Journal of Geoscience and Environment Protection, 2025, 13(6), 275-300
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Research Evolution on Environmental Risks Related to Agricultural Pesticide Use in Africa from 1990 to 2021

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How to cite this paper: Bah, A., Alonso, A., Faye, S., & Vanclooster, M. (2025). Research Evolution on Environmental Risks Related to Agricultural Pesticide Use in Africa from 1990 to 2021. *Journal of Geoscience and Environment Protection, 13,* 275-300.
https://doi.org/10.4236/gep.2025.136019

Received: May 12, 2025
Accepted: June 24, 2025
Published: June 27, 2025

Abstract

Agricultural pesticides that control weeds and pests can contaminate non-targeted environments and affect human health and natural ecosystems. The lack of in-depth knowledge about the use of agricultural pesticides and their fate in the environment exposes farmers and natural ecosystems in Africa. This paper evaluates the global productivity of research on agricultural pesticide use and management in Africa from 1990 to 2021 using various bibliometric indices. Scopus extracted a database of 1863 research papers focusing on agricultural pesticides in Africa. The publication of documents increased at an annual rate of 9.9%. The publications covered pesticide types, applied doses, pest targets, risk perception and biological and environmental exposure. Pesticide types, detection frequencies, contamination pathways and measured levels varied according to a matrix of analysis and the studied region. The studies on agricultural pesticides have focused on exposures to humans with a total number of publications (TPN = 505), crop protection (TPN = 472), natural ecosystems (TPN = 263), surface water (TPN = 183), soil (TPN = 131), sediment (TPN = 94), atmosphere (TPN = 24) and groundwater (TPN = 20). The organochlorine insecticides were the most often studied, particularly the molecules of DDT, Endosulfan, Lindane and Chlorpyrifos. The research overview shows an alarming situation. Most pesticide residues, while banned for use, persist at worrying levels in high agricultural production areas.

Keywords

Agricultural Pesticides, Human Health, Natural Ecosystem, Bibliometric Analysis, Scopus™ Database, Africa

1. Introduction

The agriculture sector, which represents the main economic sector of Africa, is a major consumer of pesticides. The consumption of pesticides in the African agricultural sector is relatively low (0.49 kg/ha) compared to other regions such as America (3.74 kg/ha), Oceania (2.13 kg/ha), Europe (1.64 kg/ha) and Asia (1.15 kg/ha) (FAO, 2021). Yet, the consumption of pesticides in agricultural activities in Africa has increased overall. The use of pesticides has increased from 64 thousand metric tons in 2000 to 108 thousand metric tons in 2019 (FAO, 2021) (**Figure 1**).

The pesticides applied in agriculture can undergo processes of transformation and exchange between different environmental compartments. They can further disperse in the environment, particularly into surface water due, for instance, to runoff loaded with pesticide residues and into groundwater due to leaching (Odabasi & Cetin, 2012). The properties of some of these products may also facilitate the bioaccumulation and biomagnification in freshwater and terrestrial organisms (Olisah et al., 2019a), with a real risk to human health (Pan et al., 2016). In particular, organochlorine pesticides can persist in environmental matrices for a considerable period (Sudaryanto et al., 2007). Persistent pesticides may exceed human and ecotoxicological norms and constitute a major ecological risk (Mrema et al., 2013). The fate of pesticides in the environment is first controlled by intrinsic properties such as partitioning coefficients at equilibrium octanol/water (Kow), octanol/air (Koa), Henry's law constant, vapor pressure and solubility (Farooq et al., 2011). Additionally, ecosystem factors such as soil type, geology, land use, and climate ultimately determine their environmental behavior. The complex relationships between agricultural pesticides' use and fate in the environment have mainly been studied in developed countries (Olisah et al., 2019b). In contrast, this knowledge is fragmented and less detailed for African agricultural systems. The pesticide risk assessment and management schemes developed from studies in developed countries do not take into account the specific environmental and farming conditions of the African agricultural sector and can therefore not be directly transposed to pesticide management in Africa. To our knowledge, no systematic compilation of scientific research papers has been carried out on the use and environmental behavior of agricultural pesticides at the scale of the African continent, limiting the design of such specific pesticide assessment and management strategies.

To contribute to filling this knowledge gap, this study aims to map the research related to the use and environmental behavior of agricultural pesticides in Africa from 1990 to 2021. To reach this objective, a bibliometric analysis was applied to peer-reviewed scientific literature published during the past three decades (from 1990 to 2021). The 1990s were marked by the return of rainfall, particularly for some parts of West Africa, after a long period of drought. Several countries in Sub-Saharan Africa thus engaged in intensive agriculture with the use of pesticides to ensure food security.

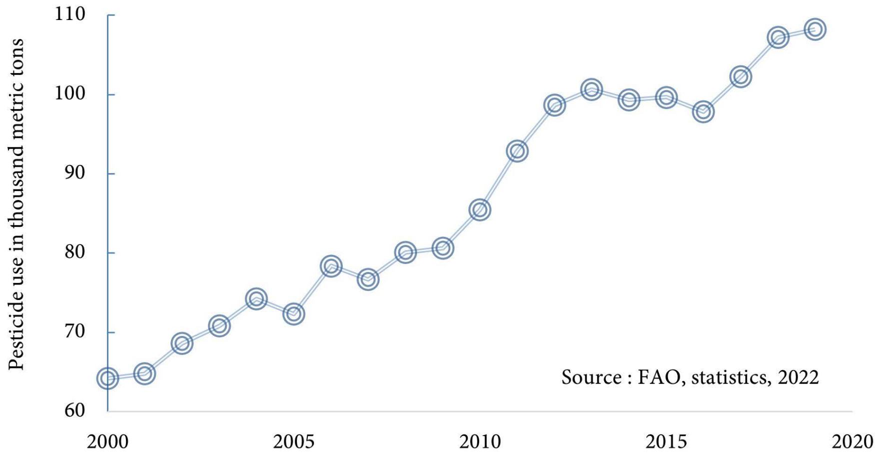


Figure 1. Agricultural pesticide consumption in Africa from 2000 to 2019 (in 1000 metric tons) (FAO, 2021).

Bibliometric analysis, first introduced by Pritchard (1969), is a set of statistical and metric methods for assessing the characteristics of articles, the evolution of science about a subject or domain (Yao et al., 2018) or the quality of a journal (Koseoglu, 2016). Bibliometric analysis is a method for assessing the publishing performance of researchers and institutions and mapping the structure and dynamics of domains through data (e.g., citations, authors' names, keywords, collaboration) obtained from written publications, including articles, books and book chapters (Cobo et al., 2011b). The bibliometric analysis is divided into two sub-analysis: 1) Productivity analysis (e.g. analyzing the number of papers per author) and impact analysis (e.g. analyzing the total of citations, citations per author or citations per given period) and 2) Relational analysis (e.g. analyzing the co-authorship, the co-citation and bibliographical coupling) (Benckendorff & Zehrer, 2013; Cobo et al., 2011a).

Bibliometrics is facilitated by the use of modern bibliometric data mining and network analysis methods. It is based on the application of practical network analysis tools on the transdisciplinary scientific corpus integrated into literature databases such as the Scopus™ database.

Here, we have evaluated the global production of agricultural pesticide research in Africa from 1990 to 2021 on papers from the Scopus™ database in terms of country and author productivity, annual productivity, paper citations, subject terms associated with keywords, international collaboration networks, matrix investigated and pesticide residues detected.

2. Evaluation Methods

2.1. Database Selection

The methodology steps are presented in **Figure 2**. The data were extracted from the international academic database Scopus™. The use of Scopus™ was based on the reliability of peer-reviewed scientific publications and the quality of web sources (Falagas et al., 2008). Furthermore, Scopus™ is a transdisciplinary database that is very practical and well-suited for this type of research. To include all documents produced on research on pesticides used in agriculture in Africa, research equations were used in the field (title, abstract, keywords). The truncation research (*) allowed the selection of several terms with a similar root or the selection of a term and all its grammatical forms in which the term could be enounced in the titles or abstracts and keywords of the papers. The quotation marks allowed the system to research the exact expression. The documents were validated by manual verification based on the reading of the abstracts and those outside the scope of the study were excluded. The types of documents considered were articles, books, book chapters, conference papers and reviews. The papers written in both English and French were considered. The "ISI Unique Article Identify" index was used to eliminate or minimize duplicates. The papers reviewed were related to the fate of agricultural pesticides in air, soil, sediments, rivers and groundwater and the associated management.

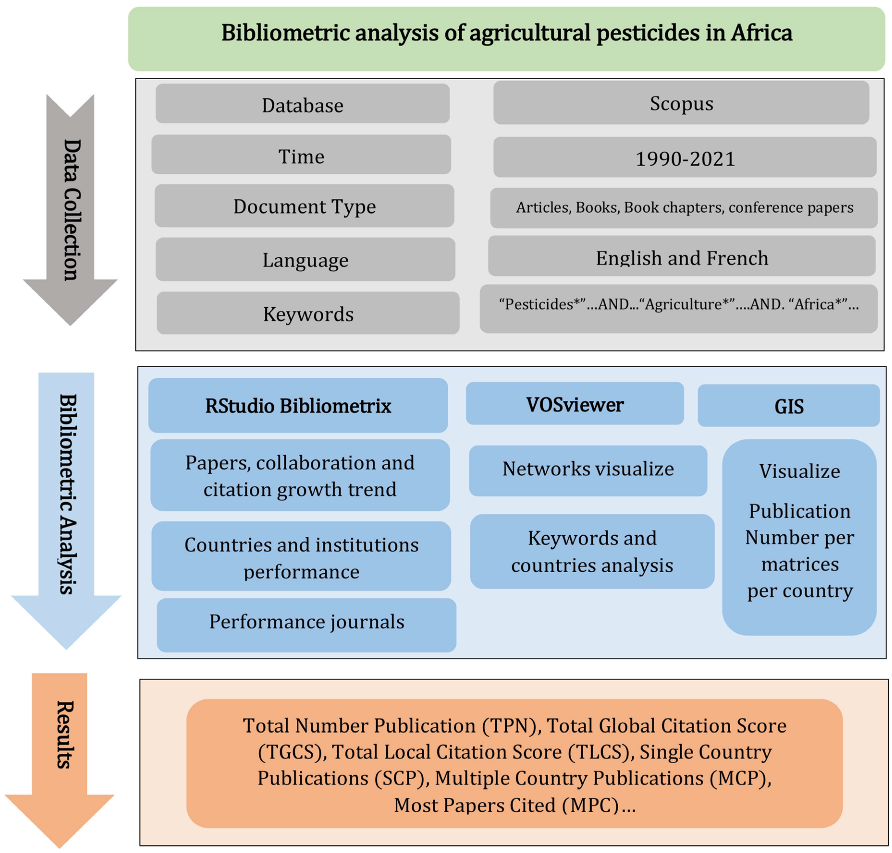


Figure 2. Overview of the methodological approach.

The following research equations were selected to build the analysis database: "Pesticides*" AND "agriculture*" AND "Africa*" AND "risks*" AND "human*" AND "Environment*" AND "health*".

The following criteria were used to further screen the body of literature resulting from the automatic search in Scopus:

- The study must be related to the use of pesticides in agriculture and their socio-economic, management, environmental or human health effects,
- The study must be carried out in a region of the African continent and/or a comparative analysis between a region of Africa and other areas of the world and
- The descriptive information of the paper must be available (title, author, year, abstract, keywords and journal).

2.2. Data Analysis

The data related to the resulting papers, such as authors, countries, affiliations, citations, abstracts, keywords, titles and journals were exported to BibTex and CSV formats for statistical and metric analysis.

The database exported from Scopus™ was analyzed with RStudio, VOSviewer and ArcGIS software. The data BibTex format was imported into RStudio and analyzed with the biblioshiny package https://www.bibliometrix.org/biblioshiny/, which is a web-based package included in the bibliometric R package http://www.bibliometrix.org (Aria & Cuccurullo, 2017). The bibliometric indices were extracted based on codes similar to those used by (Aria & Cuccurullo, 2017). To avoid ambiguities about the nomenclature of authors, institutions, keywords and journals, the "*Name Disambiguation*" box was enabled on the web-base https://www.bibliometrix.org/biblioshiny/.

This box allows combining names represented as different initials or variations of names, for example, two different terms with the same name using different initials. The occurrences of keywords with similar significances in the documents were considered identical and grouped into a single word. For example, the words "pesticide" and "pesticides" were assigned to "pesticides". The "network mapping" script made it possible to visualize the co-occurrences of the bibliometric records.

The applied R package codes and commands were used to generate bibliometric indices such as Annual Scientific Production (ASP) and Total Publication Number (TPN). These same codes were also used to generate the bibliographic linkage: Single Country Publications (SCP) and Multiple Country Publications (MCP). The Total Global Citation Score (TGCS) is the total number of citations of a paper in the Scopus™ academic database. The Total Local Citation Score (TLCS) is the number of citations of a paper in the database downloaded (example in this case study, 1863 papers). To follow the manuscript and assist in online research, authors have to specify keywords (Olisah et al., 2019b). In bibliometric, both "Author's Keywords (DE)" and "Keyword Plus (ID)" can be investigated. The ID provides the ability to capture the deep and varied content of an article (Garfield & Welljams-Dorof, 1992). The two types of keywords were evaluated to identify terms associated with agricultural pesticides in Africa.

The VOSviewer software was used to visualize the collaboration networks. The

Fruchterman-Reingold algorithm was used to visualize the nodes gravitationally (Golbeck, 2013). The influence of a node is measured relative to the number of nodes in the network that are directly connected to it (Colanzi et al., 2013). The performance of authors, institutes and countries has been analyzed using annual scientific indicators (e.g. TPN). An author's impact is measured by the number of citations that his papers register as well as the importance of a paper that has been cited by others. A publication-citation matrix was used to measure the impact of a country and to rank the authors/countries by publication performance. The research scope is measured by the keywords extracted from the papers.

The database exported in CSV format is manually explored. The agricultural pesticides frequently reviewed are identified by the reading of the "chemicals_cas" column. Additionally, the environmental and biological matrices investigated, as well as the study areas, were identified through the reading of the abstracts and titles of papers. A paper can process one to several matrices. Additionally, a paper may process one to several pesticides with the same or different biological activity in a region. The distribution of the TPN per matrices and country is visualized through ArcGIS 10.8 software. The size of the icons shows the TPN per matrices per country.

3. Results

3.1. Description of the Collected Database

The Scopus search resulted in 1863 scientific papers. The papers consist of 1622 (87%) articles, 142 (7.6%) reviews, 52 (2.8%) book chapters and 47 (2.5%) conference papers. Of the 1 863 papers, 1838 (98.6%) are published in the English language. The 1863 papers are published in 636 different journals. A total of 5581 researchers contributed to the papers with a document per author and co-authors per document ratio of 0.3 and 4.3, respectively. A total of 5424 authors participated in the writing of multi-authored papers, while 157 researchers participated in the writing of single-authored papers.

The collaboration index, which indicates the total authors of multi-authored papers/total multi-authored papers (Elango & Rajendran, 2012), is about 3.2. Hence, there is a strong multi-author involvement in scientific research in the considered research field (Siamaki et al., 2014). The score of the collaboration index could have a positive impact on the citation of papers, which averaged 22.8 citations per paper (**Table 1**).

The yearly and cumulative publication number of papers increased from 1990 to 2021 (**Figure 3(a)**). The yearly papers increased from 8 in 1990 to 153 in 2021. The year 2020 is the most documented with 164 papers. The increase in research can be explained by the promotion of sustainable agriculture for food security about the Sustainable Development Goals (UN-SDGs), but also the dynamics of institutional collaborations (Barrios et al., 2008), the emergence of new researchers (Cabral et al. 2018) and new research domains (Agbohessi et al., 2015). A total of 1739 papers were cited. The total cumulative number of citations of papers is

Table 1. Main information on agricultural pesticide research in Africa from 1990 to 2021.

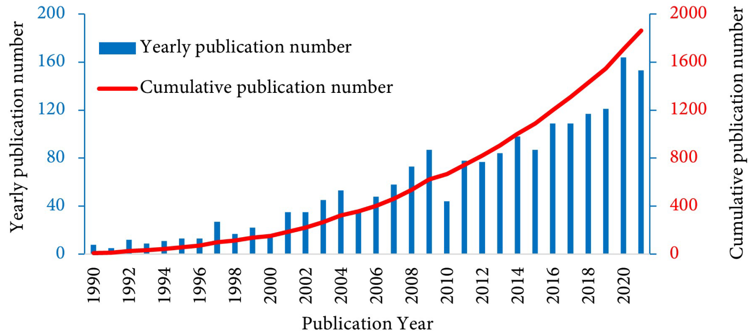
Description	Results
Papers	1863
Sources (Journals, Books, etc.)	636
Documents contents	
Keywords Plus (ID)	9212
Author's Keywords (DE)	4443
Average years from publication	9.89
Average citations per document	22.8
Average citations per year per document	2.3
References	86,198
Authors	5581
Author Appearances	8805
Authors of single-authored documents	157
Authors of multi-authored documents	5424
Authors collaboration	
Single-authored documents	185
Documents per Author	0.3
Co-Authors per Documents	4.3
Collaboration Index	3.2
Document types	
Article	1622
Review	142
Book chapter	52
Conference paper	47

42,443, with an average citation per paper of 22.8 times. The research results were highly regarded by the academic community. The annual citation in Scopus increased in 2009 with a Total Global Citation Score (TGCS = 3084). The number of citations per paper by other papers in the present collection increased in 2014 with a Total Local Citation Score (TLCS = 394) (**Figure 3(b)**). The TLCS provides crucial information on authors' self-citation. This could be due to an institutional affinity or to a common methodological approach of the authors. After 2016, the number of citations continued to decrease to an average of two per paper in 2021. This is because the new publications need more time for reading (Mo et al., 2018) and the loss of influence of articles over the years (Fu & Ho, 2015).

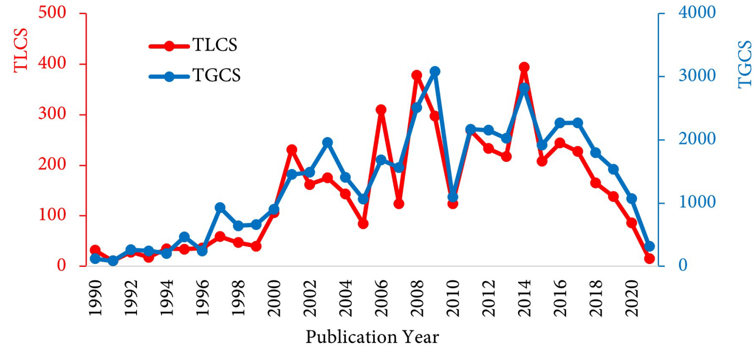
3.2. Keywords Related to Agricultural Pesticides

The 1863 papers contained 9212 Keyword Plus and 4443 Author's Keywords.

Table 2 lists the 15 most frequently used. The terms "pesticides", "humans", "South Africa", "animals", and "Africa" are the most frequently reported in publications for the Keyword Plus. For the Author's Keywords, these are "pesticides", "organochlorine pesticides", "Africa", "environmental exposure" and "risk assessment". The keywords indices mainly describe the types of pesticides frequently used, the environmental receptor and the geographical areas frequently studied. The Keyword Plus analysis identified "South Africa" as the only country present, occupying the third position highlighting. The majority of the case studies were conducted in this country.



(a)



(b)

Figure 3. Temporal evolution of papers and citations from 1990 to 2021. (a) Annual and cumulative number of publications of papers; (b): Total Local Citations Score (TLCS), which is the number of citations by other papers in this collection and Total Global Citations Score (TGCS), which is the number of citations by the paper in Scopus™.

Table 2. Top 15 author's keywords and keywords plus related agricultural pesticides from 1990 to 2021.

Rank	Keywords Plus (ID)	TPN	Author's Keywords (DE)	TPN
1	pesticides	1262	pesticides	354
2	humans	665	organochlorine pesticides	148
3	South Africa	591	Africa	93
4	animals	570	environmental exposure	85
5	Africa	461	risk assessment	70

Continued

6	organochlorine pesticides	435	vegetables	70
7	agriculture	432	agriculture	67
8	insecticides	418	sediment	66
9	risk assessment	395	herbicides	64
10	concentration response	342	water quality	64
11	female worker	323	insecticides	63
12	water pollutants	319	DDT residue	58
13	occupational exposure	276	maize	56
14	environmental exposure	257	fish	55
15	endosulfan	221	smallholder farmers	54

The Keyword Plus defines the general terms, while the Author's Keywords define the specific observations of the search (Zhang et al., 2015). **Figure 4** shows the map of research knowledge constructed from the terms of the Keyword Plus. The term "pesticides", which dominates a network, is linked to terms relating to the pesticide families and targets e.g. "herbicides, organochlorine pesticides"; the study regions e.g. "South Africa, Benin, Egypt"; pest management e.g. "integrated pest management"; human exposure pathways e.g. "toxicity, bioaccumulation" and exposed matrices e.g. "soil, fish, water, sediment".

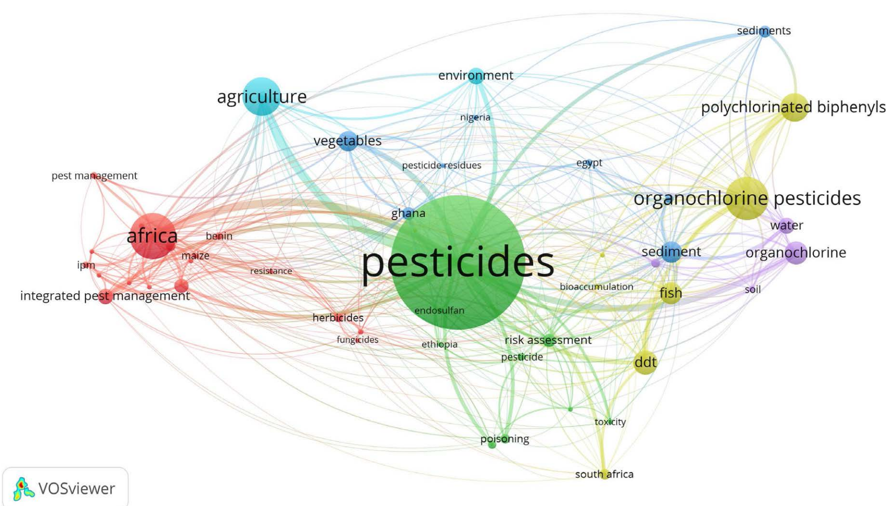


Figure 4. Co-Occurrence network of the fifty terms on agricultural pesticides research. The size of the nodes represents the frequency of occurrence in the papers. The thickness of the link between the nodes indicates the degree of relationships.

3.3. Countries' Performance

The distribution of papers by country could reflect the place occupied in scientific research (Zheng et al., 2017) but also the dynamics of methodological approaches (Patience et al., 2019). The scientists producing papers on agricultural pesticide use originate from 68 countries. South Africa is the most important country in terms of Total Publication Number (TPN = 392).

The majority of papers are produced by authors affiliated with South African research institutions, with Single Country Publications (SCP = 286 papers).

Additionally, South Africa has developed a strong research cooperation network, with a relatively high value for the Multiple Country Publications index (MCP = 106 papers). The United States (USA) and Nigeria rank second and third for TPN with 127 and 114 papers, respectively. For the African continent, 37 countries participated in the writing of papers. The most active countries in the Sub-Saharan region were Nigeria, Ghana and Kenya, with respective TPN of 114, 93 and 88 papers (**Table 3**).

Table 3. Top 15 Most productive countries on the publication and citation papers.

Rank	Country	TPN (%)	SCP	MCP	MCP/TPN	Country	TGCS	TGCS/TPN
1	South Africa	392 (23.1)	286	106	0.3	South Africa	7228	18.4
2	USA	127 (7.5)	45	82	0.6	USA	3823	30.1
3	Nigeria	114 (6.7)	84	30	0.3	Ghana	2468	26.5
4	Ghana	93 (5.4)	56	37	0.4	United Kingdom	2356	31.8
5	Kenya	88 (5.2)	41	47	0.5	Netherland	1957	45.5
6	United Kingdom	74 (4.3)	25	49	0.6	Kenya	1916	21.8
7	Egypt	67 (3.9)	54	13	0.2	Germany	1683	31.8
8	Germany	53 (3.1)	9	44	0.8	Egypt	1640	24.5
9	Tanzania	51 (3)	25	26	0.5	France	1446	29.5
10	France	49 (2.8)	14	35	0.7	Nigeria	1230	10.8
11	Benin	45 (2.6)	20	25	0.5	Tanzania	1216	23.8
12	Netherlands	43 (2.5)	10	33	0.7	Zimbabwe	1209	33.6
13	Uganda	38 (2.2)	7	31	0.8	Benin	969	21.5
14	Zimbabwe	36 (2.1)	20	16	0.4	Ethiopia	904	27.4
15	Ethiopia	33 (1.9)	12	21	0.6	Belgium	712	22.2

TPN: Total Publication Number; %: Percentage of present collection; SCP: Single Country Publications; MCP: Multiple Country Publications; TGCS: Total Global Citations Score, which is the number of citations by the paper in Scopus™ database.

In West Africa, Ghana, Nigeria and Benin exhibit a high MCP respectively. Based on the TGCS, South Africa, the USA and Ghana rank in this order. Interdisciplinary research is currently strongly supported in science policy programs. It has also become a norm in research collaboration (Lee & Bozeman, 2005). The funding institutions recommend collaboration with applicants by including it in the eligibility requirements (Kang & Park, 2012).

The international cooperation between the most productive countries is evaluated by an analysis of co-occurrences (**Figure 5**). South Africa, the United Kingdom (UK) and the USA have the strongest cooperation with other countries, with over 50 collaborations for each. For the first ranked African country in terms of TPN, South Africa, it is the South Africa-Germany collaboration research that ranks the first in terms of research cooperation with 28 papers, followed by South Africa-Netherlands (24 papers) and South Africa-Nigeria (23 papers). The countries of South Africa, the USA and the United Kingdom were also the strongest in developing collaborative research networks, with no less than fifty collaborative links with other countries.

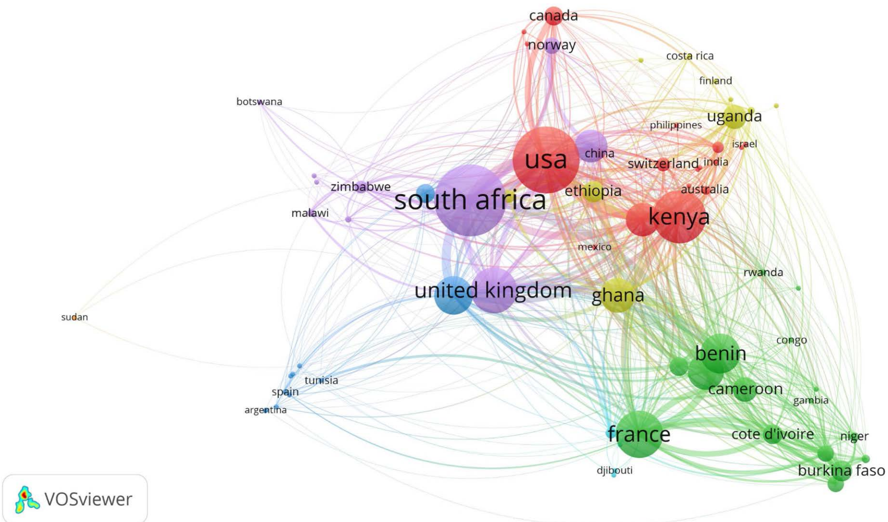


Figure 5. Cooperation network between countries. The size of the node represents the degree of openness of a country to research; the thickness of the lines connecting the nodes represents the degree of cooperation between two countries.

South Africa is the most active in south-south cooperation. Yet, in general, there is little research cooperation between African countries in this research domain. As a result, knowledge sharing is very limited.

3.4. Performance Institutions and Journals

From the 1863 papers, 941 (31%) papers are classified in the "*Agricultural and Biological Sciences*" domain, followed by the "*Environmental Science*" domain with 874 (29%) papers and the "*Human and ecological health*" domain with 696 (23%) papers. The research in the domain field of agricultural pesticide use in Africa has been directed towards the domains of human health, environmental risks and crop protection. The "*Social Sciences*" domain is poorly documented 134 (4%) (Figure 6). The main social problems related to poor knowledge of types and doses, problems of pesticide storage, scarcity of individual protective equipment, poor knowledge of health and environmental risks and ignorance of alternative methods (Stadlinger et al., 2011). The limited literature related to "pesticide risks" is of direct concern for the environment and farming community (Sibanda et al., 2000). The low level of capacity building of farmers and limited capacity may contribute to the inappropriate use of these toxic products.

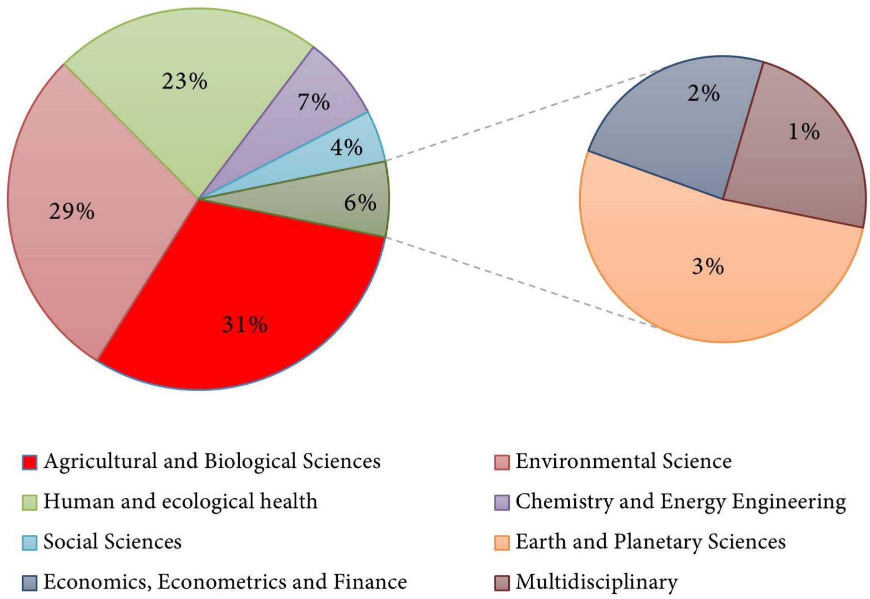


Figure 6. Documents by subject area on agricultural pesticides research in Africa (1990-2021) indexed in the Scopus™ database.

In **Table 4**, we show the top 10 research institutions and the most relevant journals ranked by the number of papers produced. The 1863 papers are published in 636 journals. The journal of *Chemosphere* publishes the most papers in this domain (TPN = 80), followed by *Crop Protection* (TPN = 72) and *Science of the Total Environment* (TPN = 58). The journal *Chemosphere* is first in terms of citation (TGCS = 2759), followed by *Crop Protection* (TGCS = 1964) and *Science of the Total Environment* (TGCS = 1671). The journals specializing in different research domains were solicited for publication papers. This is explained by the fact that researchers tend to publish in several journals during their careers. Additionally, the different specific research topics are closely related.

Table 4. Top 10 most relevant institutions and journals on agricultural pesticide research from 1990 to 2021.

Institution (Country)	TPN (%)	Journals	TPN	Hi	TGCS (R)	PY_start
University of Cape Town (South Africa)	115 (10.2)	Chemosphere	80	32	2759 (1)	1992
University of Ghana (Ghana)	81 (8.4)	Crop Protection	72	25	1964 (2)	1992
Wageningen University (Netherland)	54 (6.7)	Science Of The Total Environment	58	28	1671 (3)	1996
University of Stellenbosch (South Africa)	53 (5.5)	Bulletin Of Environmental Contamination And Toxicology (BECT)	34	18	649 (6)	1991
University of Pretoria (South Africa)	52 (5.2)	Environmental Science And Pollution Research (ESOR)	34	14	566 (7)	2012

Continued

North-West University (South Africa)	51 (3.3)	Environmental Monitoring And Assessment (EMA)	28	12	466 (9)	2004
Makerere University (Uganda)	49 (3.2)	International Journal Of Pest Management (IJPM)	27	12	477 (8)	1993
Kwame Nkrumah University (Zambia)	47 (2.9)	Water SA	25	13	422 (10)	1994
International Institute of Tropical Agriculture (Nigeria)	46 (2.7)	South Africa Journal of Plant and Soil	20	13	680 (5)	1992
University of Kwazulu-Natal (South Africa)	44 (2.5)	South Africa Journal of Science	19	13	788 (4)	1994

TPN: Total Publication Number; %: Percentage of present collection; Hi: high citations index; TGCS: Total Global Citations Score, which is the number of citations by the paper in Scopus, R: Rang, PY_Start: Year of first publication.

Five of these institutions are located in South Africa. The *University of Cape Town* ranks first with 115 papers produced, followed by the *University of Ghana* with 81 papers and the *Wageningen University* with 54 papers.

3.5. Most Cited Papers on Agricultural Pesticides Research in Africa

Although citation number presents drawbacks in evaluating an author's impact (Mo et al., 2018), it allows us to evaluate the particular interest of a research domain. In **Table 5**, we present the fifteen most cited papers published in the three top journals in terms of publication and citation. The majority of the most cited papers were published before 2013. That may be attributed to the cumulative citation effect over time. Recent papers published require more time for reading (Mo et al., 2018). The papers cited relate to agricultural practices, the persistence and bioaccumulation of pesticide residues, the perception of cost, the human health risks and the mitigation of the transfer and dispersion of pollutants in the environment.

Table 5. The fifteen most cited papers published in the three top journals on agricultural pesticide research in Africa from 1990 to 2021.

Rank	Papers	Title	Journals	TGCS	TGCS/Year
1	Ngowi et al. 2007	Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost, and health effects	Crop Protection	216	13.5
2	Williamson et al. 2008	Trends in pesticide use and drivers for safer pest management in four African countries	Crop Protection	184	12.3
3	Moore et al. 2002	Mitigation of chlorpyrifos runoff using constructed wetlands	Chemosphere	165	7.8

Continued

4	Darko et al. 2008	Persistent organochlorine pesticide residues in fish, sediments and water from Lake Bosomtwi, Ghana	Chemosphere	129	8.6
5	Matthews et al. 2003	A survey of pesticide application in Cameroon	Crop Protection	106	5.3
6	Barakat et al. 2013	Persistent organochlorine pesticide and PCB residues in surface sediments of Lake Qarun, a protected area of Egypt	Chemosphere	102	10.2
7	Matthews, 2008	Attitudes and behaviors regarding use of crop protection products-A survey of more than 8500 smallholders in 26 countries	Crop Protection	95	6.3
8	Baudron et al. 2019	Understanding the factors influencing fall armyworm (Spodoptera frugiperda J.E. Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe	Crop Protection	89	22.2
9	Schulz, 2001	Comparison of spray drift- and runoff-related input of azinphos-methyl and endosulfan from fruit orchards into the Lourens River, South Africa	Chemosphere	87	3.9
10	Hassine et al. 2012	Determination of chlorinated pesticides, polychlorinated biphenyls, and polybrominated diphenyl ethers in human milk from Bizerte (Tunisia) in 2010	Chemosphere	83	7.5
11	Akoto et al. 2013	Health risk assessment of pesticides residue in maize and cowpea from Ejura, Ghana	Chemosphere	82	8.2
12	Gerber et al. 2016	Bioaccumulation and human health risk assessment of DDT and other organochlorine pesticides in an apex aquatic predator from a premier conservation area	Science of the Total Environment	76	10.8
13	Sibanda et al. 2000	Pest management challenges for smallholder vegetable farmers in Zimbabwe	Crop Protection	75	3,2
14	Obopile et al. 2008	Farmers' knowledge, perceptions, and management of vegetable pests and diseases in Botswana	Crop Protection	73	4.8
15	Taiwo, 2019	A review of environmental and health effects of organochlorine pesticide residues in Africa	Chemosphere	71	17.7

Figure 5. Cooperation network between countries. The size of the node represents the degree of openness of a country to research; the thickness of the lines connecting the nodes represents the degree of cooperation between two countries.

The total number of citations for the papers ranged from 71 to 216. The paper titled "Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects" published in the Crop Protection Journal, was the most cited (TGCS = 216) (Ngowi et al., 2007). This study conducted an agricultural survey of smallholder farmers in northern Tanzania to investigate the relationship between agricultural practices and human health risks related to pesticide use. The significance of the results may be the reason for the high number of citations. Two recently published papers have an interesting citation score to highlight. The reference paper (Baudron et al., 2019), entitled "Understanding the factors influencing fall armyworm (Spodoptera frugiperda J.E. Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe published in the Crop Protection journal, presents a citation score (TGCS = 89) with an average of 22.2 citations per year. In this paper, the factors of maize degradation by armyworms and the quantification of impacts on yield in the eastern region of Zimbabwe were discussed. The reference paper (Taiwo, 2019), entitled "A review of environmental and health effects of organochlorine pesticide residues in Africa" published in the Chemosphere journal, presents a citation score (TGCS = 71) with an average of 17.7 citations per year.

This paper focuses on the literature review of human health and ecological risks associated with organochlorine pesticide residues presented in water and sediments in Africa. The aim of this study was also to evaluate the carcinogenic and non-carcinogenic risks to humans from the consumption of fish contaminated with organochlorine pesticide residues. The alarming results on human health risks associated with exposure to organochlorine insecticides may explain the increase in citations.

3.6. Most Frequent Pesticides Residues Researched

The most studied pesticides were determined by counting their occurrence in keywords and abstracts of the literature database. The pesticides counted in more than five publications were reported in **Figure 7**. The pesticides were then classified according to their biological activity. The most researched pesticides have a biological activity of an insecticide and herbicide nature. A large number of publications have focused on the insecticide DDT (dichlorodiphenyltrichloroethane) (TPN = 150), followed by Endosulfan (TPN = 73), Lindane (TPN = 66) and Chlorpyrifos (TPN = 61). The European Union (EU) does not approve most of the pesticides currently used in Africa (Lewis et al. 2016) (See list in the appendix supplementary data). These results suggest a significant use of organochlorine insecticides in the agricultural sector in Africa despite the Europe and Sahel region ban because of the endocrine disruption and ecosystem effects of these pollutants (Olisah et al., 2019a).

3.7. Research Themes for Agricultural Pesticides

Most papers focused on crop protection (TPN = 472), particularly the occurrence of persistent pesticide residues on crops, e.g. (Ahouangninou et al., 2011), the improvement of crop yields, e.g. (Mashele and Auerbach, 2016), the emergence of new crop varieties, e.g., (Singh & Ajeigbe, 2007), the control of weeds and crop pests, e.g., (Fourie et al., 2015) and the importance of crop rotation, e.g., (Hanyurwimfura et al., 2018; Mhlanga et al., 2016). In addition, the research focused on pesticides in the food consumption chain, e.g. (Diop et al., 2016) and

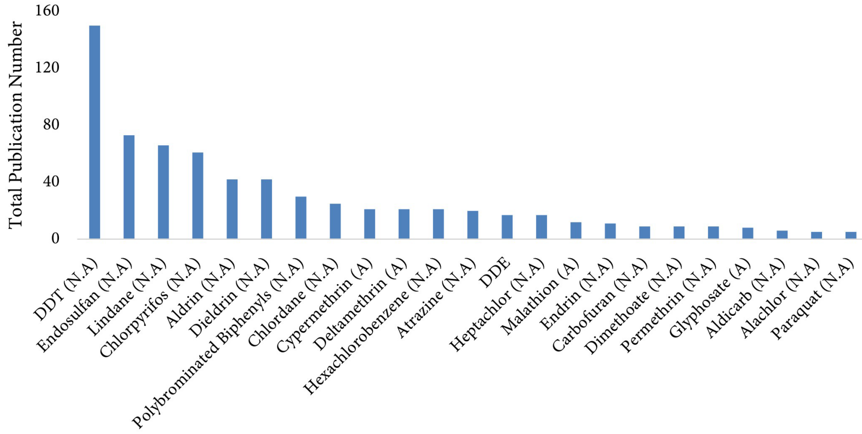
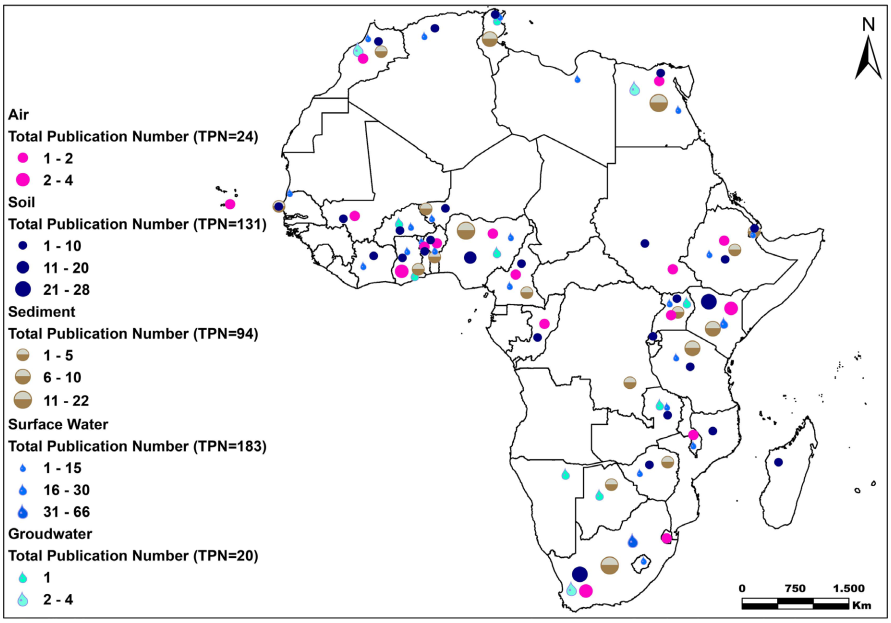
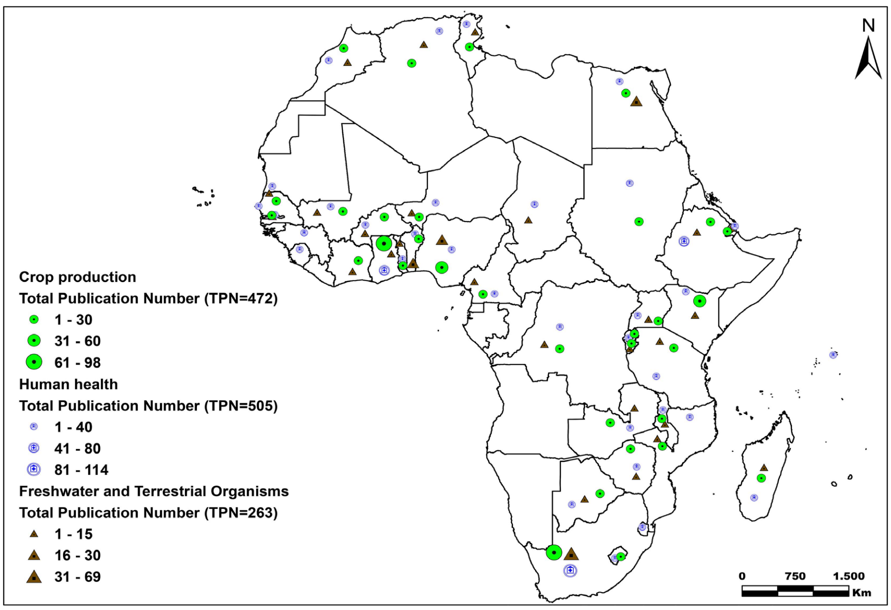


Figure 7. Most frequent pesticides studied in Africa (1990-2021) reported in the papers. (N.A): pesticide not approved for agricultural use by the EU; (A) pesticide approved for agricultural use by the EU.

the contribution of climate change to the evolution of pesticide use, e.g. (Gatto et al., 2016). For water resources (surface water TPN = 183 and groundwater TPN = 20), the studies focused on the pollution of water consumption, e.g. (Agyapong et al., 2013), the pollution of watersheds, e.g. (Kishimba et al., 2004) and the preservation of surface water quality, e.g. (Shabalala et al., 2013). The techniques for extracting residues in water, e.g. (Jacklin et al., 2019) and the water solubility of pesticides have also been studied, e.g. (Dalvie et al., 2003). For soils (TPN = 131) and sediments (TPN = 94), the authors focus on soil contamination processes, e.g. (Kolani et al. 2017), soil degradation, e.g. (Vischetti & Esposito, 1999) and the persistence of pesticide residues in soil, subsoil and sediments, e.g. (Wolmarans & Swart, 2014). The following problems were reported: the drainage processes of pesticides, e.g. (Manirakiza et al., 2003), soil quality conservation, e.g. (Lalani et al., 2016), the leaching of pesticide residues to water sources, e.g. (Baimey et al., 2015) and the techniques for the extraction of pesticide residues from the soil e.g. (Westbom et al., 2008). Little scientific productivity is observed on the effects of agricultural pesticides on groundwater (TPN = 20) and the atmosphere (TPN = 24). In these articles, the methods of analysis of residues in the air, e.g. (Naudé & Rohwer, 2012), the content of pesticides using passive samplers, e.g. (Klánová et al., 2009) and air pollution by pesticides, e.g. (Isogai et al., 2018) have been documented. For human health risks (TPN = 505), the research has been directed toward the poisoning of farmers and children e.g. (Swartz et al., 2018), the risks related to chronic diseases, e.g. (Buah-Kwofie et al., 2019), dietary exposure, e.g. (Ndlovu et al., 2014), the exposure of pregnant women and complications of pregnancy, e.g. (Naidoo et al., 2011) and the exposure of breastfeeding women and infants, e.g. (Ennaceur et al., 2008). Additionally, the carcinogenic risks related to the handling of pesticides and consumption of contaminated food have been reported, e.g. (Sosan et al., 2020). The research has also focused on the impacts of persistent residues on freshwater organisms (TPN = 283). The research has been directed toward the pollution of aquatic ecosystems by discharges of chemical contaminants that expose algae, e.g. (Carrasco et al., 2013), mollusks, e.g. (Bodin et al., 2011), bacteria, e.g. (Olanya et al., 2012) and fish, e.g. (Deribe et al., 2011). The vulnerability of non-target organisms and human consumption is highlighted e.g. (Yohannes et al., 2017) (**Figure 8**).



(a)



(b)

Figure 8. Papers by case study country based on research themes.

4. Discussion

The bibliometric analysis can be used to assess global, regional or local research patterns in a specific domain (Aria & Cuccurullo, 2017). The number of scientific publications on pesticides has increased significantly since 2000. The increase is due to growing awareness, sustainable agriculture for food security (Agbohessi et al., 2015) and the emergence of research domains and scientists (Cabral et al., 2018). The number of publications provides indications about the productivity (Sun et al., 2018). Agricultural practices, stakeholder perceptions, costs and the effects of agricultural pesticides on human health and ecosystems could boost research and publication (Ngowi et al., 2007). This agrees with our case study, which shows an increasing number of publications, from 8 in 1990 to 154 in 2021. A change in the number of publications could indicate the scientific community's major interest in a particular domain.

The keywords "pesticides", "humans" and "South Africa" were the most cited. This has to do with the large quantities, the plethoric numbers of pesticides frequently used in agriculture in Africa (Anaduaka et al., 2023), human health risk assessment (Pan et al., 2016) and because the majority of case studies were produced in South Africa (Smith et al., 2021). The Scopus database (**Table 1**) shows 1863 papers published by 636 journals. A total of 5581 authors contributed documents from 1990 to 2021, with an average of 0.3 papers per author. The collaboration index was 3.2, showing strong co-author participation (Elango & Rajendran, 2012; Siamaki et al., 2014). Smith et al., (2021) reported a slightly higher collaboration index in their study of biopesticides (3.59).

This may be explained by the interest in biopesticides as alternatives to agricultural pesticides. Among the 5581 authors, 5424 were authors of multi-authored papers and 157 were authors of single-authored papers.

Collaboration networks highlight relationships between countries, institutions and researchers (Lee & Bozeman, 2005). Many bibliometric studies have classified the United States as the leader in terms of collaboration (Supangat et al., 2025), contrary to our case study, which reveals the dominance of South Africa. We attribute this success to the government's support for research initiatives and collaboration. The scientific research is supported by collaborative efforts for knowledge synergy. The high citation of publications depends on international or local collaboration (Siamaki et al., 2014). (Ngowi et al., 2007) was the most cited paper (TGCS = 216). The most active countries in terms of publications and citations on agricultural pesticides were South Africa and the USA (**Table 3**). Except for South Africa, nine (9) African countries were in the top 15 in terms of agricultural pesticide production. They were Nigeria, Ghana, Kenya, Egypt, Tanzania, Benin, Uganda, Zimbabwe and Ethiopia, with 114, 93, 88, 67, 51, 45, 38, 36 and 33 papers, respectively. Africa is the continent with the world's lowest pesticide consumption (−5%), however scientific studies have reported the use of agrochemicals with active substances that are dangerous to human life (Ennaceur et al., 2008) and their presence in different ecological matrices at concentrations above the critical limits (Ogola et al., 2024).

Africa is a favored destination for prohibited pesticides produced in Europe. In 2018, five African countries received nearly 7500 tons of pesticides containing 25 toxic active substances. 1700 tons were exported to South Africa (Schlegel, 2020). Agricultural pesticides in Africa are frequently used by producers unable to read labels, with little training and no individual safety equipment (Ngowi et al., 2007; Schlegel, 2020). This reflects poor regulation and monitoring of pesticides by policymakers. The exposure of groundwater and air to pesticide pollution of agricultural origin is poorly documented, with less than 25 publications (**Figure 8**). In Africa, groundwater supply represents the main source of drinking water and air quality is influenced by growing agricultural and industrial activities. To minimize agricultural pesticide pollution risks, research into groundwater and air exposure should be encouraged. The organochlorine insecticides detected in the matrices investigated were DDT, endosulfan and lindane. These results are in line with those of (Olisah et al., 2019b), who reported the presence of organochlorine pollutants α-HCH, β-HCH, DDT and endosulfan. A greater priority should be given to research related to these persistent organic pollutants (POPs).

The methodological approach used in this analysis has certain limits. The first limit is that Scopus™ is a peer-reviewed academic database; therefore, important information from the grey literature might be excluded. The second concerns language selection. Only publications written in English and French were extracted from Scopus™ so that documents produced in other languages were excluded, although they reflect scientific research on agricultural pesticides in Africa. The third limit lies in the selection of the search terms. It is possible that some publications were omitted from our search. Further, it was considered to select only articles, books, book chapters, conference papers and journals. The types of documents related to procedure articles, letters, correction additions and editorials were excluded from the search even though they are related to agricultural pesticide research in Africa. Another limit is the absence of a critical analysis of the documents of sections relating to methodology, results and discussions. For example, articles and researchers were evaluated against production and citation notes that still do not reflect the content of an article. Finally, the analysis considers only the scientific corpus indexed in Scopus™. Papers dealing with agricultural pesticide research in Africa published exclusively in other databases such as Web of Sciences, Google Scholar and others were not considered. Thus, papers published exclusively in these databases and sector reports published by governments and non-governmental organizations were not analyzed even though they reflect the literature on agricultural pesticides used in Africa (Leydesdorff et al., 2015). In addition, a paper's Total Citation Score (TGCS) is not a robust indicator of search quality. In bibliometric analysis, the methods and results of the publications are not critiqued (Smith et al., 2021). In addition, information reported in the study is susceptible to evolution according to the cumulative number of publications (**Figure 3(a)**), which shows a growth of research on agricultural pesticides in Africa over time.

5. Conclusion

To our knowledge, no systematic compilation of studies on the use and environmental behavior of agricultural pesticides at the scale of the African continent has been carried out. The absence of such a synthesis of scientific research weakens the identification of priority axes of research in support of the management of pesticides in Africa. In this study, descriptive statistics were used to measure overall trends in agricultural pesticide research in Africa between 1990 and 2021. These results of research should enable monitoring programs for these pollutants, especially in regions where studies are limited. Following this statistical analysis of bibliometric indicators, a literature review is necessary to provide a more complete analysis of the research questions, methodologies and results highlighted in the articles, particularly the study areas, the sample sizes, the types of pesticide residues and the concentrations recorded.

While these limits were noted, this literature analysis on agricultural pesticide use and impacts related to socioeconomics, human health and the environment in Africa provides a significant overview of the state of knowledge for the survey period. These results complement the sectorial studies already carried out and will provide guidelines for future studies.

Acknowledgements & Funding

This research was supported by Wallonie Bruxelles Internationale (WBI), Fond de la Recherche Scientifique (FRS-FNRS), UCAD and the UCLouvain Conseil de l'Action Internationale (CAI/UCLouvain).

Authors Contributions

All authors contributed to the design, implementation and writing of the study. Alousseynou Bah was responsible for data collection and analysis. Alousseynou Bah drafted the first version of the manuscript, and all authors commented on versions of the manuscript. All authors have read and approved the final manuscript.

Data Availability Statement

Physical-chemical, health and ecological risks summary.

Conflicts of Interest

The authors have no financial or non-financial relevant interests to disclose.

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