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institutions, collaboration, citation and recommendations

OTHERS / SPECIAL ARTICLE

REVISTA DE
Biología Tropical

Bibliometrics of Sudanese scientific publications: Subjects, institutions, collaboration, citation and recommendations

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ABSTRACT

Introduction: Sudan is the third largest country in Africa and has rich reserves of petroleum and other ground resources, but its per capita Gross Domestic Product is only $808 and researchers work in insufficient institutional facilities and with little funding. Previous studies about its scientific productivity have been limited to specific subjects and relatively short periods, with no large analyses until now.

Objective: To analyze the scientific output of Sudan in depth, considering all research areas and several decades of scientific activity.

Methods: We retrieved the documents with "Sudan" in field country in the Science Citation Index Expanded for the period 1900-2019.

Results: We retrieved over 9 000 publications and found that most were articles; that citation was higher for review articles and book chapters, and that this index mostly covered articles in English. Beginning in 1972, the number of publications in this database has increased rapidly. The citation lifespan indicates slow growth in the Sudanese scientific literature, and collaboration is frequent both nationally and internationally, possibly because the scarce resources make collaboration almost compulsory. Most external collaboration is done with Saudi Arabia but citation is higher for articles resulting from international megaprojects, led by Europe and the USA, in which Sudanese researchers play secondary roles. Research focusses on applied technological subjects with little innovation value. Women play a smaller role in Sudanese science.

Conclusions: Our recommendations for Sudanese science include increasing the number of women in leading research positions; providing funding directly to researchers (i.e., bypassing bureaucratic bodies); increasing basic research to avoid stagnation; training Sudanese researchers for leading positions; and identifying specific research areas where Sudan can lead in its region.

Key words: tropical science; scientific productivity; science in Sub-Saharan countries; role of science in research and development.

With 1 882 000 km^2 and 45 million inhabitants, Sudan is the third largest country in Africa. Despite its rich reserves of petroleum, natural gas, gold and other ground resources, Sudan has a per capita Gross Domestic Product of only $ 808 and a low human development index, with extended poverty and social instability (World Bank, 2021).

The oldest study of Sudanese science seems to be one by Johann Mouton about social science in sub-Saharan Africa; it found that Sudanese scientists, like those in other countries in the region, suffered from little government support and poor institutional facilities, but it also reported that researchers continued to work and publish despite those obstacles (Mouton, 2010); this was the panorama a decade ago.

A couple years later, other studies concluded that insufficient financial and human resources, weak cooperation between universities and the productive sector, lack of management and organization ability, and a poor research and development culture, kept Sudan behind other developing countries, preventing the development of local technologies, the adaptation of imported technologies, and economic development in general (Nour, 2012; Nour, 2013).

Another study from the time, which covered the older period 1982-2009, considered the impact of human capital on economic growth, and found a need to upgrade technology and improve the quality of education and health, all factors affecting economic growth and human development in Sudan (Arabi & Abdalla, 2013).

In the field of gender equality in science, it was recently found that, while Sudanese women represent up to 80 % of undergraduates in agriculture and medical fields, they still are a minority in teaching and leading positions (Elhag & Abdelmawla, 2020). Despite all these problems, the number of educational institutions and students has grown rapidly in recent years and there is hope that new funds will improve research and linkage with industry (Beshir et al., 2020).

Despite the existence of previous studies on isolated sections, there are no scientometrics studies that consider all of Sudanese science in depth and for a prolonged period of time, so the present report is the first to consider over half a century of scientific activity in the country, including publication types, document characteristics, journals, subjects, authors, institutions, international collaboration and citation trends over time. Our study, however, is only valid for Sudanese research covered by a particular American database and this should be borne in mind when applying our results to the improvement of science in Sudan.

MATERIALS AND METHODS

We used the Science Citation Index Expanded ("SCI-EXPANDED"), Web of Science Core Collection (updated January 22, 2021). We have our analysis system built around this database and for that reason we do not use others, like Scopus. Additionally, we feel that this database is highly selective and prefer to leave other sources for additional work from other teams. We did an advanced search using the word "Sudan" in field country (CU) limited to the period 1900-2019. Data were manually reviewed by the first author, who is familiar with Sudanese science, and processed by *Excel*. The journal impact factors (IF_{2019}) were extracted from the 2019 Journal Citation Reports (JCR). This study is part of a series on the scientific output of tropical countries and all methodological details have already been published in Calahorrano et al. (2020). We chose journal articles (7 539 articles) for further analysis because they represented the majority of document types, as well as whole research ideas and results (Ho et al., 2010). We also searched for relationships between article subject and number of journals in Web of Science categories. The Web of Science can classify a document in more than one type, for example, 120 proceedings papers were also classified as articles, and thus the sum of percentages can be higher than 100 % (Usman & Ho, 2020). *Note:* South Sudan

seceded from Sudan in 2011, and this study does *not* include a small number of documents formally published with "South Sudan" in the country label.

RESULTS

We retrieved over 9 000 publications that had at least one coauthor with an institutional address in Sudan. *Note*: additional figures and tables appear as appendices.

Document type, citation, authorship and language: The database records 15 document types and 9 230 publications from Sudan for the period 1923-2019. The majority were articles (82 %), followed distantly by meeting abstracts (8.9 %) (Table 1). The maximal *total citations per publication* value (CPP_{2019}) was for reviews, with 25, which was 1.5 times the citation rate of articles. The mean number of authors per publication (*APP*) was 25 in corrections, 18 in data papers, and 11 in reprints. The mean number of coauthors was 18 in data papers, 12 in book chapters, and 11 in reprints (Table 1). Documents in this particular database

were published in a total of six languages but 99.7 % were in English, followed distantly by German (0.17 %), French (0.08 %), and others (Appendix 1).

Trends in time, output and citation lifespan: This database has fewer publications from Sudan before 1972 (probably these existed but were not included in this database), but there is a sharp increase after 2007 to reach 570 articles in 2019 (Fig. 1; Appendix 2). Despite the fact that probably many Sudanese publications are missing from this database for first half of the twentieth century, there were some small citation picks in that period, but the highest CPP_{2019} values were for articles published in 1955 and 2012 (79 and 72 citations, respectively) (Fig. 1).

The *CPP* increased more rapidly in the first two years after publication. The initial value for citations per publication was 0.41 and reached a peak with 2.22 citations per publication in the 3rd full year, for a total citation lifespan of over sixty years (Fig. 2; Appendix 3).

Collaboration patterns, countries and institutions: There were 5 015 internationally

TABLE 1
Characteristics of document type (percentage from a total of 9 230 publications)

Document type	TP	%	AU	APP	Median	TC_{2019}	CPP_{2019}
Article	7 539	82	53 897	7.1	4.0	120 666	16
Meeting abstract	817	8.9	4 290	5.3	4.0	112	0.14
Note	269	2.9	689	2.6	2.0	1 827	6.8
Review	267	2.9	2 332	8.7	4.0	6 598	25
Letter	186	2.0	651	3.5	2.0	769	4.1
Proceedings paper	120	1.3	649	5.4	5.0	2 207	18
Editorial material	105	1.1	583	5.6	3.0	619	5.9
Correction	21	0.23	520	25	6.0	4	0.19
News item	13	0.14	54	4.2	5	57	4.4
Book chapter	7	0.076	66	9.4	12	81	12
Discussion	7	0.076	24	3.4	1.0	6	0.86
Book review	5	0.054	5	1.0	1.0	0	0
Retracted publication	2	0.022	7	3.5	3.5	25	13
Data paper	1	0.011	18	18	18	0	0
Reprint	1	0.011	11	11	11	0	0

TP: number of publications; *AU*: number of authors; *APP*: number of authors per publication; TC_{2019}: the total number of citations from Web of Science Core Collection since publication year to the end of 2019; CPP_{2019}: mean number of citations (TC_{2019}) per publication (*TP*).
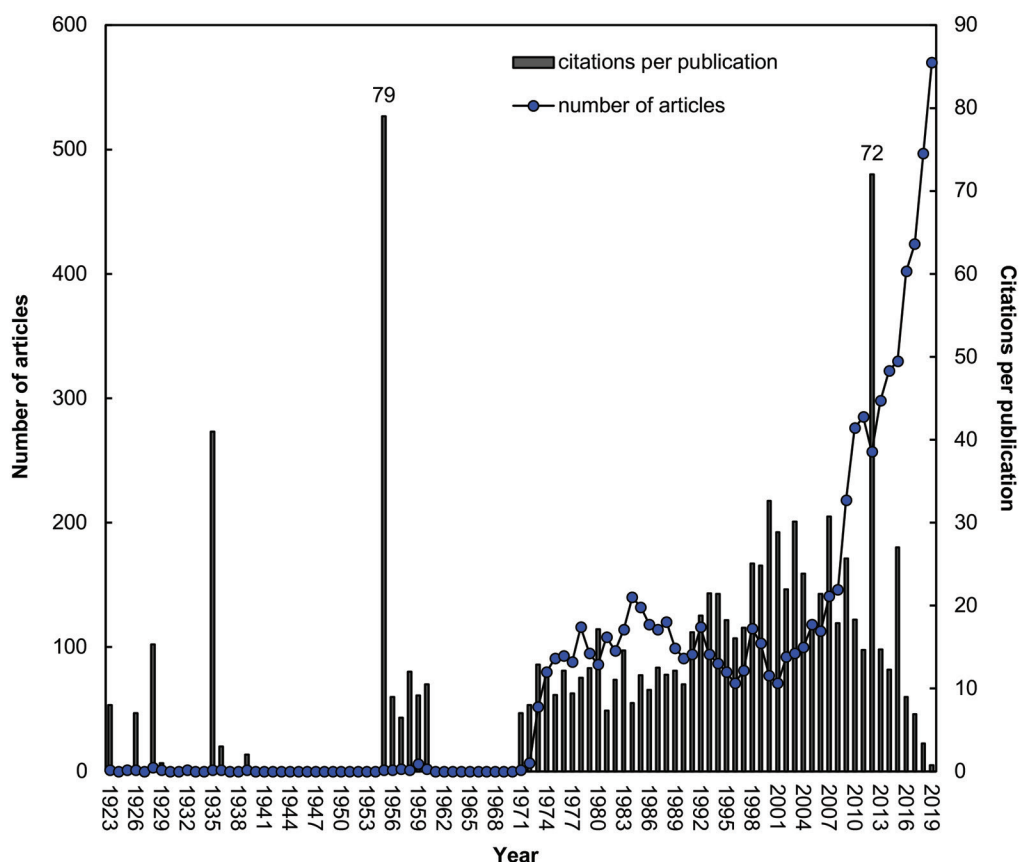
Fig. 1. Number of Sudan articles and citations per publication by year.

collaborative articles and 2 524 Sudan-independent articles; of these 630 were collaborations among Sudanese institutions (Appendix 4).

Sudanese researchers collaborated the most with Saudi Arabia (898 publications) and collaboration is increasing rapidly (Appendix 5). Nevertheless, China had the most *first-author* and *corresponding-author* articles (6.4 % and 6.6 %, respectively). Articles with France, Sweden, Japan, and Kenya had more citations per publication (the lowest values were for papers co-published with Saudi Arabia, Malaysia, and Egypt) (Appendix 4, Appendix 6).

A total of 5 645 were inter-institutionally collaborative articles coproduced by Sudanese institutions (*CP*), only 1 894 articles were single-institution articles (*IP*) (Appendix 4).

The University of Khartoum ranked top in all indicators, with *TP* of 3 687 articles, *IP* of 1 079 articles (57 % of single institute articles), *CP* of 2 608 articles (46 % of inter-institutionally collaborative articles), *FP* of 1 896 articles (25 % of first-author articles), *RP* of 1 755 articles (25 % of corresponding-author articles), and *SP* of 396 articles (51 % of single-author articles). The Federal Ministry of Health published 281 articles, including 15 single-institute articles and 11 single-author articles, and it had the highest CPP_{2019} of 68 (Appendix 7).

Institutionally, Sudan collaborated the most with the King Saud University in Saudi Arabia (257 articles) followed by the University of Putra Malaysia in Malaysia, the London
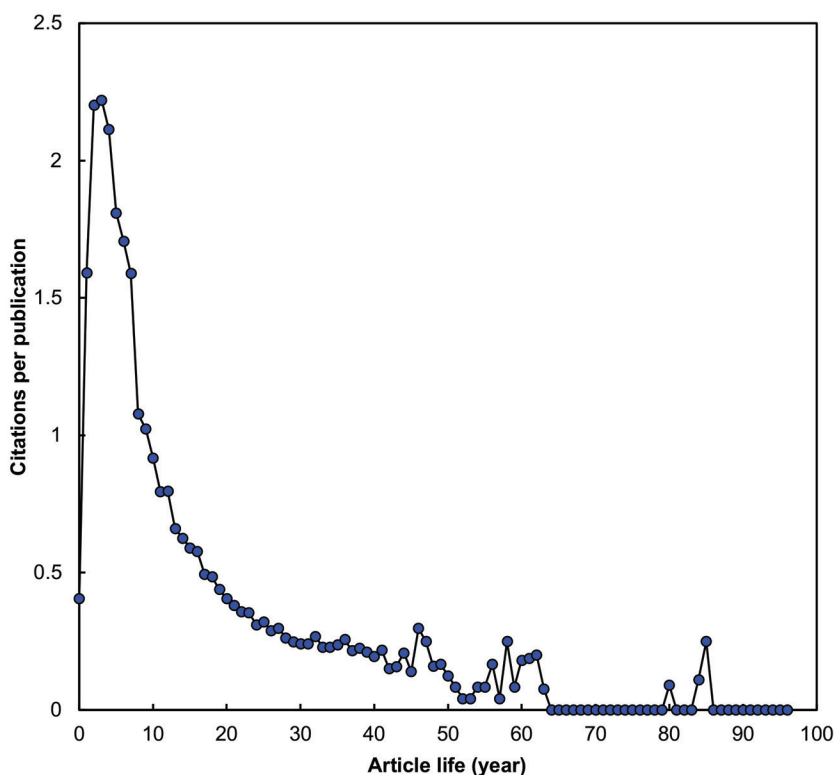
Fig. 2. Citation life span for Sudan articles.

School of Hygiene & Tropical Medicine in the UK, and the University of Copenhagen in Denmark. The King Saud University also published the most first-author and corresponding-author articles, with 112 and 139 articles, respectively. The University of Edinburgh in the UK and the University of Cape Town in South Africa had high CPP_{2019} values (315 and 311, respectively).

Overall, the internationally collaborative articles had a higher CPP_{2019} (20), while Sudan independent articles had a CPP_{2019} of 8.6 (Fig. 3). Articles published with Sudanese researchers as first-authors, or corresponding-authors, had lower CPP_{2019} values: 9.3 and 9.0, respectively. There were no Sudanese researchers among the first-authors, or the corresponding-authors, of the most cited articles.

Journals and subjects (Web of Science categories): Most studies were about tropical medicine; public, environmental and occupational health; and veterinary sciences (Table 2; Appendix 8).

The Sudanese articles were published in 2 185 journals among 173 categories. A total of 132 articles were published in *Transactions of the Royal Society of Tropical Medicine and Hygiene*, followed by *East African Medical Journal* and *American Journal of Tropical Medicine and Hygiene*. Comparing the top ten productive journals, articles published in *American Journal of Tropical Medicine and Hygiene* had the highest CPP_{2019} (32). The journal with the highest IF_{2019} of 60.390 was *Lancet* with 25 articles, followed by *Nature* (IF_{2019} = 42.779) with six articles, and *Science* (IF_{2019} = 41.846) with three articles (Table 3).

Top cited articles: Until 2019, a total of 104 articles had received at least 100 citations in this database: 23 of them with first
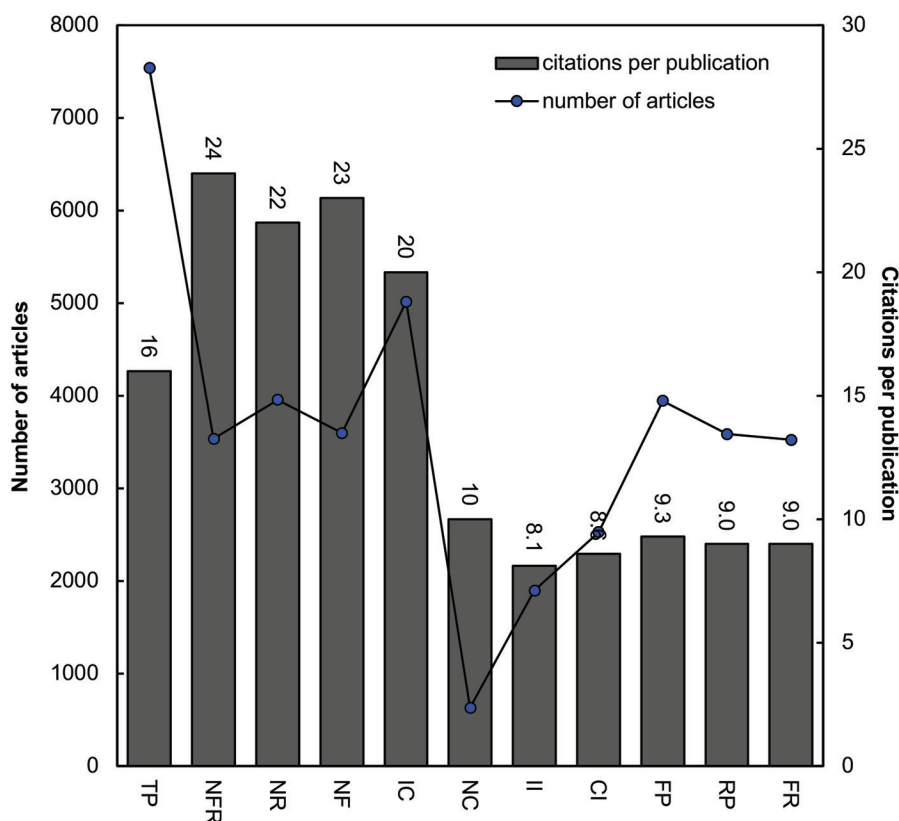
Fig. 3. Characteristics of publication type and their citations per publication. *TP*: total articles, *NFR*: both first and corresponding-authors are not from Sudan, *NR*: corresponding-author is not from Sudan, *NF*: first author is not from Sudan, *IC*: internationally collaborative articles, *NC*: nationally collaborative articles, *II*: institutional independent articles, *CI*: Sudan independent articles, *FP*: first author is from Sudan, *RP*: corresponding-author is from Sudan, *FR*: both first and corresponding-authors are from Sudan.

TABLE 2
Top 10 Web of Science categories

Web of Science category	*TP* (%)	*APP*	*CPP*$_{2019}$	No. *J*
Tropical medicine	806 (11)	6.7	18	23
Public, environmental and occupational health	775 (10)	8.2	18	193
Veterinary sciences	600 (8.0)	3.9	8.4	142
Parasitology	481 (6.4)	7.4	17	39
Infectious diseases	411 (5.5)	18	19	93
Food science and technology	362 (4.8)	4.1	13	139
Agronomy	347 (4.6)	3.5	9.0	91
Plant sciences	320 (4.2)	5.0	16	234
General and internal medicine	300 (4.0)	15	79	165
Pharmacology and pharmacy	295 (3.9)	5.0	14	270

TP: number of publications; *APP*: number of authors per publication; *CPP*$_{2019}$: number of citations per publication (TC_{2019})/(TP); No. *J*: number of journals in a Web of Science category.

TABLE 3
Top ten most productive journals

Journals	TP	IF_{2019}	Web of Science category	APP	CPP_{2019}
Transactions of the Royal Society of Tropical Medicine and Hygiene	132	1.868	Public, environmental and occupational health Tropical medicine	5.8	26
East African Medical Journal	116	0.221 (IF_{2001})	General and internal medicine	3.1	4.4
American Journal of Tropical Medicine and Hygiene	102	2.126	Public, environmental and occupational health Tropical medicine	9.4	32
Annals of Tropical Medicine and Parasitology	84	1.203 (IF_{2013})	Public, environmental and occupational health Parasitology Tropical medicine	4.4	17
PLoS Neglected Tropical Diseases	78	3.885	Infectious diseases Parasitology Tropical medicine	11	16
Saudi Medical Journal	76	1.195	General and internal medicine	3.0	4.6
PLoS One	74	2.740	Multidisciplinary sciences	7.8	12
Malaria Journal	73	2.631	Infectious diseases Parasitology Tropical medicine	11	18
Food Chemistry	70	6.306	Applied chemistry Food science and technology Nutrition and dietetics	3.6	29
Journal of Tropical Medicine and Hygiene	66	0.916 (IF_{1997})	Public, environmental and occupational health Tropical medicine	3.3	10

TP (%): rank and the percentage of number of articles; IF_{2019}: journal impact factor in 2019; TC_{2019}: the total number of citations from Web of Science Core Collection since publication year to the end of 2019; CPP_{2019}: number of citations (TC_{2019}) per publication (TP).

author from the USA, 17 from Sudan, and 12 from the UK (19 % with corresponding author from the USA, 14 % from Sudan and 14 % from the UK).

Five of the top cited articles were from international mega-projects with 713 authors (Naghavi et al., 2015), 679 authors (Vos et al., 2015), 359 authors (Murray et al., 2012), 355 authors (Vos et al., 2012), and 207 authors (Lim et al., 2012). Sudan's article with the highest TC_{2019} (191 citations) was "Effects of algal grazing and aggressive-behavior of fishes *Pomacentrus lividus* and *Acanthurus sohal* on coral-reef ecology" (Vine, 1974), whose author, P. J. Vine, had two affiliations: Cambridge Marine Research Laboratories and Suakin Marine Laboratory (Appendix 9). Citation histories of the top ten most cited articles appear in Appendix 10 and Appendix 3. Depending on the particular article, they follow two citation curves, one flat and the other with a rapid increase shape.

DISCUSSION

The document types published by African countries have also been reported by other workers (e.g. Confraria & Godinho, 2015; Sooryamoorthy, 2018) who, like us, found a clear domination of articles over other types of documents, higher citation rates for reviews and books; the appearance over time of more complex articles with more coauthors and references; as well as the limitation of the Web of Science and its impact reports to only publications in English and in large journals (Bah et al., 2019; Chiware & Becker, 2018; Ho et al., 2018; Trang et al., 2020). This means that much relevant information, published in smaller journals and other languages, is missing in most scientometrics studies.

On the one hand, the near lack of coverage of tropical science in the Web of Science before 1980, and the insufficient coverage after that period, have been reported before (e.g., Monge-Nájera et al., 2020) and Sudan is not an exception. On the other hand, a similar increase in the number of scientific papers from Africa in the 21st. century has been reported before, and, interestingly, the African increase rate is faster than the world average (Confraria & Godinho, 2015). The leading researchers in Africa are South Africa, Egypt, and Tunisia: Sudan still has a large gap to fill (Sooryamoorthy, 2018).

The long lifespan in citation of tropical research reflects the slow pace at which science advances in poorer countries, and also has been widely reported before (Bah et al., 2019; Ho et al., 2018; Trang et al., 2020).

While the central importance of collaboration for productivity and visibility has been reported for other African countries (Confraria & Godinho, 2015; Trang et al., 2020), only large emerging countries like China and Brazil obtain leading roles for their researchers in international collaborative projects; smaller countries are normally excluded from the leading roles (González-Alcaide et al., 2017), and this is the case with Sudan as well.

The geographic collaboration pattern, in which the USA, ex-colonial powers, culturally similar countries and geographic neighbors are the main collaborators, has been reported previously by numerous studies about science in tropical countries (Bah et al., 2019; Ho et al., 2018; Sooryamoorthy, 2018; Trang et al., 2020).

The strong level of local collaboration among Sudanese researchers is unusual for a developing country: most studies of tropical countries have found little collaboration among local scientists (e.g., González-Alcaide et al., 2017). A hypothetical explanation for our findings is the poor facilities and small funding that Sudanese researchers face; those conditions make collaboration mandatory if any significant research is to be done. Additionally, our hypothesis is consistent with reports from Ghana, a similar African country, where local collaboration is important and focusses on basic fieldwork (Chiware & Becker, 2018; Owusu-Nimo & Boshoff, 2017; Trang et al., 2020).

As is typical of developing countries, Ghana focuses research on applied subjects meant to solve urgent local problems, like health and food production (Sooryamoorthy, 2018; Trang et al., 2020), an option that also favors stagnation and reduces innovation. Interesting exceptions are South Africa and Vietnam, where technological innovation plays a larger role in research and leads to better financial results in the long term (Confraria, & Godinho 2015; Trang, et al., 2020). The dispersion of publications among such a large number of journals is also unusual and deserves further study (Confraria & Godinho 2015; Sooryamoorthy, 2018; Trang et al., 2020), we have no hypothesis for this result.

While other studies of African science found that well-funded international mega-projects open the door to powerful journals with high citation rates in the Web of Science (Confraria & Godinho, 2015), there are few that analyze citation trends *over time*. Those that did, also found the two basic citation curves that we report here, some with a surge and quick fall, and some curves with a flatter shape (e.g., Monge-Nájera et al., 2020). This probably reflects fashionable subjects, in which there are bubbles of production that collapse when interest in those subjects suddenly falls, against the rest of subjects that have a relatively constant level of interest and output.

We have five recommendations for Sudanese science: increasing the number of women in leading research positions (Elhag & Abdel-mawla, 2020); providing direct funding to researchers and not funneling it through bureaucratic bodies (Owusu-Nimo, & Boshoff, 2017); increasing basic research to leave behind the stagnation caused by the "applied research only" model (Elliott et al., 2015; Owusu-Nimo & Boshoff, 2017); educating Sudanese researchers at the highest level, so that they can occupy leading positions in international projects (Arabi & Abdalla, 2013; Confraria & Godinho, 2015; Elliott et al., 2015); and

identifying specific research areas where Sudan can lead (Sooryamoorthy, 2018).

Ethical statement: the authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgements section. A signed document has been filed in the journal archives.

See Digital Appendix

ACKNOWLEDGMENTS

RESUMEN

Bibliometría de publicaciones científicas sudanesas: temas, instituciones, colaboración, citas y recomendaciones

Introducción: Sudán es el tercer país más grande de África y tiene ricas reservas de petróleo y otros recursos terrestres, pero su Producto Interno Bruto per cápita es de solo $ 808 y los investigadores trabajan en instalaciones institucionales deficientes y con poca financiación. Los estudios previos sobre su productividad científica se han limitado a temas específicos y períodos relativamente cortos.
Objetivo: Analizar la producción científica de Sudán en profundidad, considerando todas las áreas de investigación y varias décadas.
Métodos: Recuperamos los documentos con "Sudán" como país de origen en el *Science Citation Index Expanded* para el período 1900-2019.
Resultados: Hallamos más de 9 000 publicaciones y encontramos que la mayoría eran artículos; que fueron más citados los artículos de revisión y capítulos de libros, y que esta base de datos cubría principalmente artículos en inglés; desde 1972, el número de publicaciones en ella ha aumentado rápidamente. La vida útil de las citas indica un crecimiento lento en la literatura científica sudanesa, y la colaboración es frecuente tanto a nivel nacional como internacional, posiblemente porque los escasos recursos hacen que la colaboración sea casi obligatoria. La mayor parte de la colaboración externa se realiza con Arabia Saudita, pero hay más citas para los artículos resultantes de megaproyectos internacionales, dirigidos por Europa y Estados Unidos, en los cuales los investigadores sudaneses desempeñan papeles secundarios. La investigación se centra en temas de tecnología aplicada con poco valor de innovación.
Conclusiones: Nuestras recomendaciones para la ciencia sudanesa incluyen aumentar el número de mujeres en altos puestos; proporcionar financiación directamente a los investigadores (sin pasar por organismos burocráticos); ir más allá de la investigación aplicada para evitar el estancamiento; capacitar al personal sudanés para puestos de liderazgo; e identificar áreas de investigación específicas donde Sudán puede liderar en su región.

Palabras clave: ciencia tropical; productividad científica; ciencia en los países subsaharianos; papel de la ciencia en la investigación y el desarrollo.

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