

Trends and Prospects from Climatic Research of Inner-Niger-Delta Wetland: A Bibliometric Analysis

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Abstract

The fate of wetlands in arid regions has become a matter of concern in the context of global warming. The Inner Niger Delta (IND) has received increasing attention from researchers and others to explore whether this largest wetland in Africa will shrivel due to climate change and increasing water use. An essential study goal is to understand what has been done so far in the Research of Inner-Niger-Delta Wetland in order to address its future challenges. The present study provides a comprehensive analysis of climate related research on the IND wetland through bibliometric means to diagnosis the evolution, lag and hotspot of relevant features in the literature. Key aspects of analysis included 1) trends of IND wetland related research 2) nature of collaboration networks, 3) co-occurrence of keywords and 4) emerging themes related to IND wetland over the last three decades, between the years 1991-2022. The results indicate that the IND wetland gained momentum in 2000, peaking in 2013 and then in 2018. IND wetland research has, on average, reach 2.5 publication in 2000 and exceed 5 papers by 2017. The leading countries that have produced high numbers of published documents are in order, France, Nigeria, USA, Germany and Mali. Therefore, more efficient scientific collaboration among regional African institutions is recommended to face local perspectives. The identified emerging topics are Niger delta, climate change, floods and rivers. The variables considered in analyses are river discharge, evapotranspiration, water level and rain. Variables relevant to global temperature warming are missing, which implies that researches on Inner Niger Delta wetland are less focusing on climate change and variability analyses.

Keywords

Inner-Niger-Delta, Climate Change, West Africa

1. Introduction

Wetlands are a valuable natural resource of considerable scientific interest because they are associated with biological diversity, important ecosystem functions and processes, and useful, economically viable products (Mitsch & Gosselink, 1993). Floodplains play a vital role in preserving biodiversity and providing environmental services to human populations (Di Baldassarre, 2012). The Inner Niger Delta (IND) in Mali, is the biggest floodplains in Africa, covering four million hectares and supporting over one million herders, fishermen and farmers (De Noray, 2003; Zwarts et al., 2005). IND wetland represents a vast natural resource that continues to attract many people to live in and around the delta (Liersch et al., 2012; Zwarts et al., 2005). Since the beginning of the drought in the early 1970s, the IND wetland has been faced with a problem of sustainability of renewable natural resources. The management of these fragile resources, by a population with diverse practices (agriculture, livestock, fishing) in order to ensure their sustainability, involves multiple decision-making criteria and constraints (Kuper et al., 2002). Wetlands provide a wide range of ecosystem services that contribute to human well-being, such as fish and fibre, water supply, maintenance of water quality, climate regulation, flood regulation, coastal protection, and recreation and tourism opportunities (Millennium Ecosystem Assessment, 2005). Wetlands are also critical for the conservation of biological diversity. There is increasing recognition of the value of these functions and other ecosystem services provided by wetlands. In particular, wetlands are vitally important for providing the regulating and supporting ecosystem services that underpin water resources management, and can thus be considered as essential components of overall water infrastructure (Emerton & Bos, 2004). Liersch et al. (2012) investigated the impacts of climate change and upstream water management on food production in the IND under two population growth scenarios. In their article, the focus was on the assessment of external impacts on the carrying capacity of the IND with regard to the number of people who can be supported by the ecosystem service related to rice production. During and after the rainy season in Mali (June–October), large area of the IND are flooded. Naturally, these floodplains provide vital habitats supporting livelihoods in fishing, farming, and stock farming (Zwarts et al., 2006). Being already subject to large interannual variations of rainfall, particularly in the Niger and Bani headwaters, these habitats are additionally threatened by a variety of anthropogenic pressures and unsustainable uses (WWF, 2008). All activities in the area of IND wetland are highly depending on flooding patterns and duration, water depths, and the management practices. Hence, all factors that influence the inflow into the wetland. The spatio-temporal inundation patterns within the IND

wetland have an impact on food production and food security in the wetland area. Mali's population is projected to increase from 14 million (2011) to 40 million people in 2050 (van Vuuren et al., 2007). Food and energy demand, as well as improving living standards, will increase the pressure on natural resources. Thus, studying the sustainability and the vulnerability of the IND wetland is as important to insure the demand of the growing population. The present study seeks to provide a comprehensive review of trends and prospects of climate-based research on the IND wetland during the last three decades.

2. Method and Materials

The current study used the Scopus databases to retrieve relevant documents on the wetland situated in the Niger river in Mali—namely, the Inner Niger Delta. Scopus is a typical online academic database that has a great impact on academic literature due to its access to a wide range of journals and sources in all kinds of knowledge areas (Baas et al., 2020). A literature review was conducted on the Scopus platform in order to assess the publication pattern relevant to IND wetland. The approach consists of conducting a scientific mapping of research topics related to the IND wetland in order to understand thematic trends, developments, the nature of collaboration networks and general narrative in line with the biggest wetland in Africa. Bibliometric analysis was defined by Pritchard as the application of mathematics and statistical methods to books and other media of communication (Pritchard, 1969). Two widely used bibliometric methods are citation analysis and content analysis. Citation analysis implies a relationship between citing and cited works in a particular research area and allows one to identify core literatures, journals, countries, etc., (Pilkington & Meredith, 2009). Publications using bibliometric methods have grown over the years. Yet, large bibliographic datasets have made classic review methods cumbersome and impractical (Ramos-Rodríguez & Ruíz-Navarro, 2004). The search term used was “Inner Niger delta Wetland” and an analysis was performed through Scopus Science, which provides information such as the number of publications per year, the countries in which studies have been published and, the authors who have published the most papers on a particular subject. In total, 223 articles were initially found and 153 publications were finally selected on May 11, 2023. The dataset extracted from Scopus for the bibliometric analysis was downloaded as bib (BibTeX Bibliographical Database) file and the Bibliometrix package in R is used to process the information. These extracted data comprised much information such as the author's name, author affiliation, article title, keywords, abstracts, and multiple citations.

3. Results

3.1. General Characteristics of Bibliometric Analysis

The general information about the data used for this study is presented in **Table 1**. Details are based on search results in the scopus database, which included 153

publications for the period from 1966 to 2022. These articles were compiled by 533 authors and published in 110 sources with an average number of publication years of 11.4. The publications are mainly research article (122) and conference paper (22) with 47.06% of international co-authorships.

Figure 1 shows the evolution of the number of publications over the study period; the curve shows the cumulative number of publications. It highlighted an increase in the number of publications of about 2.5 per year from 1966 to 2022. The cumulative number of posts showed an upward trend over time. The evolution of the annual average of the number of publications is low from 1966 to 2000, from 2000 to 2022 the curve increases in sawtooth and reaches its Maximin in 2013 and 2018, the value of 2022 is low compared to the previous year's exception of 2014. IND wetland research has reached 2.5 publications in 2000 and exceeded 5 papers by 2017.

Table 1. The main information about the analyzed articles based on our keyword research.

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1966:2022
Sources (Journals, Books, etc)	110
Documents	153
Annual Growth Rate %	2.51
Document Average Age	11.4
Average citations per doc	16.31
References	5865
Keywords Plus (ID)	1402
Author's Keywords (DE)	427
Authors	533
Authors of single-authored docs	16
Single-authored docs	20
Co-Authors per Doc	4.68
International co-authorships %	47.06
article	122
book chapter	4
conference paper	22
conference review	3
review	2

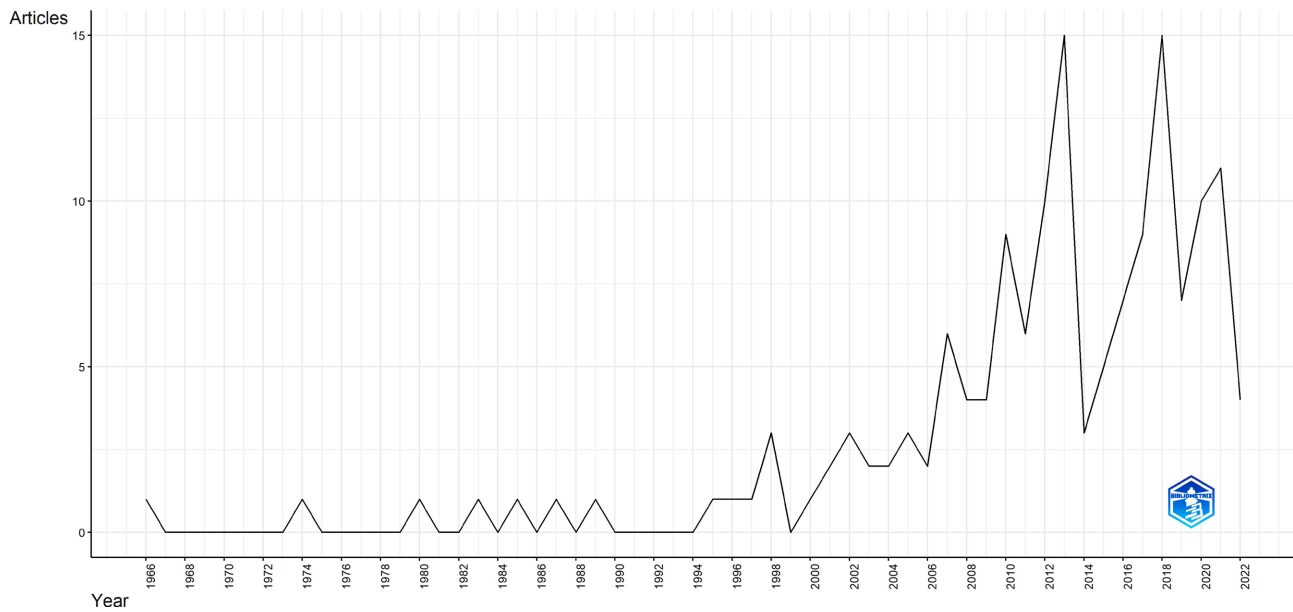


Figure 1. Annual evolution and the cumulative distribution of the number of publications over the study period.

3.2. Source Patterns

Table 2. The assessment of journals based on their impact.

	Source	H_Index	TC	NP	PY_Start
1	Journal of African Earth Sciences	4	29	7	2016
2	Environmental Science and Policy	3	84	3	2013
3	Hydrological Sciences Journal	3	45	4	2016
4	Iahs-Aish Proceedings and Reports	3	10	4	2013
5	Iahs-Aish Publication	3	44	5	1998
6	Journal of Ornithology	3	48	3	2011
7	Ostrich	3	26	3	2007
8	Water (Switzerland)	3	45	3	2016
9	Arabian Journal of Geosciences	2	7	2	2015
10	Climatic Change	2	69	2	2012

A total of 153 scientific articles were published for the period from 1966 to 2022 in 110 sources. The h-index is a specific index that refers to the number of published articles that have been cited at least h times (Bertoli-Barsotti & Lando, 2017). As shown in Table 2, “Journal of African Earth Sciences” and “Environmental Science and Policy” are the two most relevant and top-ranked sources with the highest h-index (7 and 3 papers, respectively) and the total number of citations (29 and 84, respectively). The journal “Hydrological Sciences Journal” ranks third with 4 cited articles and 45 citations. Figure 2 depicts the tendency of production source over time. After 2008, production reaches a significant peak,

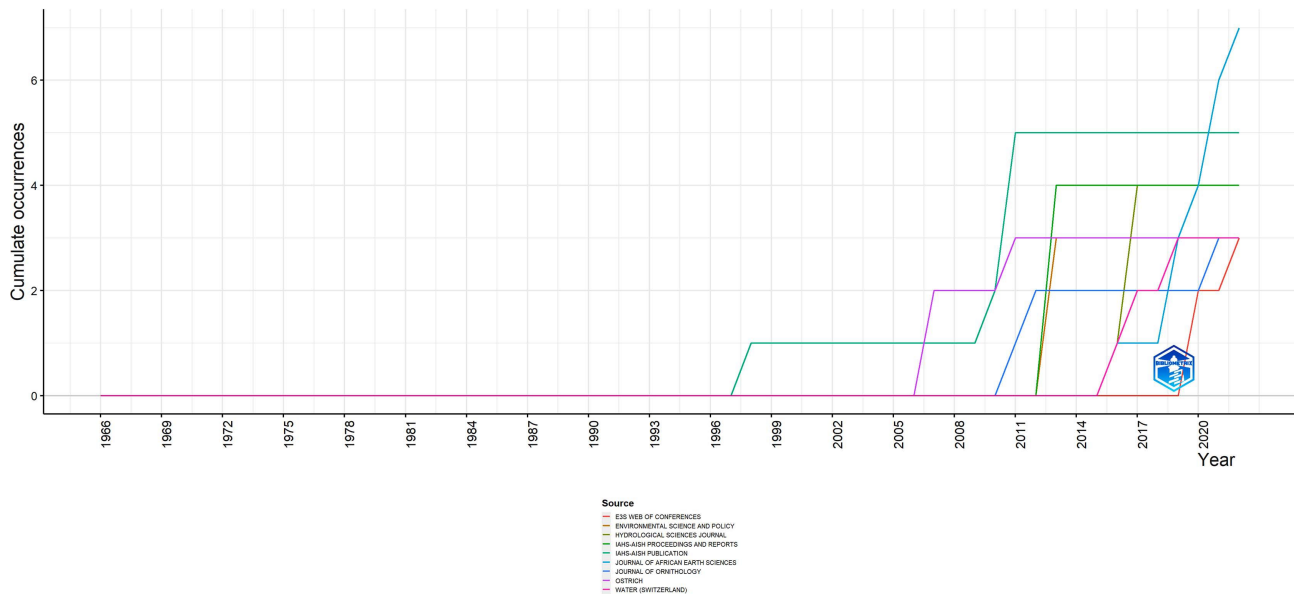


Figure 2. The source production over time.

and the diversity of sources increases significantly (**Figure 2**). This diversification of sources indicates that IND-related issues are now of interest to a wide range of researchers, not only in hydrology but also in other fields such as ecology, natural resource management and environmental policy.

3.3. Main Authors

Table 3. The top 10 of the most relevant authors.

#	Authors	H_Index	TC	NP	PY_Start
1	Granjon L	5	142	5	2002
2	Liersch S	5	100	6	2012
3	Mahe G	5	81	10	1997
4	Bamba F	4	75	4	1997
5	Flade M	4	56	4	2011
6	Fofana B	4	62	4	2007
7	Fournet S	4	87	5	2012
8	Hattermann Ff	4	109	5	2012
9	Kone B	4	88	6	2007
10	Mariko A	4	54	5	2003

Authors' reports included a filter to identify the main authors and countries on the Inner Niger Delta studies. **Table 3** summarizes author productivity characterized by h-index, total number of citations (Tc), number of articles (Np) and year of first publication (Py_Start) during the study period. In terms of h-index,

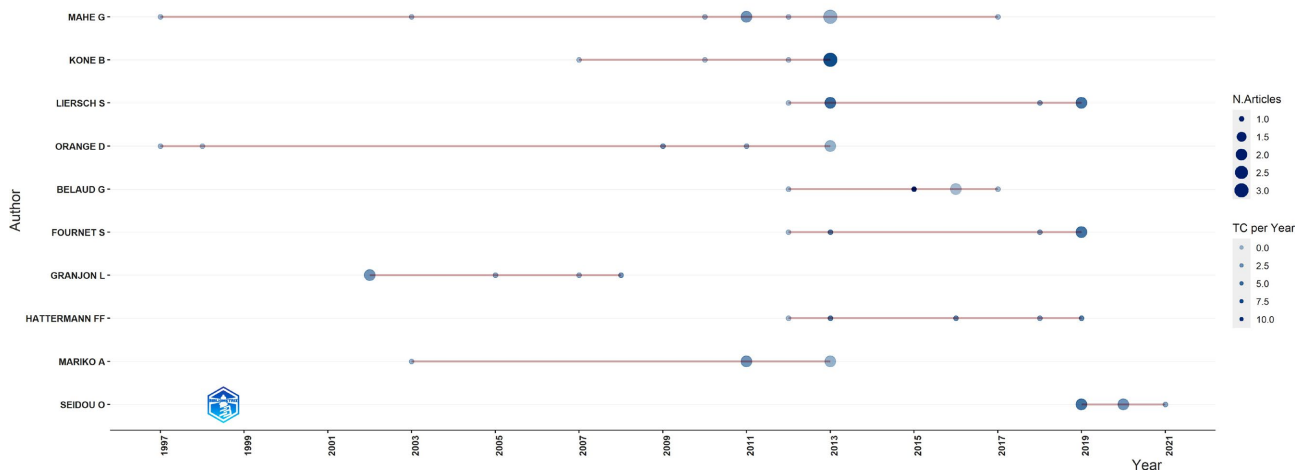


Figure 3. Author’s production over time.

Granjon L, de Liersch S, and Mahe G have the greatest influence, with an index value of 5, followed by Bamba F., Fofana B. and Flade M., who have an index value of 4 each. Regarding the number of citations, the first two places are occupied by Granjon L and Liersch S with 5 and 6 articles respectively. The third place is occupied by Kone B with 6 articles. Figure 3 shows the evolution of authors over time. The volume and color depth of the sphere are related to the annual number of article citations. This shows that Mahe G has the large number of posts over time followed by Kone B and Liersch S with 6 posts each.

3.4. Main Countries

Publishing articles in different countries can usually reflect the influence and importance of a given topic. Fifty-one countries are involved in this study. Figure 4

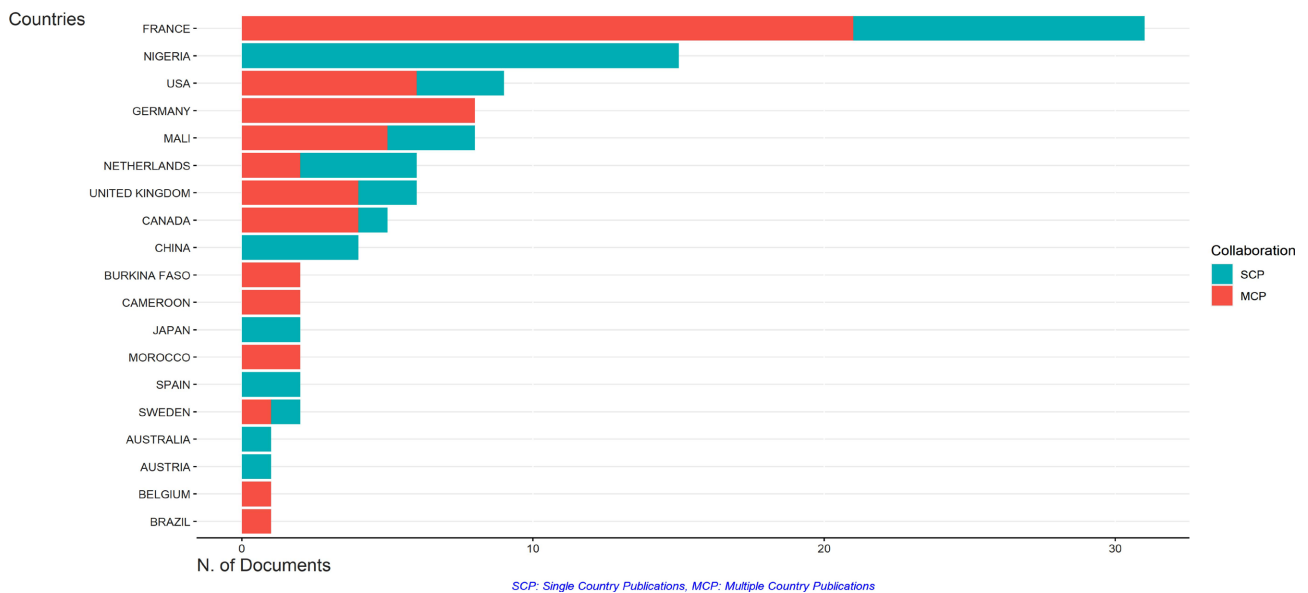


Figure 4. Top 20 countries of study’s authors.

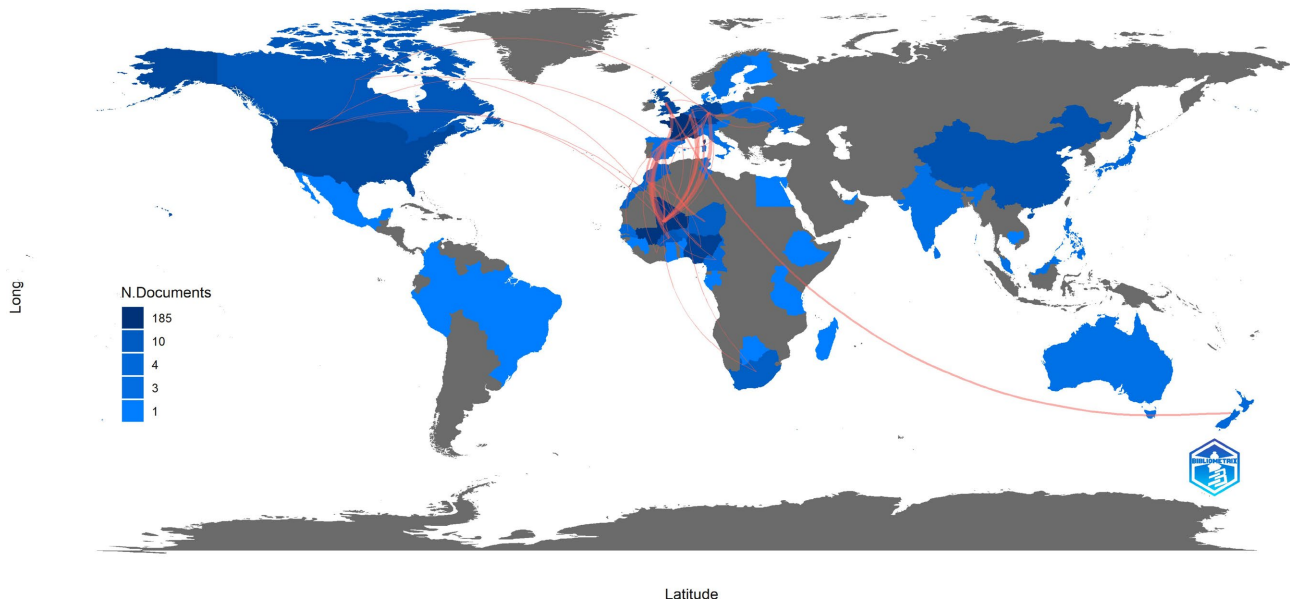


Figure 5. Collaboration by countries.

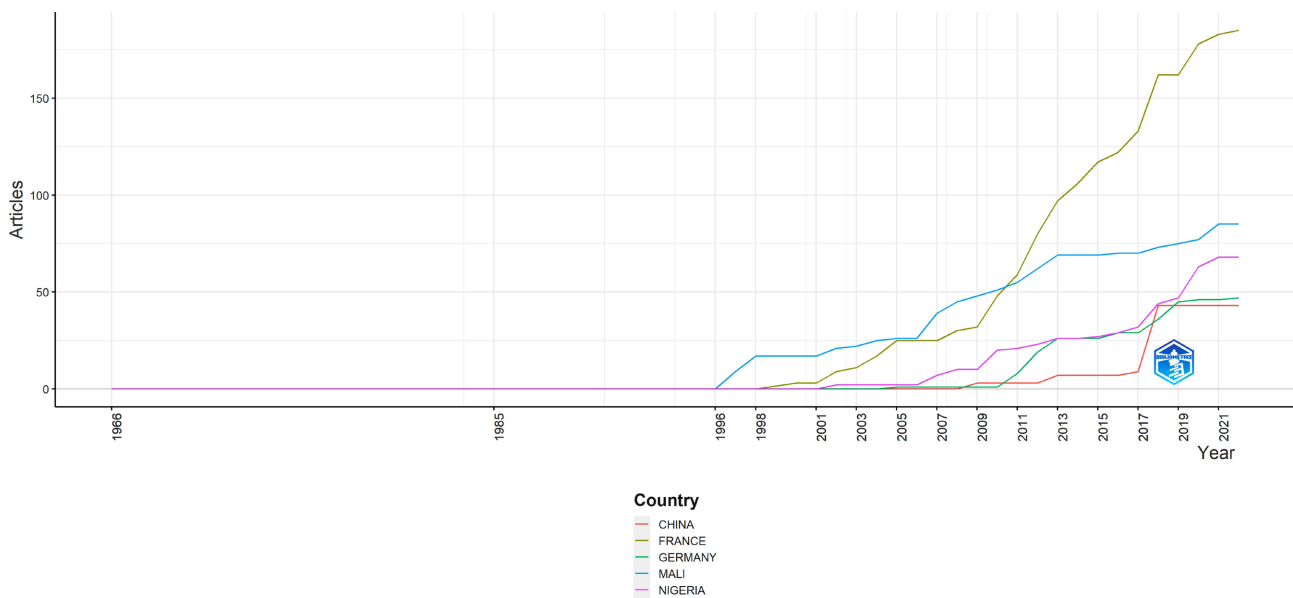


Figure 6. Journal production by countries.

describes the top 15 countries where authors have collaborated within the same country: single-country publications (SCP) and between countries: multi-country publications (MCP). The total number of items is the sum of SCP and MCP. France occupies the first position with 31 publications, representing approximately 20.26% of the total articles published (national and international), followed by Nigeria with 15 articles, representing 9.80% of the total publications. France is far ahead of other countries in terms of multi-country publications (21 articles), which partly reflects the fact that France is more active in researching the sustainability of the Inner Niger Delta. Regarding the average amount of article citations,

France and Germany have the highest cross-country publication rates (0.20 and 0.05, respectively). African countries occupy an important place with the participation of 19 countries over the 51 countries ahead of Europe and Asia. Most of the top 19 countries are developed countries, with the exception of three African countries. The scientific production of the country is shown in **Figure 5**. The greatest number of articles published in terms of frequency is indicated by the darker blue. **Figure 6** reveals an increase in the number of scientific articles published since 2005, with France, Germany, China, Mali and Nigeria continuing to record steady growth. This result also shows the interest of researchers for the inner delta of the Niger which contributes to the achievement of sustainable development objectives in the West African sub-region.

3.5. Most-Cited Articles in the World

Table 4. Ten global cited documents dealing with the Inner Niger Delta wetland.

#	Paper	Journal	Years	Total Citations
1	DEPTUCK ME	Marine and Petroleum Geology	2003	335
2	OGBONDA KH	Bioresource Technology	2007	163
3	SULTAN N	Journal Of Geophysical Research	2010	116
4	OGILVIE A	Journal of Hydrology	2015	98
5	JOBE ZR	Journal of Sedimentary Research	2015	65
6	Reyment (1966)	Palaeogeography, Palaeoclimatology, Palaeoecology	1966	64
7	CUBRY P	Current Biology	2018	56
8	FLEISCHMANN A	Journal of Hydrology	2018	53
9	NORMANDIN C	Remote sensing	2018	51
10	PEDINOTTI V	Hydrology and Earth System Sciences	2012	50

Commonly cited references from a specific research area can reveal the knowledge base of that area (Marx et al., 2017). **Table 4** shows the 10 global papers cited related to the Inner Niger Delta over the period of 1966 to 2022. Publications by Deptuck et al. (2003) Analyzed high resolution 2D and 3D multichannel seismic data, mainly from the upper fan of near seafloor channel-dig systems on the Niger Delta Slope and in the Arabian Sea, reveal a high level of detail and architectural complexity. Detailed study of one particular channel-dig system on the Niger Delta Slope shows a period of incision followed by three distinct phases of channel development during its aggradation history. Channel sinuosity evolves dynamically, with some meander loops undergoing periods of accelerated

meander growth while others show little lateral migration. [Ogbonda et al. \(2007\)](#) studied the influence of temperature and pH on biomass production and protein biosynthesis in an environment isolated from hydrocarbon pollution in the brackish Niger Delta. The effect of pH was modulated by temperature and vice versa during biomass production. Offers a good source of natural protein that could be readily accepted by rural communities as single cell protein in the form of feed, food and health supplements when properly processed. [Sultan et al. \(2010\)](#) used acquired geophysical, geological and geotechnical modeling to monitor the evolution of hydrate dissolution causing sediment collapse and pockmark formation in the Niger Delta. The results showed that gas hydrate dissolution (gas hydrate becomes a mixture of water and dissolved gas) under a local decrease in gas concentration at the base of the Gas Hydrate Occurrence Zone (GHOZ) can explain the excess pore pressure and fluid flow surrounding the central hydrate zone and the collapse of sediments at the edge of the GHOZ. The different stages of deformation (or development) of the detected pockmarks confirm that a local process, such as the amount of gas flow across faults rather than a regional one is driving these depressions. [Ogilvie et al. \(2015\)](#) exploited 526 MODIS satellite images for 8 days with 500 m resolution to study the spatial and temporal dynamics of the annual flood in the Inner Niger Delta over the period 2000-2011. Results show that previous correlations between discharge levels and inundated areas were refined to account for hysteresis as the flood recedes and the variable magnitude of the flood. Direct precipitation assessed over the flooded areas refined the wetland water balance and infiltration estimates. Knowledge gained about the timing, duration, and extent of flooding across the wetland and in lakes, floodplains, and irrigated plots can assist farmers in agricultural water management. [Jobe et al. \(2015\)](#) Investigated changes in sediment supply and sizing over the past 130 years in the complex architectural evolution of the Y-channel system on the western slope of the Niger Delta. The show that the inner dikes accumulated rapidly as flows sought equilibrium. The dataset unequivocally links changes in underwater channel architecture to changes in sediment supply and size. Changes in the upstream-downstream sediment delivery system have profound implications for submarine channel architecture and reservoir connectivity. [Cubry et al. \(2018\)](#) used 246 new whole genome sequences, to find the geographic origin of the domestication of African rice (*Oryza glaberrima*) which remains elusive, the results showed that the cradle of its domestication was in the Inner Niger Delta. [Fleischmann et al. \(2018\)](#) included a bidirectional coupling scheme in a large-scale hydrological-hydrodynamic model (HHM) and tested different model structures, in order to assess which processes are important to simulate in large semi-arid wetlands and how these processes interact with the water balance components. Model outputs were in good agreement with flow and water levels at upstream and downstream stations in the inner Niger delta, as well as for flooded areas in the delta region. Model estimates of annual water loss in the delta ranged from 20.1 to 30.6 km³/yr, while annual evapotranspiration ranged from 760 mm/yr to 1130 mm/yr.

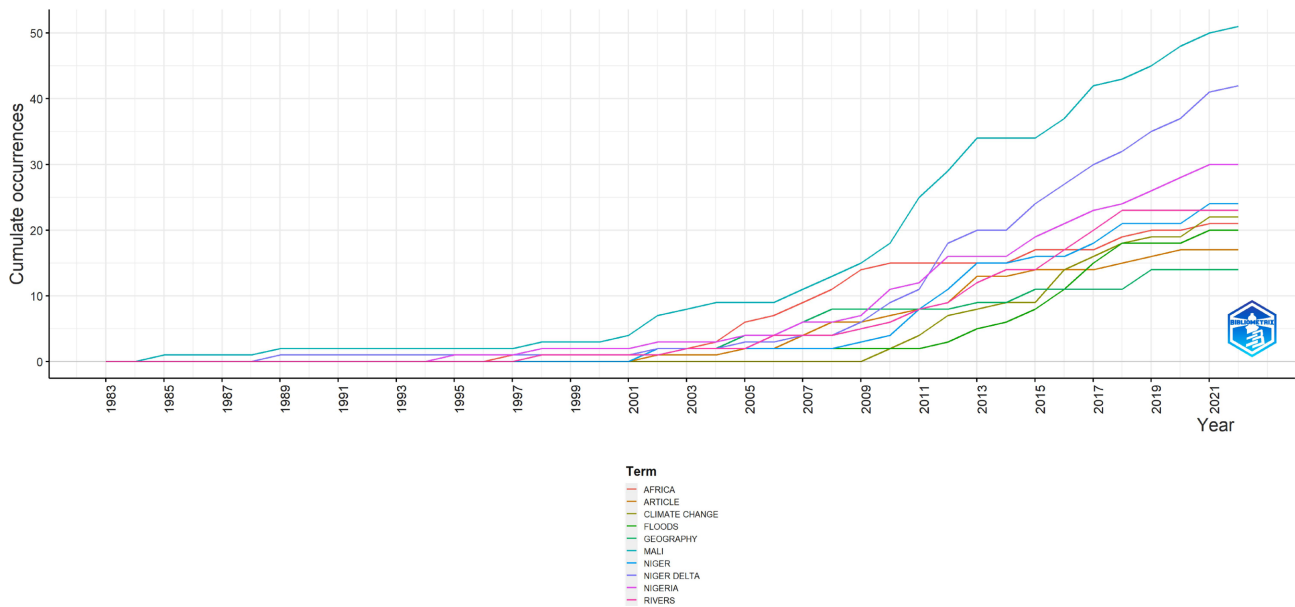


Figure 8. Change and evolution of keyword annual occurrence over time.

occurrence of the words “Mali”, “Niger Delta”, “climate change”, “hydrological modeling”, “floods”, “rivers” and “water management” was noted. This showed that during this second period, many studies have focused on the impact of climate change, economic impact of the inner Niger delta in the West African region and the hydrological system of the study area.

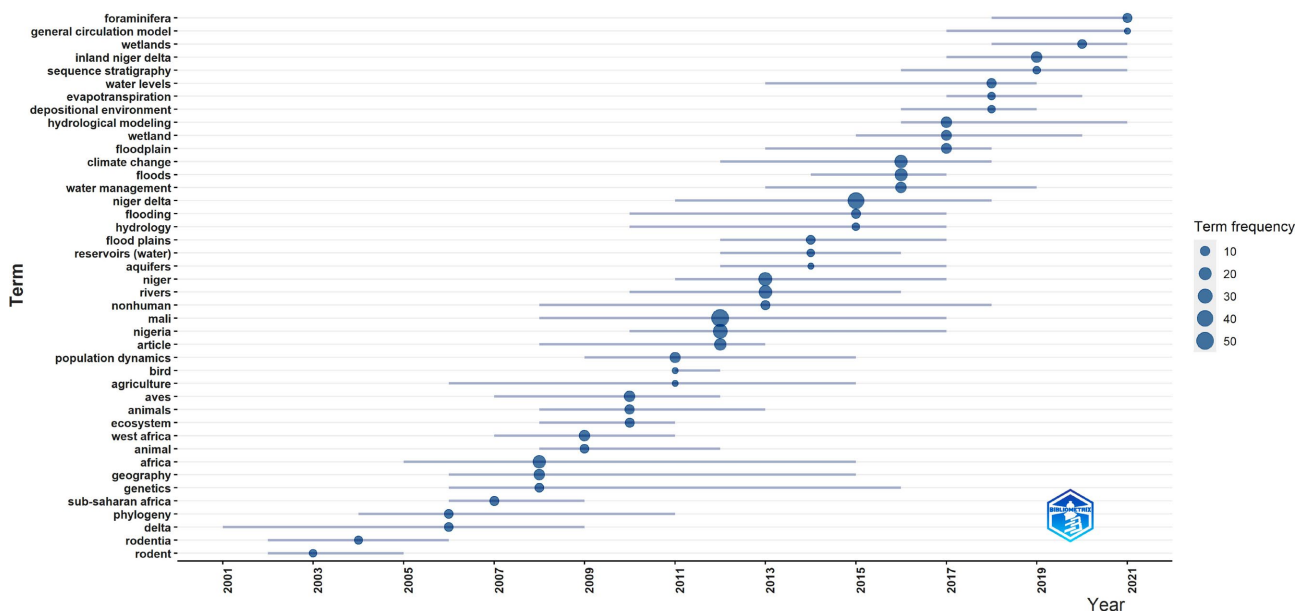


Figure 9. The trend topics of Inner Niger Delta over time.

Regarding the keywords related to the topics understudy, **Figure 9** depicts the entry of keywords in the search over a period of study, from 2000 to 2013 the

studies focused on agriculture, the evolution of the population, endangered animals. However, during this last decade, more and more researchers started to pay attention to the water management, the floodplain, the climate change, the hydrology modeling, the evapotranspiration, the general circulation model which really contribute to advance research in study area. Therefore, recent dynamics seem to focus on the hydrology and climate change impact of the Inner Niger Delta.

4. Discussion

The IND is one of the largest floodplains in the world and is located in the Sahelian Zone in Mali in West Africa. Food production in the IND encompasses mainly three sectors: agriculture, fishery, and livestock. The agricultural system in the IND is therefore very complex and the multiple usage of natural resources is based on community rules and customs that have shaped the way in which societies have administrated this area for a long time (Marie et al., 2007; Moorehead, 1997). Some upstream dams and irrigation structures are already in place, while more are at the planning stage. The infrastructures aim to increase economic development and food security (Haque et al., 2019). This study can help researchers better understand how the subject has evolved over time and varied from one place to another place.

The whole of West Africa has been faced with extreme climate variations over the past 5 decades with extended extreme drought conditions during the 70s and 80s (Lebel & Ali, 2009). Inner Niger Delta research has attracted the attention of researchers over the past two decades, with several annual publications, which increased from 1 in 2000 to 11 in 2021 and peaked in 2013 and 2018 with 15 publications. Indeed, since the beginning of the 20th century, there has been a decline in the trend of precipitation in Mali (Funk et al., 2012). This increasing number of publications shows a trend of continued growth, demonstrating that more and more researchers have become interested in this area of research. A total of 51 countries had published in this research area. Among these countries, Europe is the most represented by France and Germany, which are led by more published articles. France is of great interest with approximately 20.26% of the total number of articles published. Followed by Africa represents by 19 countries out of the 51 countries; nevertheless, Nigeria and Mali with respectively 9.80% and 5.22% of the articles published. The current research situation exhibits the weak collaboration among regional institution to undertake scientific research with local perspectives. However, research on the Inner Niger Delta is characterized by the limited availability of literature and databases according to the Ministry of the Environment (2002 annual report). In the same perspective, according to (Neal et al., 2012; Kuper et al., 2003), despite the availability of global numerical models, and the extent of their field of application and in-depth studies carried out in the field, knowledge on the state of the environment are still insufficient. Knowledge of floodplain topography remains insufficient to properly model floodplains.

Therefore, with all of the above, more similar studies reinforce the need for continued research and knowledge generation as the Inner Niger Delta contributes significantly to food security and employment in West Africa, particularly in Mali. The research on the Inner Niger Delta is multidisciplinary which combines climate, agriculture, livestock, fisheries, ecosystems, environment, bioresources technology, biochemistry, and plant and soil science. Given the economic importance of the inundation areas, there have been several studies examining the dynamics of the flooded areas. The techniques used include the generation of time series of inundation maps using satellite imagery (Berge-Nguyen & Cretaux, 2015; Ogilvie et al., 2015; Zwarts et al., 2005; Mariko, 2003), the development of empirical functions that linked the water level at key stations to the inundation extent (Mahe et al., 2011; Zwarts et al., 2005; Mariko, 2003), and numerical simulations using numerical models (Haque et al., 2019; Schröder et al., 2019; Fleischmann et al., 2018; Haag, 2015; Neal et al., 2012; Dadson et al., 2010). The evolution of the keywords during the study period revealed that the Inner Niger Delta contributes to the achievement of sustainable development objectives in the West African region. The current focus of studies on the Inner Niger Delta has shown that more researchers are interested in hydrology, agriculture, livestock, fisheries and the impacts of climate change on the flooded area of the delta. Having adequate knowledge of the characteristics of observed and future changes in flood and rainfall extremes is important for developing appropriate adaptation measures to minimize the impacts on society and the environment. This is particularly important because extreme rainfall is expected to intensify with global warming over large parts of the globe as the concentration of atmospheric water vapor which is a source of rainfall increases in proportion to the saturation concentrations at a rate of about 6% - 7% per degree rise in temperature according to the thermodynamic Clausius–Clapeyron relationship (Ingram, 2016; Allen & Ingram, 2002).

5. Conclusion

The IND is considered as a hub of human activities, including agriculture, fishing, transport, and tourism. The Delta plays an important role in promoting sustainable development for food security, water management, and the environment.

The current research situation on the IND wetland is dominated by results from developed countries research institution which claims for more efficient collaborations among regional institution in Africa to undertake scientific research with local perspectives. Keyword analysis of relevant publications illustrates the importance of the topic, and analysis of cited references highlights the starting point for further discussion. The results reveal that the topic of research has received increasing attention and that the number of annual publications has followed an upward trend. Although many research papers using the IND were found, very few of them took into account the impact of climate change and the hydrology of the area. They focused on agricultural productivity, fisheries, livestock and water levels. Thus, one of the main challenges of research on IND is therefore to pursue

research projects by applying them in the impact of climate change in the short and long term period and the hydrology of the area. In order to assess the potential of the IND in achieving the objectives of sustainable development in West Africa in general, particular in Mali. Many aspects could be considered for the future direction of effective mitigation of climate change impacts. It might be interesting to understand the economic potential of the IND. However, many factors influence the development of activities in the area, such as insecurity, the lack of training of farmers to adapt to the evolution of their trades and the management policy of the area. Therefore, even with an increased number of publications in recent years, further research is still needed to understand the evolution of IND in the short and long term as well as the aspects necessary to optimize the economic potential, improve sustainability and mitigate the impacts of climate exchange.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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