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Trends of unmanned aerial vehicles in smart farming: a bibliometric analysis

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ABSTRACT

This paper presents a review of the trends of unmanned aerial vehicles (UAV) in agriculture using a bibliometric analysis. This bibliometric analysis shows that 1676 articles were accessed from the Elsevier Scopus database between 2013 and 2023. Our findings indicate research related to UAVs in agriculture has surged over the years, but the adoption and acceptance of smart farming technology in sub-Saharan Africa remains inert. This study employed VosViewer in data analysis and bibliometrics. Our findings show that China leads all countries and followed by the United States on UAV publications in smart farming research foci. Our findings indicate that UAVs are impactful in improving crop growth, crop health monitoring, and may be beneficial to small-holder farmers with increased yields. We recommend that sub-Saharan Africa nations accelerate collaboration with China and United States in advancing climate smart agriculture practices to mitigate food insecurity risks.

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1. INTRODUCTION

Today the world population is 8 billion and is estimated to rise rapidly in future [1]. This increase in population is paralleled by the growing concerns about water scarcity, food insecurity [2], and climate change [3] challenges worldwide. In recent years, smart farming technologies (SFT) identified as revolutionary in agriculture denote the utilization of drones [4], [5], the internet of things (IoT) [6], [7], smart sensors, big data, cloud computing, machine learning [8], [9] and adaptive analytics that impact real-time decision-making in farming [10], [11]. However, the adoption of this technology, particularly among smallholder farmers in Africa, is inert due to prominent factors such as costs [12], awareness [13], readiness [14], and lack of adequate skills ranking significantly high [15]–[17].

Sub-Saharan Africa has the fastest population growth rate with rampant poverty problems [1], [18]. Recent studies reveal that the demand for quality food is increasing worldwide [1], [19], [20]. Smallholder farmers in Africa lack adequate technology that impacts the food supply chain [15], [19]. In [20] asserts that the limited use and slow pace of SFT adoption among small-scale farmers in Africa may exacerbate inequalities. The recent report by the Food and Allied Organization (FAO) attributes rising inflation as an impediment to ending poverty and achieving UN sustainable goals of zero hunger by 2030 [1]. Despite the challenges of reduced arable land [21]–[24], problems due to rising temperature [3], El-Nino drought [22], [23], [24] that affect crops and limited income, small-scale farmers have shown some resilience in the global South [25].

Several studies have stated that the acceptance and adoption of SFT among African smallholder farmers is long overdue [15], [26], [27]. Crop damage brought by insects, extreme weather, pest infestations, diseases, and weeds are often a prevalent issue faced by smallholder farmers that leads to crop losses [11], [15], [27]–[29]. The crop produced by small-scale farmers is characterized by low quality [15], [20], [28], [29]. SFT provides a paradigm shift in farming and agriculture practices with forecasts to increase crop production efficiently and improve food supply [7], [13], [30]–[32]. Unmanned aerial vehicles (UAV) or drones refer to highly sophisticated powered robotic device aircraft without a human pilot to fly but employ aerodynamic forces to lift and can carry lethal or nonlethal goods [10], [17], [30], [33], [34]. Recently UAV innovative technology has emerged impactful in crop health monitoring [5], [7], [34]. Furthermore, [35] showed that UAV is effective in crop spraying with quality maize yields. In Vlakfontein farm, South Africa, De Villiers *et al.* demonstrated drone-based remote sensing to be compelling in weed detection, leading to insights into maize crop growth [29]. Maize is therefore an essential staple food particularly in Sub-Saharan Africa [3], [15], [29], [36]. An inadequate supply of maize may further threaten and put Africa's fastest growing population in absolute paralysis [3].

This study will employ bibliometric analysis to examine the adoption of UAVs by smallholder farmers. Previous studies conducting bibliometric analysis on the UAV and agriculture [35], [37], lacked in-depth investigation on small-scale farmers' impact. There is a significant knowledge gap among smallholder farmers on UAVs usage in agriculture. Only recently [28] contributed a bibliometric analysis study with a focus on relations and constraints on UAV usage among small-scale farmers. This study will add to paucity of literature on bibliometric analysis studies on UAV utilization among emerging or smallholder farmers. The significant role that small-holder farmers play is instrumental in the reduction of poverty, particularly in the context of Sub-Saharan Africa [38].

2. OVERVIEW OF BIBLIOMETRIC ANALYSIS

Bibliometric analysis is a multidisciplinary research method that combines mathematics with statistics and bibliography to quantitatively analyze large volumes of data in a rigorous scientific approach [39]. Bibliometric analysis provides researchers with two key main techniques performance analysis [39], science mapping [40] and an enhancement network analysis employed during the duration of the research [41]. Thus, bibliometric analysis techniques allow the researcher to measure the impact of articles, publications, and journals in a quantitative approach. Bibliometric analysis allows researchers to broaden understanding of a particular research field and to grasp the dynamics of knowledge domains from quantitative lens constructs [40]. Bibliometric analysis is an emerging method that reveals research knowledge gaps, trends, and hot topics, allowing researchers to derive novel ideas or insights [39]. Apart from providing rigorous methods for future research directions, bibliometric analysis enables and empowers scholars in respective field by measuring research outputs, novel contributions, and collaboration across institutions and departments [39], [41]. Thus, bibliometric analysis is one of the important research methods aimed at social advancement and human development.

This study purpose is to review the research constructed among smallholder farmers use of UAVs in agriculture practices employing bibliometric analysis. The review focusses on the bounded research questions (RQs) below.

RQ1: What are the publication dynamics on UAV use in agriculture-related journals, countries, and institutions?

RQ2: Which authors and documents on UAV usage in agriculture have had an impact from 2013 to 2023?

RQ3: What is the growth in yearly scientific literature publications on UAVs in agriculture context?

RQ4: What is the current trend of publications on the use of UAVs in small-scale farming?

RQ5: What are the most prominent keywords linked to the UAV and agriculture research topic?

This paper is structured with the introduction in section 1, then followed by a synthesis of the literature review on UAVs smart farming technology in section 2. The study methodology is presented and delineated in section 3. The main findings and results of the bibliometric analysis are discussed and presented in section 4. The study discussions, limitations, and future research are presented in section 5. The study conclusion is tabled in section 6 and the recommendations with references presented last.

3. LITERATURE REVIEW

In [38] conducted a review and bibliometric analysis on UAVs utilization in agriculture, focusing first on benefits and then on citation and keyword analysis. This study indicated that the most frequently used keyword was "unmanned aerial vehicles" with 1628 occurrences between 2011-2021 followed by "remote sensing" in the same period with 489 [37]. The study deduced that the most influential author ranked number one was Lopez-Grandas F., with 1963 citations and de Castro A.I., was number 10 with 1036 citations [37].

This study employed the Scopus [42] database for data collection due to in-depth, rigorous, reliable, and predictable results on agricultural UAVs [37]. The data analysis method focused on the keyword analysis that excludes off-topic publications [37]. Furthermore, data analysis fused citation analysis by drawing links between authors and documents to show the related constructs, patterns, and structures. The search string criteria included ("drone" OR "unmanned aerial vehicle") AND ("agriculture" OR "farmer") in September 2021 [37].

Recently [35] employed a bibliometric analysis on the suitability of UAVs and Artificial Intelligence in the smart farming paradigm. The study found that the most prominent or influential journal produced 1998 citations over eighty-five publications and the "Computers and Electronics in journal ranked number one [35]. The least number of journals had only 16 citations and five articles ranked 10th out of the top ten journals in the "Electronics" publication [35]. The "Sensors" and "Drones" publications ranked second and third with 19 and 17 articles, respectively [35]. This bibliometric analysis employed dual databases Scopus [35] plus Web of Science in data gathering and collection. The search string constituted ("crops" or "agriculture") AND ("drone or UAV") AND ("artificial intelligence" OR "deep learning") while limited to English-only published articles. The Web of Science database indicates that 953 studies and Scopus [35] with 984 from 2013-2022 timeline [35]. The exclusion list consisted of books, notes, editorials, and 1937 articles from two databases was retrieved, and the bibliometric analysis study only used 234 published articles [35]. The data coding and its associated analysis segmented by publication dates from 2013-2017 and 2018-2022 with a five-year gap between the two datasets showed compelling results [35]. The immediate results indicate that between 2013 and 2022, the publications on the subject of AI-enabled drones in agriculture increased with a single article in 2013 compared to 2022, showing sixty-three publications [35].

The study by [28] performed a bibliometric analysis and review among the smallholder farmers on the utilization of UAV in agriculture [28]. This study traced that literature on UAV usage in crop monitoring surfaced in 2016 in small-scale farms and has been increasing since then with a 31% growth rate [28]. The study stated that in 2018 showed significant publication results at 30.8% compared to 2020 with 36.00% in crop monitoring among smallholder farms. This research used the Elsevier Scopus [28] plus "Web of Science (WOS)" datasets to conduct bibliometric analysis on December 6, 2022 [28]. The search string criteria employed in this study constituted ("small-scale agriculture" OR "smallholder farm") AND ("UAV OR "Drone"). The study excluded notes, books, and non-English articles and only included peer-reviewed journals without year filter limits. The Scopus database showed 36 published articles and Web of Science yielded 31 journals [28]. The total results indicated that 67 journals were added to the R-Studio environment with the bibliometric-R software used [28].

In [42] conducted a bibliometric analysis of drones in precision agriculture (PA) in sustainable agriculture. This study deduced that precision viticulture (PV) is underlined by PA, its importance in Europe is due to economic benefits and the least expensive remote sensing and data collection technologies such as UAVs [42]. The study also attributes its uniqueness in addressing the PV gap as being the first of its kind. The study inferred that aerial robotic crop spraying techniques allow for less soil compaction and those fertilizers are only applied in areas showing infestation leading to cost-savings [42]. The study reiterated that drone-based imaging rarely disturbs well-watered crops, rather the images are used by farmers in the crop growth phases [42]. This study revealed that in the acceptance and adoption of drones by using global trends, the Unites States is at the forefront, followed by China, and Italy coming in at third place [42]. This study traced 80 countries around the world are engaged in UAV-PA adoption, with the USA leading with 238 papers. China trails the Unites States with 202 publications, and Italy produced no less than 120 articles [42]. Concerning prominent authors, Lopez Granados leads in UAV-PA research foci with 1525 citations. The study found that the most cited document with 371 citations was published in 2014 in the journal "Remote Sensing" by Bendig *et al.* [43] focusing on the drone "RGB imaging in crop surface models" [44]. This study found that the "Remote Sensing" journal was the most popular in the adoption of UAV-PA adoption ranked as number one with hundred and eleven documents and its h-Index was at 124. In the global trends in UAV-PV research results contrasted showed that Italy leads followed in second place by the USA and Spain at third place. The research results indicated that the most cited author on UAV-PV is thus Dr. Alessandro Matese with 777 citations [42].

4. METHODOLOGY

This study selected Scopus database in conducting bibliometric analysis due to in-depth peer-reviewed, broader publications on the topic of UAV usage in farming and agricultural activities. This methodology will quantify publication trends, authorship dynamics, and citation networks to elucidate key contributions and emergent themes within the discipline. The study collected data on a 10-year period starting in 2013 to 2023 on 11 September 2024. This study employed search string constituted *(TITLE- ABS-KEY (agriculture OR crop OR plant OR smart AND farming OR farm OR yield) AND TITLE-ABS-KEY (drone OR uav)) AND PUBYEAR > 2012 AND PUBYEAR < 2024 AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re"))* [42]. The search string results returned 1,676 documents.

The literature search criteria included English only articles and journals. The exclusion criteria included books, notes, papers, patent records, and non-English publications. The literature search on Scopus [42] focused on titles, abstracts, keywords on the studies relevant to answer the research question. This study employed RStudio Desktop version 4.1.2 with Bibliometric and BiblioShiny in the context of data analysis. Bibliometric has in-depth functionality to show collaborative network analysis. VosViewer software version 1.6.20 was used for data visualization and added in the citation analysis, co-authorship analysis to answer the research questions. The data from Bibliometric was exported to MS-Excel to construct tables, charts, and then imported to the Word Document. Citation analysis determines influential publications, authors, journals, and institutions in a specific discipline. Co-occurrence author keyword analysis used fractional counting with ten clusters available [39]. For instance, the citation analysis included 106 countries influential in UAV agriculture research. The flow chart Figure 1 presents an outline of article inclusion criteria due to mitigate against bias.

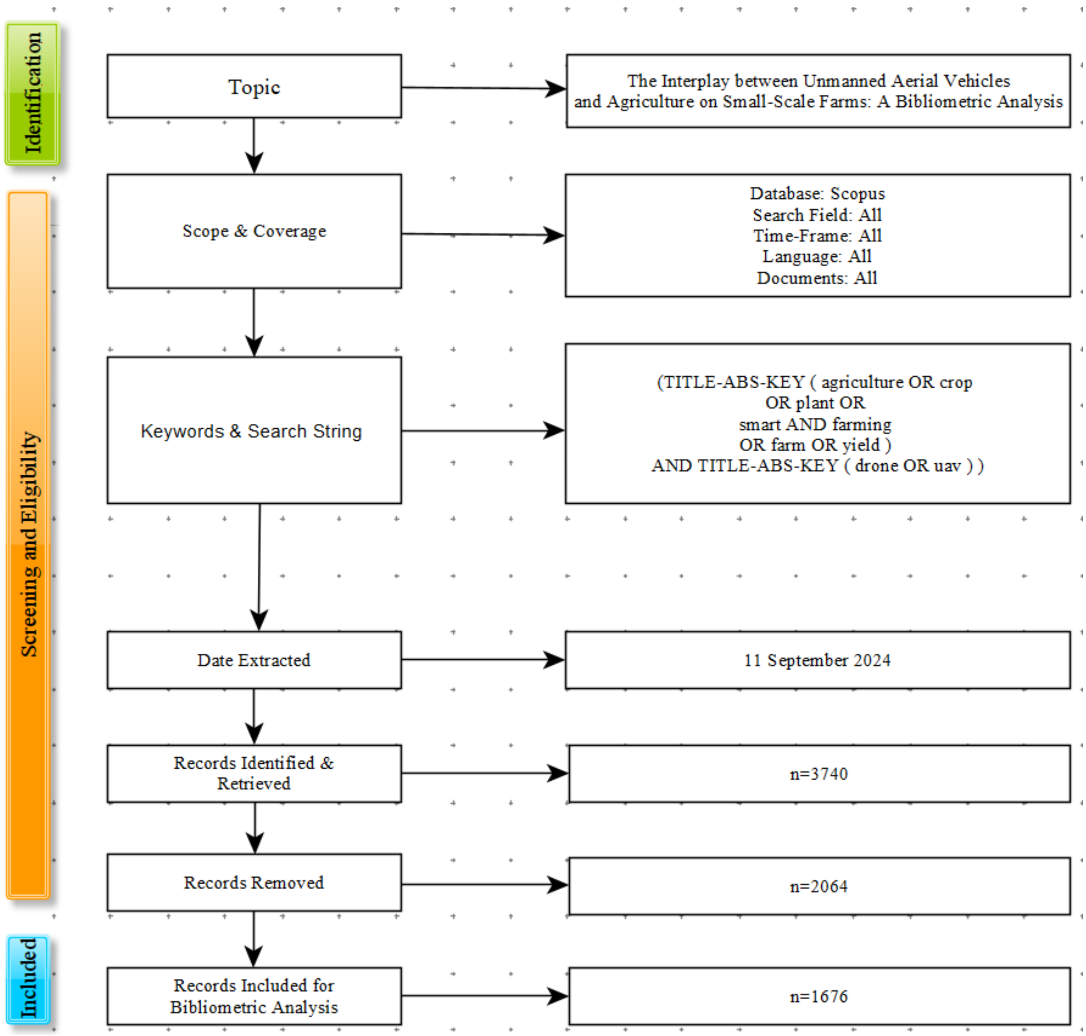

Figure 1. Flowchart smart farming UAV search strategy

5. ANALYSIS AND RESULTS

In this section, we present the results of bibliometric analysis constructed on 447 papers published in the research field of agriculture and unmanned aerial vehicles between 2013 and 2023.

5.1. Performance analysis
5.1.1. Trends in the number of publications
Table 1 represents main information on the datasets between 2013 and 2023 with 1676 documents in total, 447 journals from the Scopus database [42]. The average number of citations per document was 34.59% and annual growth rate at 51.5 per cent. The international co-authorship was 28.76%, with highest publications reaching a peak of 446 in 2023. The results show that 5,976 authors are engaged in UAV related research in agriculture within the ten-year time frame. The results indicate that UAVs in the context of agriculture are a crucial research domain that expands annually confirming literature review studies [28], [35], [37], [40]

Table 1. Information pertaining to data collection

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2013:2023
Sources (Journals and Books)	447
Documents	1676
Annual Growth Rate %	51.5
Document Average Age	3.1
Average citations per doc	34.59
References	78709
DOCUMENT CONTENTS	
Keywords Plus (ID)	6519
Author's Keywords (DE)	4091
AUTHORS	
Authors	5976
Authors of single-authored docs	33
AUTHORS COLLABORATION	
Single-authored docs	33
Co-Authors per Doc	5.77
International co-authorships %	28.76
DOCUMENT TYPES	
Article	1558
Review	118

5.1.2. Publication dynamics
A descriptive statistical analysis was employed to discover prominent trends of the number of articles and citation over the years. Figure 2 shows Y-axis annual scientific production whereas X-axis indicates over number of years. The results indicate that the topic of UAV and its association to agriculture have been growing rapidly since 2013 with only seven articles then, whereas by the end of 2023 publications were at 446 confirming significant growth. The recent surge in the number of publications on UAVs in agriculture can be attributed to food insecurity [2] problems and climate variability [3] challenges impacting agriculture, changes in research focus, and the fact that SFT [6], [30] is a profitable business.

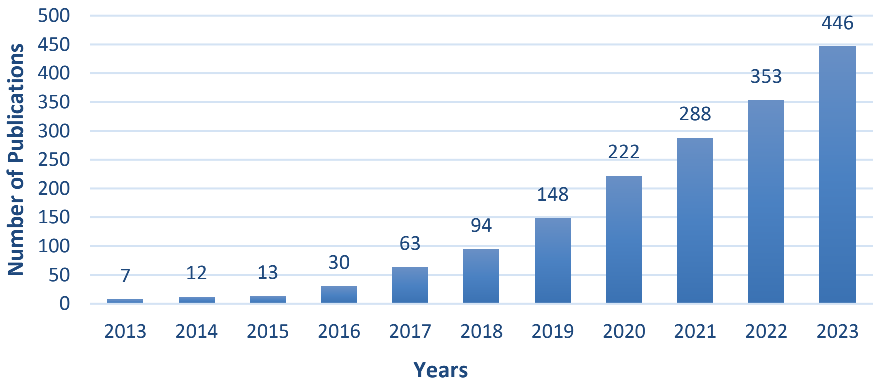

Figure 2. Annual scientific publication growth from 2013 to 2023 on unmanned aerial vehicles and agriculture

5.1.3. Top 10 journals

Table 2 represents the number of articles published in academic journals according to the agriculture drone research foci. The top ten journal articles produced 74.5% of the studies on smart farming drones or agriculture UAVs. The "Remote Sensing" journal ranked number 1 produced at least 246 articles. The multidisciplinary journals provide pertinent scholarly, academic contributions indicative of growth in the topic of smart sustainable agriculture on a global scale with UAVs featuring prominently [28], [35], [37], [42].

Table 2. Top ten cited documents

Rank	Sources	Articles
1	Remote Sensing	246
2	Computers and Electronics in Agriculture	129
3	Agronomy	76
4	Frontiers in Plant Science	74
5	Drones	45
6	Precision Agriculture	45
7	Agriculture (Switzerland)	43
8	Sensors	31
9	International Journal of Remote Sensing	29
10	IEEE Access	27

5.1.4. Top 10 most cited countries

Table 3 lists top ten most cited countries. China with 13,130 total citations leads all countries in the research foci on UAVs linked to agriculture or smart farming. China is followed by the USA with 9,080, India ranked third with 2,714 and Italy assumed fourth place with 4269 articles total citations. The results indicate a lack of citations emerging from sub-Saharan Africa. France average article citations are ranked higher at 118.40 in comparison to China far lower at 32.30. The result indicates that in 2013 German was at the forefront of UAV research in smart agriculture but ranked seventh in 2023 compared to China had little or no citations in the same year. The results highlight that German decline in citations might be due to change in research focus. China's dominance in UAVs may be attributed not only to the efficient drone manufacturing sector, but also to agriculture research conducted over the years with significant return on investments.

Table 3. Top ten most cited countries

Rank	Country	TC	Average article citations
1	China	13130	32.30
2	USA	9080	39.70
3	India	2714	30.20
4	Italy	2698	42.20
5	Spain	2561	39.40
6	Australia	2163	42.40
7	Germany	2113	29.80
8	France	1895	118.40
9	Brazil	1894	33.20
10	Greece	1432	59.70

5.1.5. Top 10 cited institutions

Table 4 represents the leading institutions or universities in research focused on agriculture employing UAVs. The results indicate that the nine top prominent universities in the UAV research domain have shifted to China. The leading institutions produced 207 articles by China Agricultural University founded in 1905. The results indicate that the USA, sub-Saharan Africa, and India were not in the top ten list of influential universities on the UAV research. Europe in the tenth position was represented by Wageningen University and Research in the Netherlands with 75 articles. The results indicate that Chinese institutions are collaborating more on a country-level influencing the both the present and future research domain on UAVs in agriculture. The results indicate that the Chinese state plays an indispensable role in the amelioration of agriculture and SFT with the help of Ministry of Agriculture prominently featured in the affiliations and empowering its farmers.

5.1.6. Top ten global cited documents

Table 5 represents top ten global cited documents on UAV suitability in agriculture. The leading paper with 631 total citations by Tsourous *et al.* investigated drones in small-scale or farms larger than 10 hectares and found UAV remote sensing impactful in crop monitoring and plant growth stages leading to predictable yields [45]. The second most cited paper in Table 5 by Candiago *et al.* with 576 citations explored UAV in the context of vegetation indices (NVDI, SAVI) and deduced multispectral imaging in vineyard and tomato crops is impactful in the fast outline of crop diseases [45]. The third most cited paper by Maes and Steppe with 555 citations, examined the suitability of drones in agriculture and found UAV sensors and imaging results in drought stress analysis influential in smart irrigation in fields with water scarcity and early detection of diseases and weeds [46]. The results of these papers indicate that leaf area index plus biomass are key indicators in crop health and UAV facilitates insights into crop nutrient status, leading to effective crop growth and predictable yields [45]–[47].

Table 4. Top 10 cited institutions

Rank	Affiliation	Articles
1	China Agricultural University	207
2	Nanjing Agricultural University	161
3	Huazhong Agricultural University	115
4	South China Agricultural University	107
5	Zhejiang University	105
6	Wuhan University	99
7	Beijing Academy of Agriculture and Forestry Sciences	91
8	Institute of Crop Sciences	86
9	Northwest Aandf University	75
10	Wageningen University and Research	69

Table 5. Top global cited documents

Paper	DOI	Total Citations	TC per Year	Normalized TC
Tsouros *et al.* [45], INFORMATION	10.3390/info10110349	631	105.17	9.78
Candiago *et al.* [47], REMOTE SENS	10.3390/rs70404026	576	57.60	3.64
Maes and Steppe [46], TRENDS PLANT SCI	10.1016/j.tplants.2018.11.007	555	92.50	8.60
Bendig *et al.* [43], REMOTE SENS	10.3390/rs61110395	555	50.45	4.55
Maimaitijiang *et al.* [48], REMOTE SENS ENVIRON	10.1016/j.rse.2019.111599	548	109.60	11.03
Yang *et al.* [49], FRONT PLANT SCI	10.3389/fpls.2017.01111	537	67.13	5.62
Sishodia *et al.* [50], REMOTE SENS	10.3390/rs12193136	521	104.20	10.49
Lezoche *et al.* [19], COMPUT IND	10.1016/j.compind.2020.103187	473	94.60	9.52
Zhou *et al.* [51], ISPRS J PHOTOGRAM REMOTE SENS	10.1016/j.isprsjprs.2017.05.003	462	57.75	4.83
Talaviya *et al.* [52], ARTIF. INTELL. AGRIC	10.1016/j.aiia.2020.04.002	458	91.60	9.22

5.1.7. Top ten most relevant authors

Table 6 shows top ten most relevant authors with Zhou J leads with thirty-eight articles ranked number one. In second place is Yang G with three papers less than Zhou J. The results indicate an equal number of articles tied at 28 between Li Y and Li Z ranked number 5 and 6, respectively. Comparable results indicate a tie of 26 articles each between Zhang J and Zhang Z occupying spots 8 and 9, respectively. The difference between the rankings for the articles tied seems to be the importance of articles fractionalized showing distinct results impacting ranking. Results in Table 6 from number one up to tenth position highlights the dominance of authors in China affiliated with research institutions/universities positively impacting UAV research in agriculture.

Table 6. Top ten most relevant authors

Rank	Authors	Articles	Articles Fractionalized
1	Zhou J	38	5.98
2	Yang G	35	4.60
3	Liu Y	34	4.07
4	Zhang Y	33	4.66
5	Li Y	28	4.37
6	Li Z	28	3.65
7	Zhu Y	27	3.23
8	Zhang J	26	3.09
9	Zhang Z	26	4.28
10	Wang J	25	4.63

5.2. Science mapping analysis
5.2.1. Co-occurrence analysis with author keywords

Co-occurrence analysis of keywords aid in understanding hot topics pertinent to research foci [41]. In Figure 3 the co-occurrence with author keywords used the fractional counting method [39], [41]. The minimum number of keywords were five with threshold results 198, links 2582, ten clusters and links strength at 1861.00. The yellow cluster shows “UAV” keyword dominates with link strength of 300.00 followed by the red cluster on “precision agriculture” with 217.00 link strength. The yellow cluster shows linkage between precision agriculture to smart farming with “IoT,” “sensors,” big data, “AI,” “cloud computing,” “hyperspectral imaging,” smart farming with 162 links. The green cluster showed remote sensing with 162 links with keywords on phenotyping, “crop water stress,” “multispectral imaging,” “NVDI,” “yields.” The orange cluster shows deep learning links 133, SVM, disease detection, “object detection,” “AI,” “smart farming.”

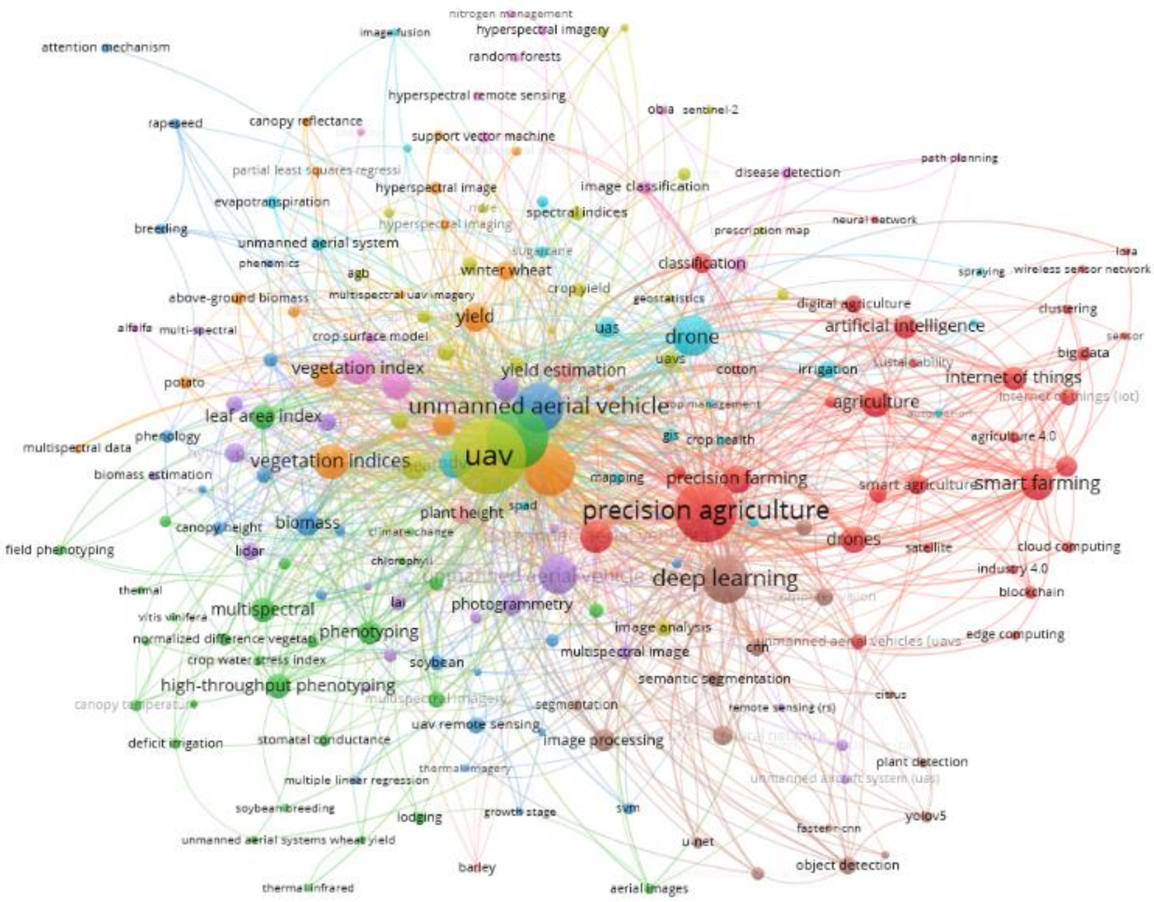

Figure 3. Co-occurrence analysis with author keywords

5.2.2. Co-authorship analysis and authors

Figure 4 shows co-authorship and author analysis with maximum number of authors per document set at 25. The counting method used fractional counting [39], [41], 5documents per author selected with 0 citations. The results indicate that 7,113 authors were selected from the dataset with 14 clusters, 314 links, and link strength at 324.50 and its threshold 143. In the red cluster ranked number 1, Yang Guijun contributed 28 documents showed 29 links with total link strength at 35.00. Authors such as Yang, Guijun show close collaboration with multiple authors in the red cluster, interestingly forging authorship relation with authors such Xiao, Yonggui in green cluster with 14 links. Ian, Yubin with 20 documents in the sky-blue cluster with 4 links collaborates closely with Han, Wenting and Niu, Axia in cyan cluster and Lootens, Peter from Belgium in light blue cluster confirming across country engagement. The results indicate absence of authors from sub-Saharan Africa on agriculture and UAV related research foci.

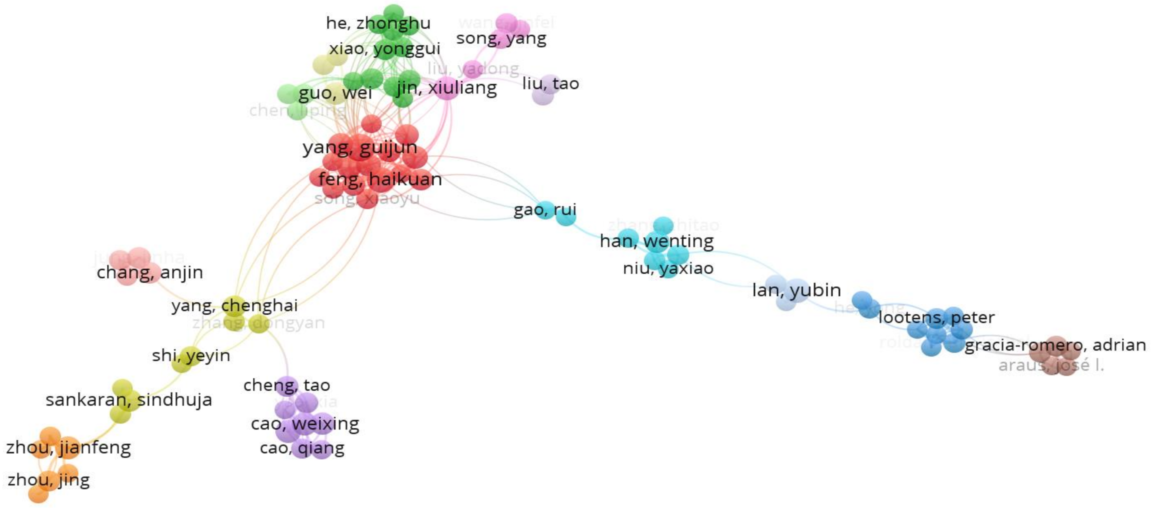

Figure 4. Co-authorship analysis and authors

5.2.3. Citation analysis with country

The citation analysis employed fractional counting [39], [41] method with maximum of 25 countries. Furthermore, the minimum number of documents was 6 with a threshold of 56. The results indicated that 106 countries were considered with total link strength of 3697. Figure 5 shows countries collaborative network analysis from 2013 to 2023. The results indicate that China the United States, India, Spain, UK, and Germany are critical in connecting countries in the collaboration network illustrated by solid lines.

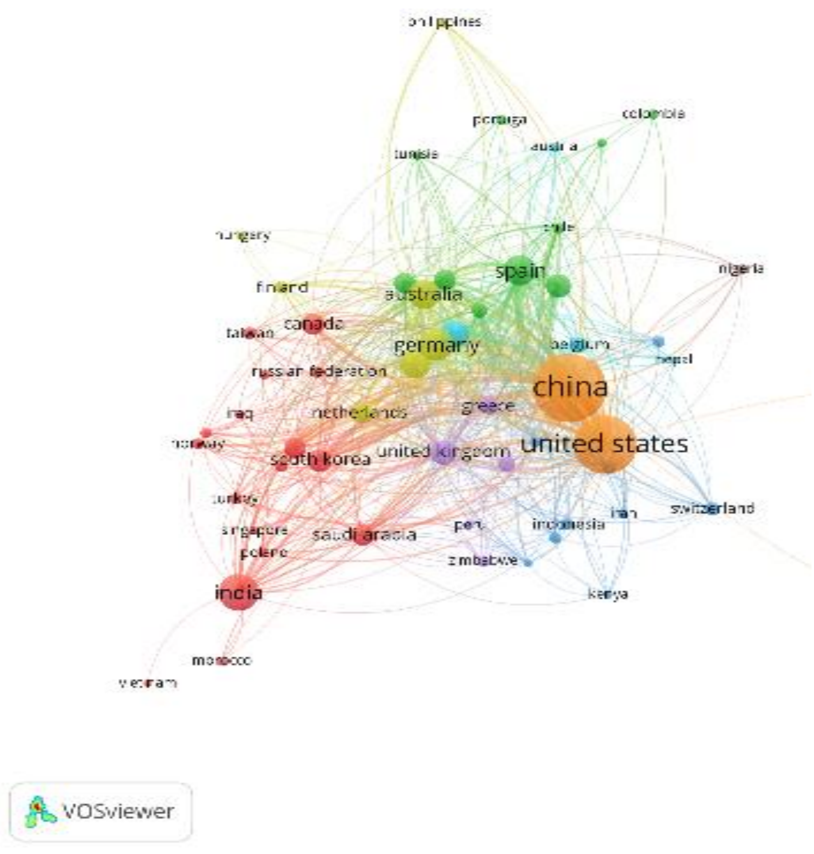

Figure 5. Country collaboration network

5.2.4. Co-citation analysis and cited authors

The minimum number of citations per author was set to 20 and 2664 threshold was met out of 109388 authors in Figure 6 the selected authors were set at 999. The results indicate that in blue cluster 3 leading author Zhu Y. had 892 citations with total link strength of 877.47. In the second place is Yang G., at 848 citations and 836.07 total link strength. The results show that Lopez Granados F in green cluster rated higher in the literature review [37], [44], here, however, the ranking is 16th place with 590 citations with total links strength at 570.85 indicating substantial decline.

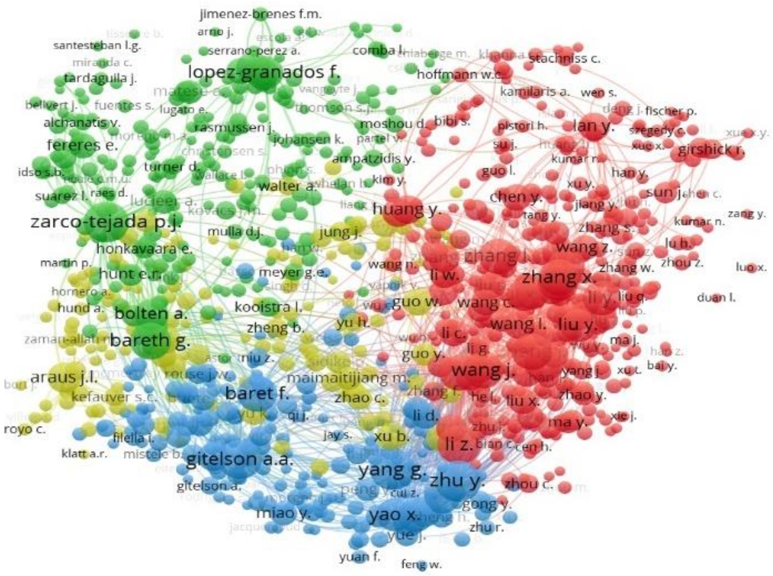

Figure 6. Co-citation analysis/cited authors network visualization

5.3. Summary of findings

The findings undertaken in this study show that the most influential authors in the research foci on UAV in the context of agriculture has shifted to China dominating the top ten list with leading author Zhou J with 38 articles. Unexpectedly, USA and Europe authors did not feature in top ten list of prominent authors. The results show lack of prominent authors emerging from sub-Saharan Africa. Similarly, if the research institutions are factored in, the results seem to suggest that China universities are at the forefront in the UAV research in relation to agriculture. The findings indicate Sub-Saharan Africa problems of slow adoption of smart farming technologies may also be weaknesses at its own research institutions/universities with limited collaboration with China and the United States. The findings reveal that UAV research in the context of agriculture has been growing substantially since 2013 and China has been unyielding at the apex.

The results highlight that large quantity of publications on UAV or drones in agriculture appear to be published in "Remote Sensing" journal ranked number one, possibly due to rigorous peer-review methods. The findings indicate that the crop health monitoring derived from drone data is proportionally related to crop growth [28], [35], [37], [44], [47], [49]. The findings show that UAV is important in SFT, particularly in weed detection and pest classification that leads to crop savings. The findings highlight that sub-Saharan rainfed crops such as maize in particular may benefit immensely from UAV hyper-multispectral imaging during all phases of crop growth stages that impacts quality yields. The findings indicate that UAV linked with IoT sensors, smart irrigation, big data [19], artificial intelligence fused with deep learning facilitates sustainable agriculture practices [28], [44], [45], [47]. The findings indicate that SFT may improve small-scale farms agricultural outputs in a predictable manner [28], [35], [43], [44], [46].

6. DISCUSSION

In [43] corroborated the results found in previous studies by [28] on the utilization of drone-enabled multi-hyperspectral sensors are paramount in crop health monitoring. Several studies results reveal vegetation indices [43] outlining soil condition (SAVI) cannot be used without linking to NVDI and its impact on crop growth [37]. The studies indicate that further consideration needs to be examined in the use of UAVs in the weed detection [37] and plant diseases detection [35]. Sentinel-2 satellite [28] remote sensing data only surface after 7 days and drone results may be impactful due to flexibility, real-time analysis in field or crop monitoring [46]. The results show that UAVs are an effective smart farming technology in estimating crop yield despite current excessive costs problems [28], [43], [47]. Smallholder farmers facing crop losses may benefit enormously from UAV imaging and detection that lead to effective decision making [20], [28], [47]. The results indicate that smallholder farms with less than 10 hectares may benefit from the UAVs due to real-time crop health monitoring that leads to predictable yields [44], [43].

6.1. Limitations

This study is, however, limited in that a single database Scopus [42] was used in the bibliometric analysis. Furthermore, research will need to consider two or more databases to enhance results and findings. Future studies need to address methods of data collection to arrive at conclusive findings. The literature search was restricted to English only publications, other languages, and papers such as books, notes were excluded and possibility of missed relevant studies may not be ruled out. Future studies should consider excluded papers that offer a paradigm shift but have fewer citations. This study was limited to crops, and further research on UAV livestock management should be examined.

6.2. Future research

Future research on bibliometric analysis studies should consider solar-enabled drones due to smallholder farmers often experiencing disruptions in power supply that affect agricultural production outputs. Future research should consider AI-enabled UAVs in the context of in-depth soil analysis. Small-scale farmers often face soil degradation/erosion without clear methods to determine soil health. This may be part of the problem that affects smallholder farms that produce low crops due to the lack of remote sensing technology for real-time soil quality analysis. Future research should explore drought tolerant maize particularly in semi-arid regions. In future research, close collaboration between Sub-Saharan Africa and China and the United States on SFT is needed to mitigate food security risks. Future research should link AI-UAV with deep learning in enhancing crop health monitoring with LIDAR sensors.

7. CONCLUSION

This study analyzed publications about the interplay between UAVs and small-scale farms using bibliometric analysis. Our findings reveal that despite an upsurge in drone publications in agriculture between 2013 and 2023, the acceptance and adoption in sub-Saharan smallholder farming remains inert. The implications for small-scale farmers in the sub-Saharan Africa goals of ending poverty by 2030 may not be met. The results reveal that China followed by the Unites States dominate publications on UAVs in agriculture. We recommend that sub-Saharan Africa accelerates network collaboration with leading countries on UAVs to facilitate climate smart sustainable agriculture practices. Our findings show that SFT is impactful in smart irrigation, crop health and analysis, yield estimation with UAVs at the center of crop monitoring, pests and weed detection, crop spraying, crop harvesting is long overdue in sub-Saharan Africa. We recommend that small-scale farmers, particularly in maize staple crops, consider adopting SFT UAV to reduce crop losses.

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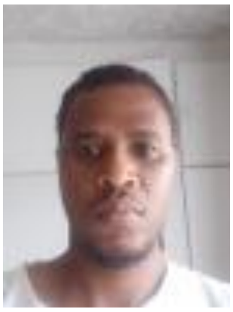

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