a deeper transformation in how agricultural systems are conceptualized. Rather than focusing solely on productivity, recent studies increasingly situate tidal rice farming within broader frameworks of climate resilience, ecosystem management, and sustainable intensification. This shift is closely linked to global policy agendas such as the SDGs and international climate agreements, which have redefined the objectives of agricultural development [30, 31]. The frequent appearance of keywords related to climate change, ecosystems, and water management suggests that tidal rice systems are now being studied not only as production systems, but also as critical components of environmental sustainability and adaptation strategies [32, 33].

Another notable development is the increasing integration of interdisciplinary perspectives. The emergence of themes such as ecosystem services, ecological economics, and environmental monitoring indicates that researchers are moving beyond purely agronomic approaches. This reflects a growing recognition that tidal wetlands are complex systems where agricultural productivity must be balanced with ecological integrity and social considerations [34]. In this sense, the evolution of the literature mirrors a broader transition in sustainability science toward more holistic and systems-oriented approaches.

However, one of the most striking findings—and one that warrants deeper reflection is the highly uneven geographical distribution of research output. The dominance of Asian countries, particularly Indonesia, China, India, and Bangladesh, is not surprising given that these regions host the majority of tidal rice ecosystems. Their strong representation can be explained by both ecological relevance and long-standing national investments in rice research and development. In contrast, the near absence of African contributions is more complex and cannot be attributed to a single factor.

Several overlapping explanations may account for this imbalance. First, there may indeed be a relative scarcity of research specifically focused on tidal wetland rice systems in Africa, as such agroecosystems are less extensive compared to those in Asia. However, this explanation is only partial. Second, and perhaps more importantly, structural biases in global scientific indexing systems likely play a significant role. Databases such as Scopus tend to underrepresent journals from developing regions, particularly those published in local languages or with limited international visibility [35]. As a result, relevant African research may exist but remain invisible within the dataset used in this study.

Third, differences in terminology and research framing may also contribute to this apparent absence. Research conducted in African contexts may not explicitly use terms such as “tidal wetlands” or “tidal rice farming,” instead employing alternative descriptors related to floodplain agriculture, coastal farming, or wetland cultivation. Such variations in terminology can lead to systematic omissions in bibliometric searches, thereby reinforcing perceived regional disparities. This highlights an important methodological limitation:

bibliometric outcomes are not only shaped by actual research activity but also by how knowledge is labeled, indexed, and retrieved.

Finally, disparities in research capacity, funding availability, and access to international collaboration networks further exacerbate these imbalances. Countries with stronger institutional support and global partnerships are more likely to produce and disseminate research that is visible at the international level. In contrast, regions with limited resources may struggle to participate fully in global knowledge production, even when facing equally pressing agricultural and environmental challenges.

These insights suggest that the observed regional imbalance should not be interpreted simply as a lack of research activity in certain regions, but rather as the outcome of interconnected structural, methodological, and institutional factors. Addressing this issue requires not only expanding research efforts in underrepresented regions but also improving the inclusiveness of global scientific databases and adopting more flexible search strategies in bibliometric studies.

Beyond geographical disparities, the analysis also reveals an important conceptual gap within the literature. While environmental and technical dimensions of sustainability are extensively explored, socio-economic and institutional aspects remain relatively underdeveloped. This imbalance reflects a broader tendency in agricultural research to prioritize biophysical efficiency over issues such as farmer behavior, governance systems, and market dynamics [36]. Without a stronger integration of these dimensions, the practical implementation of sustainable practices may remain limited.

In terms of efficiency, the findings indicate a clear shift toward resource-use efficiency, particularly in water and nutrient management. This is especially relevant in tidal systems, where fluctuating hydrological conditions and salinity stress require precise and adaptive management strategies. The literature increasingly recognizes that improving efficiency can simultaneously enhance productivity and reduce environmental impacts, reinforcing the idea that efficiency and sustainability are mutually supportive rather than competing goals [37-39].

Nevertheless, this study is not without limitations. The exclusive reliance on the Scopus database, the restriction to English-language publications, and potential indexing delays all introduce biases that may affect the completeness of the analysis. These constraints reinforce the need for cautious interpretation, particularly when assessing global research patterns and regional representation.

Looking ahead, future research should aim to bridge existing gaps by integrating socio-economic perspectives, strengthening governance and policy analysis, and expanding cross-regional comparisons. In particular, fostering collaboration between Asia, Africa, and Latin America could help generate more inclusive and globally relevant knowledge. Such efforts are essential to ensure that innovations in tidal rice farming are not only technically effective but also socially equitable and widely applicable.

4. CONCLUSIONS

This study employed a bibliometric approach using Scopus data (2000–2025) to systematically map the evolution, structure, and thematic development of research on efficiency and sustainability in tidal wetland rice farming. The findings

confirm a rapid increase in scientific output, reflecting growing global attention to tidal lands as strategic systems for addressing food security under climate and resource constraints. The literature has evolved from predominantly agronomic and productivity-oriented studies toward multidisciplinary approaches integrating sustainability, climate resilience, and environmental management.

Despite this progress, the analysis identifies several critical gaps. Research remains strongly concentrated on biophysical and environmental aspects, with limited integration of socio-economic and institutional dimensions. In addition, efficiency and sustainability are often treated as separate constructs, with few studies offering integrated assessment frameworks. Climate change is widely discussed, yet quantitative evaluations of mitigation potential remain insufficient. Furthermore, the geographical concentration of research in Asia highlights persistent disparities in global knowledge production, influenced by differences in research capacity, indexing systems, and terminology.

These findings suggest that advancing tidal rice farming research requires a shift toward integrated and system-based approaches that combine resource-use efficiency, environmental performance, and socio-economic viability. Strengthening cross-regional collaboration and developing more inclusive research frameworks will be essential to ensure that future innovations are both globally relevant and practically applicable in diverse tidal environments.

These findings imply that policy frameworks should prioritize integrated and inclusive approaches to tidal land management, combining resource-use efficiency, climate-resilient technologies, and socio-institutional support, while strengthening cross-regional collaboration to ensure globally applicable and sustainable rice farming systems.

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