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Out of Africa: The underrepresentation of African authors in high-impact geoscience literature

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ABSTRACT

Several studies have highlighted the persistent lack of impact that African researchers have in international science. To examine this in the geosciences, we reviewed the representation and contribution of African authors using a bibliometric study of international high-impact geoscience journals. Detailed metadata from all articles (n = 182,996) published in these journals (n = 21), and from two Africa-based journals, were extracted from the Web of Science™. We then assembled information related to the research to track how frequently African authors and studies appear, relative to their international peers. The results show that, on average, 3573 high-impact geoscience articles are published each year, and 3.9% of these articles are on an African topic. Only 30% of these African articles contain an African author. In terms of authorship, the continent of Africa has produced 2.3% of the geoscience literature surveyed, which is comparable to the Netherlands (2.2%), a country 70 times smaller than Africa by population. Geoscience output from Africa over time shows concerning trends, in that it persistently lags behind global output, especially in comparison with high-income countries. For example, the five years of most prolific output from Africa occurred more than 25 years ago (1978, 1979, 1982, 1983, 1990). In terms of academic impact, the 25 most highly cited geoscience articles for each of the journals surveyed were found to be written by 2744 authors, of which only 13 are African. There is also an intra-Africa imbalance in authorship, given that more than 80% of African authorships stem from only five countries (South Africa, Egypt, Morocco, Ethiopia, Algeria, and Cameroon). Lastly, we show that most countries produce 60–80% of their own geoscience articles (i.e., by in-country authors), while this number for Africa is 30%. This is clear evidence of 'parachute' geoscience in Africa, a practise that marginalises the prospects of in-country researchers. Such practises may have also developed because the next generation of researchers in Africa is not developing, a problem caused by the lowest tertiary education enrolment rate in the world, and the well-documented 'brain-drain' of scientists from the continent. There is also a strong parallelism between research expenditure per capita and research output globally: high-income countries, which produce most of the geoscience research, spent US $1064 per capita on research in 2017, while Africa spent only US$42. Such low expenditure results not only from difficulties in raising research funds, but also from weak institutional support for African researchers, except in South Africa. For those researchers who are productive, they are reluctant to submit work to high-impact journals, for fear of rejection, and many do not become involved in international collaborations because of high teaching loads and lack of incentive. Indeed, there is even a distinct lack of intra-Africa collaboration—only 6 countries collaborate internally, mostly with South Africa. However, there are positive international collaborations being developed in the earth and environmental sciences in Africa, such as the UNESCO-supported online training program (GEOLOOC), the West African Exploration Initiative, the Africa Array program, and other programs initiated by the British Geological Survey in East Africa.

1. Introduction

Africa has the second largest population by continent (1.24 billion; UNDESA, 2019), and yet it is underrepresented in science and scientific literature (King, 2004; Okeke et al., 2017; Salager-Meyer, 2008). It has been shown that Africa's global stake in published research articles has steadily declined and there is a persistent lack of impact internationally (Tijssen, 2007). The study of scientific impact by King (2004) found

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Table 1
Selected high-impact global and African geoscience journals, based on rank by h-index, total citations per article and Scimago Journal Rank. Note that the list is alphabetical and should not be construed as hierarchical.

Selected Geoscience Journals	Abbreviation
High-Impact Journals	
AAPG Bulletin	AAPG Bull.
Bulletin of the Geological Society of America	Geol. Soc. Am. Bull.
Chemical Geology	Chem. Geol.
Contributions to Mineralogy and Petrology	Contrib. Mineral. Petrol.
Earth and Planetary Science Letters	Earth Planet. Sci. Lett.
Earth-Science Reviews	Earth-Sci. Rev.
Engineering Geology	Eng. Geol.
Geochimica et Cosmochimica Acta	Geochim. Cosmochim. Acta
Geology	Geology
Geophysical Research Letters	Geophys. Res. Lett.
Gondwana Research	Gondwana Res.
International Journal of Coal Geology	Int. J. Coal Geol.
Journal of Geophysical Research: Solid Earth	J. Geophys. Res.-Solid Earth
Journal of Geotechnical and Geoenvironmental Engineering - ASCE	J. Geotech. Geoenviron. Eng.
Journal of Metamorphic Geology	J. Metamorph. Geol.
Journal of Petrology	J. Petrol.
Lithos	Lithos
Nature Geoscience	Nat. Geosci.
Precambrian Research	Precambrian Res.
Quaternary Science Reviews	Quat. Sci. Rev.
Tectonics	Tectonics
African Journals	
Journal of African Earth Sciences	J. Afr. Earth Sci.
South African Journal of Geology	S. Afr. J. Geol.

that 31 nations out of 191 accounted for 98% of citations, and the only African country on the list was South Africa, in 29th place.

More than a third of African countries derive 50% or more of their export revenue from mining, and most West African countries are economically dependent on their mineral resources (Jessell et al., 2018). This includes Burkina Faso, Ghana, Guinea, Ivory Coast, Niger, Nigeria, Mali, Mauritania, Sierra Leone and Togo. There are currently 18 African countries that actively extract petroleum resources and, as of 2017, there was an estimated reserve of 127 billion barrels of oil in Africa, mostly contained in the proven offshore oilfields of Nigeria and Angola (Graham and Ovadia, 2019). Africa also ranks first or second in terms of global reserves of many non-fuel minerals. For example, the Democratic Republic of the Congo produces 68% of the world's cobalt and Rwanda, Ethiopia and Mozambique together produce 41% of global tantalum output, an important constituent in capacitors in modern electronic devices. South Africa, Ghana and Gabon together contain 40% of global manganese reserves and Morocco and Western Sahara contain over 70% of the world's phosphate reserves, a mineral critical to food security. South Africa's mineral wealth is led by platinum and palladium (92% of the global reserves) and chromite (42% of the global reserves) (Kay et al., 2013; U.S. Geological Survey, 2019). Cobalt, platinum and palladium are of prime importance currently, as these metals form the basis of the rapidly evolving renewable energy and electric vehicle market (Yong et al., 2015). Indeed, substantial lithium and graphite deposits (key components of electric vehicle batteries) also occur in Africa (U.S. Geological Survey, 2019). Africa's stake in the earth sciences is certainly clear, provided it can leverage its own geological and technical resources to its advantage.

Recent research has highlighted the importance of training in the earth and environmental sciences for sustainable development in Africa (Gill and Bullough, 2017; Gill et al., 2019; Lubchenco et al., 2015; Omisore, 2018). Work by the British Geological Survey in East Africa (Gill et al., 2019) reveals that local practitioners see progress in African earth science being related to improvements in scientific training, refined integration of data (e.g., geology, soils, water) to improve food security and environmental policies/management, and applied research opportunities linked with food security, health, water, minerals, energy and climate change—opportunities with clear links to Africa's mineral wealth. Nevertheless, Africa's academic contribution within the earth sciences is likely underrepresented, as is the case for African literature in general (Beaudry et al., 2018), and has not been previously assessed.

The main aim of this study is to evaluate the representation of African geoscience by surveying articles from high-impact solid-earth science journals, and to investigate the patterns of African authorship therein. These aims are addressed by asking the following questions: i) To what extent are these high-impact articles authored by Africans? ii) What proportion of these articles are about Africa? iii) To what extent is African geoscience research conducted by Africans?

This paper attempts to answer these questions using a detailed bibliometric analysis of articles from selected high-impact geoscience journals, from the past 40 years. Thus, we aim to present a clear picture of the historic and current state of geoscience research in Africa relative to international trends. We also highlight potential links between these trends and those in expenditure on research and conclude with some observations of research challenges and opportunities in Africa.

2. Methodology

2.1. Journal selection

To provide ourselves with a manageable sample of geoscience literature (and authors) we focus only on "classical" geology. The Oxford English dictionary defines geology as "*The science which deals with the physical structure and substance of the earth, their history, and the processes which act on them*", and, based on this definition, resulted in our selection of only "solid-earth" journals (hereafter referred to as geoscience journals). The following types of journals were excluded as a result:

1. Multi- and interdisciplinary earth science journals
2. Journals related exclusively or primarily to limnology, oceanography, hydrology, meteorology and climate or climate change
3. Journals which publish only invited reviews
4. Exclusively planetary journals

A list of all these journals was then downloaded from Scimago (www.scimagojr.com) and ranked according to: (1) *h*-index, (2) total citations per article in the journal and (3) Scimago Journal Rank. The top 25 journals which ranked highest across all three criteria were selected, and from these only "solid-earth" journals were retained—based on careful examination of the aims and scope of each journal title. Twenty-one journals ultimately met all criteria; hereafter referred to as "high-impact journals". Two prominent African geological journals (*South African Journal of Geology* and *Journal of African Earth Sciences*) were also examined for comparative purposes relative to these 21 high-impact titles, hereon referred to as "African journals". We therefore examined 23 journals in total (see Table 1).

2.2. Determining African representation

The Web of Science™ Core Collection (v. 5.3.1., available online) (Clarivate Analytics, USA) was used for all literature searches. The Core Collection is suited to our purpose because of the advanced search functions and export capabilities of the detailed metadata, which is not available directly from each journal.

For each of the 23 journals, we recorded the following from Web of Science™:

1. The total number of articles published by each journal over its history (up to and including 2017),
2. The number of African-authored articles published by each journal over its history,
3. The number of articles published by each journal over its history on African topics.

By "African-authored articles" we mean all articles where at least one author is listed as having an African affiliation (or co-affiliation), regardless of their position in the list of authors. By "African topics" we mean articles where an African country is in the subject of the article. To identify African authorship or topic, a list of African countries was used to search using the 'address' or 'topic' (title, abstract and keywords) search fields, respectively, in the Web of Science™ (for details of the search strategies and terms, see Supplementary Information SI.1 and SI.2).

Metadata of all articles in which an African country was the topic were also gathered and stored separately for each of the 23 journals. The metadata included, but was not limited to title, abstract, year of publication, list of authors and their affiliations.

The total number of articles referring to each African country in the title or abstract, and the total number of authors with an African affiliation was determined for each of the 21 high-impact journals, to provide an indication of the representation of African countries and experts therein. Variations in country name (language or abbreviations) were accounted for (e.g., Cabo Verde versus Cape Verde, or Ivory Coast vs Côte d'Ivoire). Because the data obtained are historical (1973–2017) we tracked article output over time, for both international and African-authored geology articles. For every article in each of the 21 high-impact journals, we also recorded the country of affiliation of every African author. The total number of '*authorships*' (author-publication unit, see Section 2.4) was then calculated for each country and plotted geographically. Similarly, the number of times each African country was mentioned in the title or abstract of articles was plotted geographically.

2.3. Determining African contribution to high-impact journals

To determine the contribution of African geoscientists to high-impact journals, metadata from the top 25 articles (ranked by citation count) published between 2007 and 2017 in each of the 21 high-impact journals and the two African journals were obtained from the Web of Science™. The date cut-off of 2017 was selected to correspond with the latest Scimago journal ranking.

For each article we recorded the number of times it was cited, the number of authors, the number of African authors, and whether the article was on an African topic. The names of the authors with an African affiliation were catalogued, and additional academic details about each were obtained from Scopus®. This includes the number of times the author featured in a top 25 article, the total number of articles they have published, their primary affiliation (African or non-African institution and country), and *h*-index. The *h*-index is one measure of citation impact and productivity (with respect to peer-reviewed publications) of a researcher or journal. The *h*-index indicates that a researcher/journal that has published *h*-articles will have an index of *h* if each of the articles has been cited *h*-times (Hirsch, 2005). In other words, if a researcher/journal has published 20 articles, each of which has been cited 20 times, the *h*-index will be 20. We did not calculate the *h*-index of the journals or authors ourselves, but obtained these from Scimago and Scopus®, respectively.

In some instances, it was necessary to compare research output by country, region or continent, and to do so we have normalized research output on a 'per capita' basis using population data (UNDESA, 2019). This allows for more reasonable comparison, along with examining economic data which were obtained from the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics (http://data.uis.unesco.org).

2.4. Definitions and limitations

Before examining the results, we acknowledge the following definitions and limitations:

- *African*—an "African" author may not be ethnically African and/or may no longer reside/work in Africa. Also, many African authors may have primary affiliations at non-African institutions. Nevertheless, all authors with an affiliation to an African institution were treated as "African".
- *Authorships*—Refers to author-publication units, not individuals (Larivière et al., 2013), that is, we are primarily interested in identifying the nationality of each African authorship. For example, one African country has 3356 authorships, from approximately 1084 individual authors, each of whom may have authored between one and ~60 articles. Authorship versus individual-level information is specified throughout.
- *Differentiation of terms*—It was found that some terminology for certain countries overlaps with geographic and geological terms. For example, a search for "Niger" may return results not only for the country Niger, but also "Niger Delta" or "Niger River". This may result in overrepresentation of topics apparently related to such a country. As such, "Niger Delta" was ascribed to Nigeria, and "Niger River" to the country Niger. Similarly, results for "Congo" may refer to the Congo Craton (which underlies a large portion of central Africa), and was thus ascribed to the Republic of the Congo, or the "Congo River", which we ascribed to the Democratic Republic of Congo (DRC), but which also borders the Republic of the Congo for some distance.
- *Impact*—We use the number of most highly-cited publications from high-impact journals as a proxy for impact when comparing researchers or countries. In other words, we consider that any highly productive authors, and those in high-impact literature, are high-impact researchers (Sandström and van den Besselaar, 2016). We also verified this by finding their *h*-index as recorded by Scopus. We have not accounted for any other types of work (such as patents or policy) that may be of significant impact in, for example, the mining or exploration sectors.
- *Language of publication*—Only English-language journals were included in the sample of high-impact journals used for this study, since no non-English geoscience journals were ranked within the top

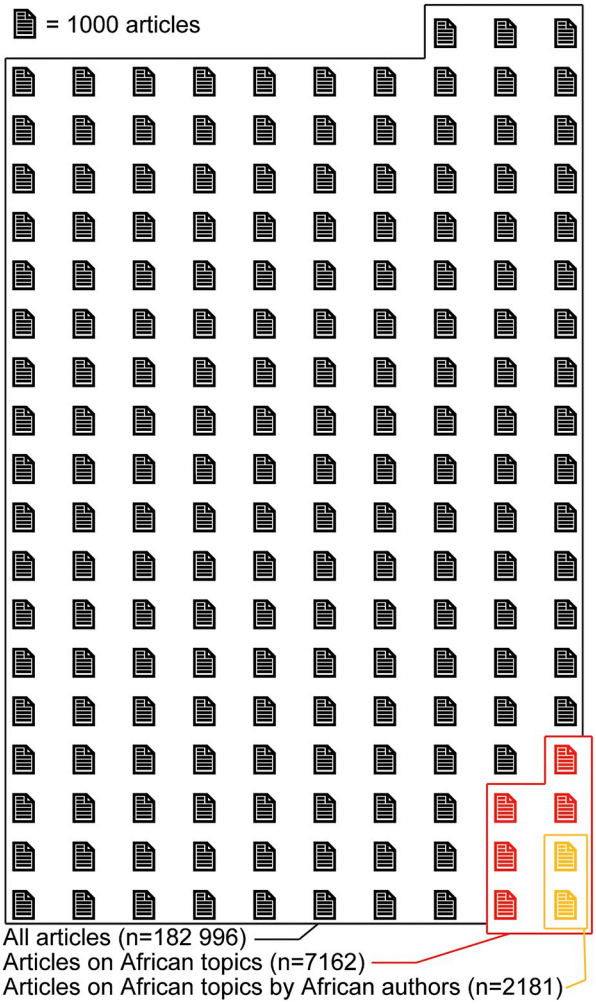

Fig. 1. Schematic illustration of the proportion of African articles (red) and African-topic articles written by African (yellow) in the 21 high-impact geoscience journals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

50 Scimago rankings. We acknowledge that this neglects French or Arabic geoscience journals which may attract African authors. However, we are rather presenting our insights based on an objective ranking of the geoscience literature.

3. Results

3.1. African representation in high-impact journals

In the high-impact geoscience journals, the publication of articles by African authors or on African topics shows several distinct trends. Over their history, a total of 182,996 articles were published by the 21 high-impact journals, of which 7162 (3.9%) were on African topics. It is noteworthy that only 2181 of these studies based in Africa had at least one African author, which means that 70% of the articles on African topics did not involve any African authors/collaborators (Fig. 1).

The number of articles on African topics varies between 0.05% and 23% among individual journals, with an average of 4% (Fig. 2). Only three journals (*Precambrian Research*, *Gondwana Research*, *Lithos*) contain > 10% of articles on African topics (23%, 13% and 11%, respectively).

It is also evident that the number of African topic articles always greatly exceeds (in some cases up to double) the number of articles published by African authors (Fig. 2). The only exception being the *Journal of Geotechnical and Geoenvironmental Engineering*, in which only two articles were published on African topics, while 62 had African authors.

The second trend observed in Fig. 2 is that African authors tend to publish more on non-African than African topics—in other words, most studies do not mention the country in which they were conducted or are not site-specific. For example, in the journal *Chemical Geology*, 239 articles were published by African authors, and only 139 on African topics, indicating that 100 African-authored articles were not on an African topic according to our definition.

The third trend observed in these journals is that, on average, ~2% of the articles on African topics have African authors (range = 0.02–11.4%; see Table SI.2). The notable exception to this is *Precambrian Research*, in which 11.4% of all articles are African-authored articles on African topics.

Trends for the two African journals are markedly different, both showing a significant number of African authorships and African topics (> 75% on average) (Fig. 2). Furthermore, across both journals, 58% of the African topic studies were authored by Africans; an order of magnitude higher than in the high-impact journals. The authorship of articles in the *South African Journal of Geology* is dominated by African authors with more articles published by African authors than on African topics. The *Journal of African Earth Sciences* mimics the dominant trend of the high-impact journals (more articles on African topics than by African authors); however, the numbers are significantly higher in all categories compared to the high-impact journals.

To ensure comparison between African and non-African topics is reasonable, the number of articles mentioning African country names was compared to those mentioning the names of any global country. This is quantified in Fig. 3, which shows that for 13 of the 21 high-impact journals, less than 50% of the articles included a global country name in the 'topic'. *Precambrian Research* and *Gondwana Research* have the highest percentages of site-specific articles, with 84% and 81%, respectively. Within these country-specific articles, it can be seen that Africa lacks representation in certain journals (e.g., < 5% for *Engineering Geology* and *Journal of Geotechnical and Geoenvironmental Engineering*), but appears more frequently in others (e.g., 28% in *Precambrian Research* and 15% in *Gondwana Research*). On average, 12% of the country-specific geoscience literature is on African topics.

The trend of the African journals is different, where most of the site-specific articles were undertaken in African countries (i.e., > 85% of the country-specific articles are on African topics).

It is of course important to consider the extent to which geoscientists in other countries contribute to studies in their own countries, to allow meaningful comparison with Africa. To achieve this, we identified the top five producers of geoscience research by country (UNESCO, 2015) and completed a Web of Science™ search for each, within the same 21 high-impact journals. Along with population data (UNDESA, 2019) we have also normalized high-impact geoscience article output per inhabitant for these countries, as shown in Table 2.

These countries typically produce 60–76% of their own geoscience literature, while in Africa, only 30% is produced by African geoscientists (fourth row of Table 2). When these output figures are normalized on a per capita basis, we find that in Africa there is approximately one geoscience article per 568,546 people, significantly lower than all countries considered. Then, if we define a ratio of country-specific geoscience articles relative to Africa (i.e., relative to 568,546 inhabitants) we find that all countries generate at least twice as many articles. Indeed, Canada and Australia show very high figures; 40 times and 77 times greater output than Africa, respectively.

3.2. Geographic distribution of articles and authorships

The number of geoscience articles listing an African country in their title or abstract over the history of the 21 high-impact journals and authorships from each African country are illustrated geographically in

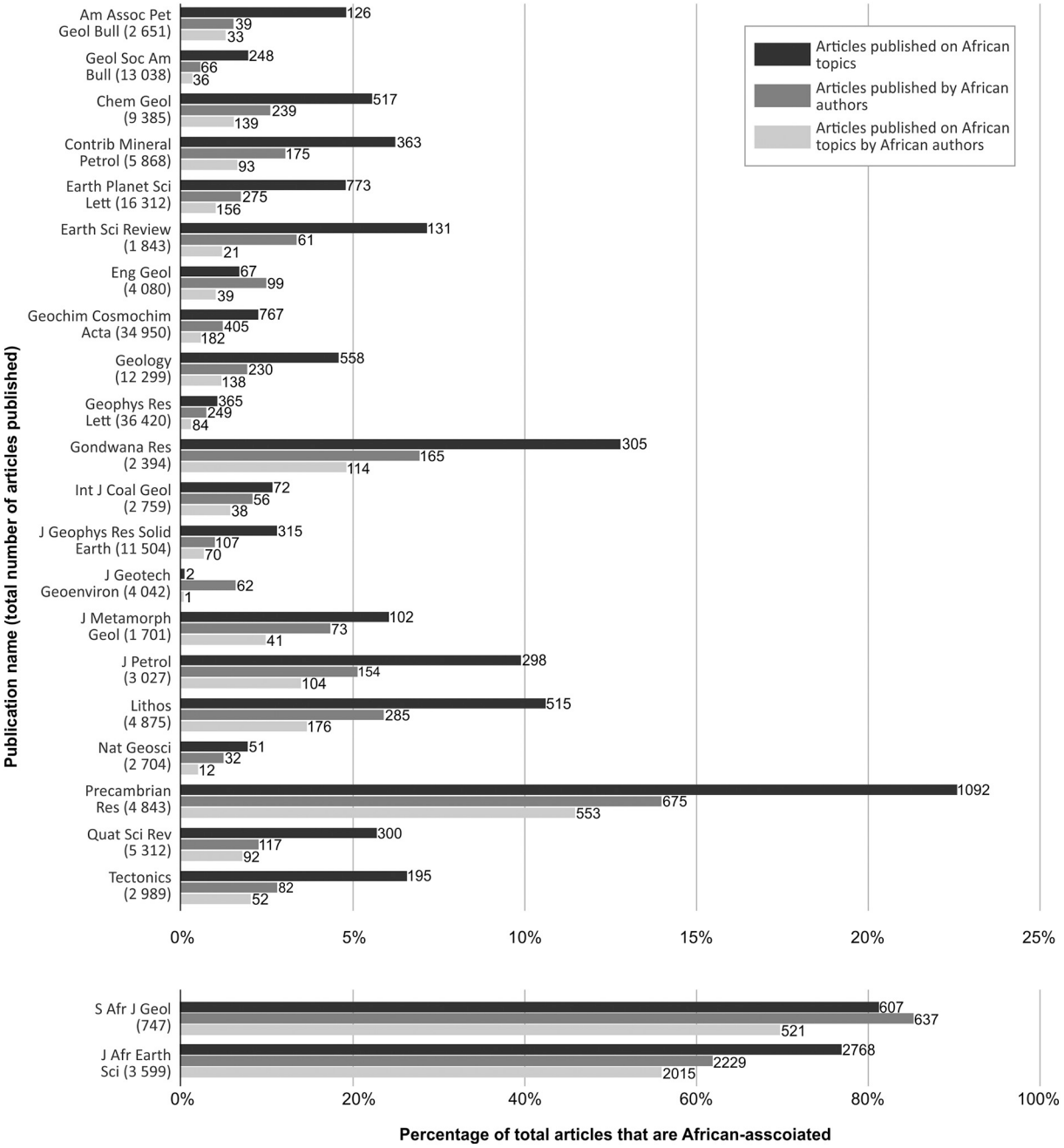

Fig. 2. Trends in authorship of the high-impact geoscience journals (upper 21) and the African journals (bottom 2). The number of articles for each category is displayed to the right of each bar.

Fig. 4.

The African countries featuring most frequently as topics of research are South Africa, Egypt, Namibia, Morocco, Ethiopia and Zimbabwe, each with more than 100 articles (Fig. 4a). The patterns of authorship largely mimic this density pattern, with 3352 of the 5728 African authorships coming from South Africa (58.5%), followed by Egypt, Morocco, Ethiopia, Algeria and Cameroon (Fig. 4b). These six countries (shown in bold text in Fig. 4c) together contribute more than 80% to Africa's total authorships to these high-impact journals. Interestingly, these findings closely match the Scimago Journal and Country Ranks (www.scimagojr.com) for global geoscience research: South Africa ranked 20th, Egypt 39th, Morocco 41st, Algeria 60th, Cameroon 65th and Ethiopia 66th (out of 206 countries). When normalized for population, South Africa remains highest ranked, with 58.9 authorships per million, followed by Seychelles (41.7), Botswana (41.3), Namibia (26.2), and Mauritius (11.0). The ranking of all African countries is presented in Table SI.3.

Together, almost half of all African countries (26 countries of 54) contain less than 5% of the authors found on the continent (Fig. 4c), and there are some interesting discrepancies between the article and authorship patterns: Somalia has 0 authorships, but 16 articles and Western Sahara has 0 authorships, but 5 articles. This suggests that these articles represent research conducted by visiting (international) geoscientists. This trend is also observed for Namibia, Zimbabwe and Mozambique, which are the subjects of 127, 105 and 70 articles, but are home to only 63, 61 and 22 authorships, respectively.

3.3. Temporal distribution of African-authored articles

The total number of articles published per high-impact journal per

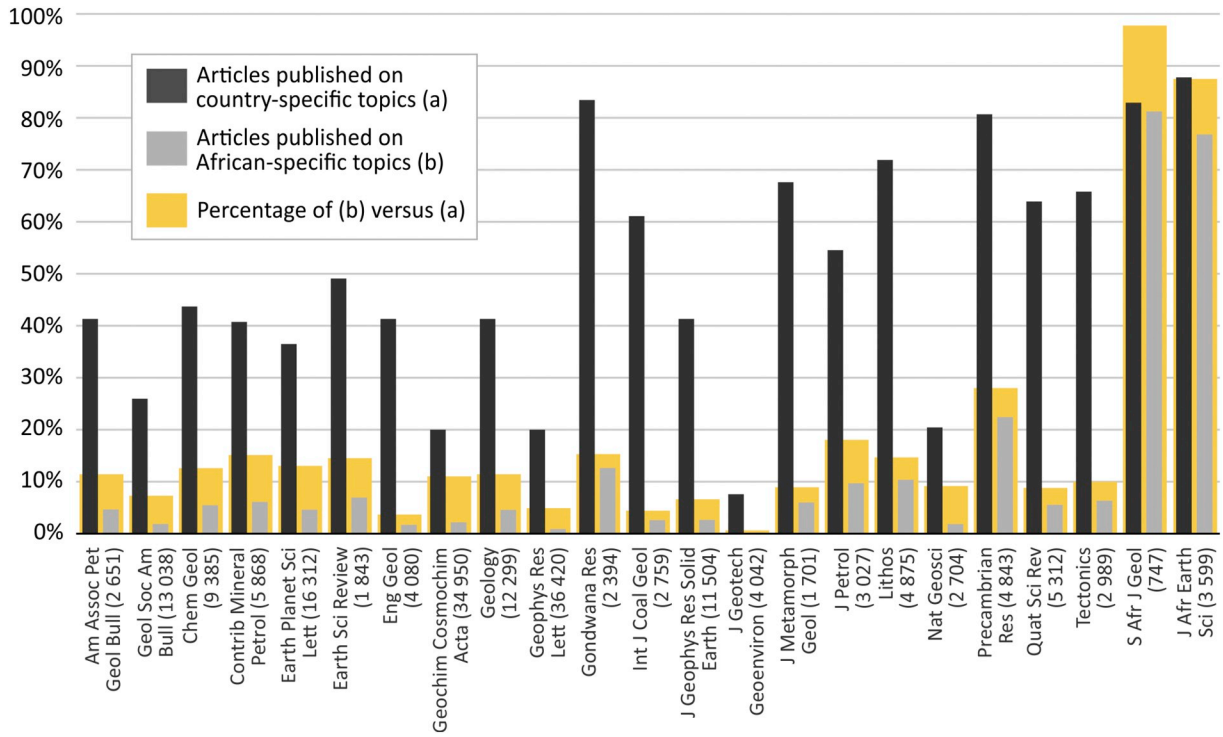

Fig. 3. Publication of articles with countries specified in the article topic, by journal: global countries (black bars) vs. African countries only (grey bars) The orange bars are a comparative percentage of non-African vs. African-topic articles.

year, as well as a breakdown of those containing at least one African author (African-authored articles) over the same period is presented graphically in Fig. 5. The most striking feature is the departure between the number of African-authored articles and that of international literature since the 1970s.

For example, the number of African-authored articles in 1973 was 10, compared to the global number of 419; by 2017 the global output was 6504, compared to the African output of 207. The average number of African-authored articles per year is 81, while the global average is 3572.

Specifically, the relative contribution of African-authored articles to the international geoscience literature from 1973 to 2017 is 2.3% on average, which is very low compared to contributions by authors from the USA (47.0%), a country one quarter the population of Africa (UNDESA, 2019). This is also less than the UK (10.6%), France (10.4%) or Germany (9.5%). The African contribution is comparable to that of the Netherlands (2.2%), a country of only 17 million people. Notably, South Africa contributed more than half of all African-authored articles to the total.

The five years of highest output of African-authored articles were 1978, 1979, 1982, 1983 and 1990. The five years of lowest output were 1993, 1994, 1995, 2005 and 2007. Africa has not contributed more than 5% to geoscience literature since 1982. The histogram also shows more clearly the trends in African-authored articles, with an overall decrease from the 1980s to 1990s, and then an increase in output from the mid-2000s. However, some apparent increases in the African contribution are due to decreases in international output, e.g., 1982, 1990, and post-2009.

3.4. High-impact African geoscience

Of the 525 most-cited articles from the high-impact journals (top 25 articles per journal), only ten (1.9%) are on African topics, a comparable figure (2.3%) to African-authored articles in all the high-impact literature surveyed. Of these ten articles, four had at least one African-based author and six were conducted by international authors without African collaborators. Although authorship is quantified in the next section, it is worth noting that only four articles on an African topic have an African author in first-author position.

The same articles described above were analysed in terms of their authorship to determine where most of the African authors are (or were) located. The 525 articles were written by 2744 authorships, of which 13 authors listed African affiliations (Fig. 6a). These 13 authors appear 17 times out of the 2744 authorships, which equates to a very

Table 2
Comparison of the five most productive countries in the 21 high-impact geoscience journals, relative to Africa.

Country		USA	China	Australia	Japan	Canada	***Africa***
2017 Population[a]		325 million	1.42 billion	24.5 million	127 million	36.7 million	***1.24 billion***
Web of Science™	*n* papers about country	26,859	8942	5482	4220	4170	***7243***
	n papers about country by in-country author(s)[b]	17,544	6834	3308	2909	2576	***2181***
Calculated	Proportion of articles produced by in-country geoscientists	65%	76%	60%	69%	62%	***30%***
	Ratio of country-specific geoscience articles per inhabitant	1:18,525	1:207,785	1:7406	1:43,658	1:14,247	***1:568,546***
	Ratio of country-specific geoscience articles by in-country authors per inhabitant, relative to Africa	30.7	2.7	76.8	13.0	39.9	***1***

[a] United Nations, (2019).
[b] Totals for Africa are for the continent (all 54 countries).

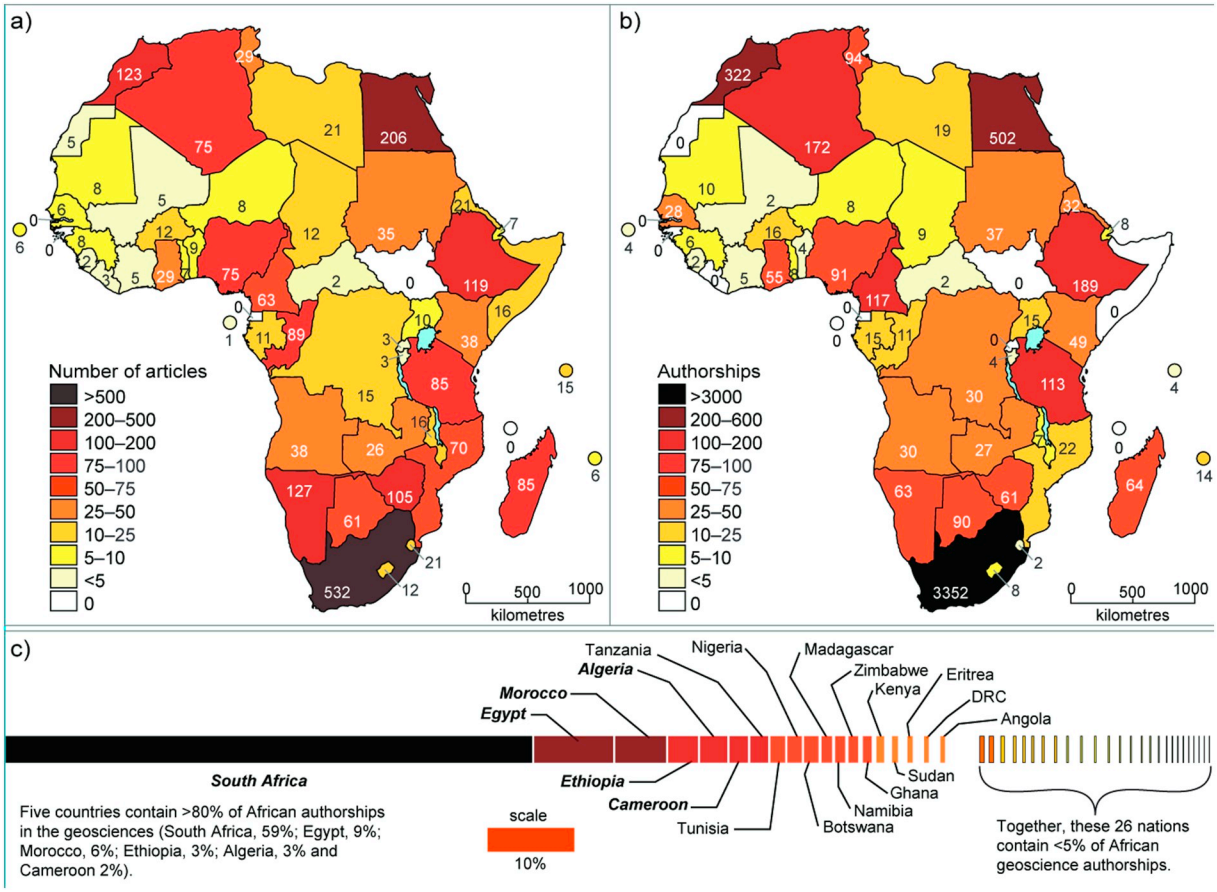

Fig. 4. Geographic distribution of (a) the number of articles on topics relating to each African country, (b) African authorships, and (c) relative contribution of different African countries to geoscience authorship for the 21 high-impact geoscience journals.

low representation of African authors in these highly cited articles (0.6%).

Eight of the 13 authors (from seven articles) have a primary African affiliation. These authors are from South Africa (five), Ethiopia (two) and Tanzania (one), which are countries that dominate authorship in Africa (Fig. 4b and c). The other five authors appeared in eight articles and each listed primary affiliation with non-African institutions (two from France, one from Norway, one from the USA and one from the UK) despite all being co-affiliated with South African universities.

The two African journals contain noticeably more African authors (right panel in Fig. 6a); however, the authorship trends between the two are different. Of the 25 most-cited articles from the *South African Journal of Geology*, 20 articles have African authors, whilst the five other articles have no African-affiliated authors. As such, all but one article were focused on site-specific studies in Africa. The 41 authors from the *South African Journal of Geology* articles hail from 39 institutions across five countries; 27 from South Africa (19 articles), eight from Mozambique (2 articles), two from Zimbabwe (1 article), and one each from Madagascar and Senegal. Two of the authors have African co-affiliations but have primary affiliations to institutes in Germany and Switzerland.

The top 25 articles in the *Journal of African Earth Sciences* yielded only 13 articles written by 28 African authors, 11 of which were on African topics. Seven other articles were published on site-specific African topics by authors without African affiliations. South African authors were most represented (6 authors, 5 articles) with a large spread of authorship among several countries: Egypt (4 authors, 1 article), Ethiopia (4 authors, 2 articles), Tunisia (4 authors, 1 article), Ghana (3 authors, 2 articles), Botswana (2 authors, 1 article), Morocco (2 authors, 1 article), Eritrea (1 author, 1 article), Kenya (1 author, 1 article) and Tanzania (1 author, 1 article).

We also compared the impact of African-authored articles (number of citations, Fig. 6b), African author output (number of publications, Fig. 6c) and the impact of these African authors (*h*-index, Fig. 6d) for the 21 high-impact geoscience journals relative to the African journals. It is evident that the high-impact articles containing African authors are highly cited (median of 233 citations), whereas those in the African journals are cited less frequently (median of 46 citations). Interestingly, the African authors who appear in the high-impact journals are typically more highly published than those publishing in the African journals (median of 81 vs. 19 publications, respectively) although the ranges for both are similar (13–233 vs. 1–205, respectively). This is borne out in the *h*-index data as well, given that the African authors in high-impact literature publish more and are more highly cited (median *h*-index of 27) than those appearing in the African journals (median *h*-index of 10).

4. Discussion and conclusion

4.1. Trends in African geoscience research

Between 1973 and 2017, up to 30% of articles in high-impact geoscience journals on African topics were written by African authors, which seems to be a healthy contribution to the literature (Fig. 1). However, this implies that 70% of the geoscience articles written in and about Africa did not involve any African collaborators. In examining representation further, it is evident that, of the articles in high-impact journals which mention a country by name, approximately 12% mention African countries (Fig. 3), compared with 85% of articles in the African journals. Additionally, African authors are nearly absent from

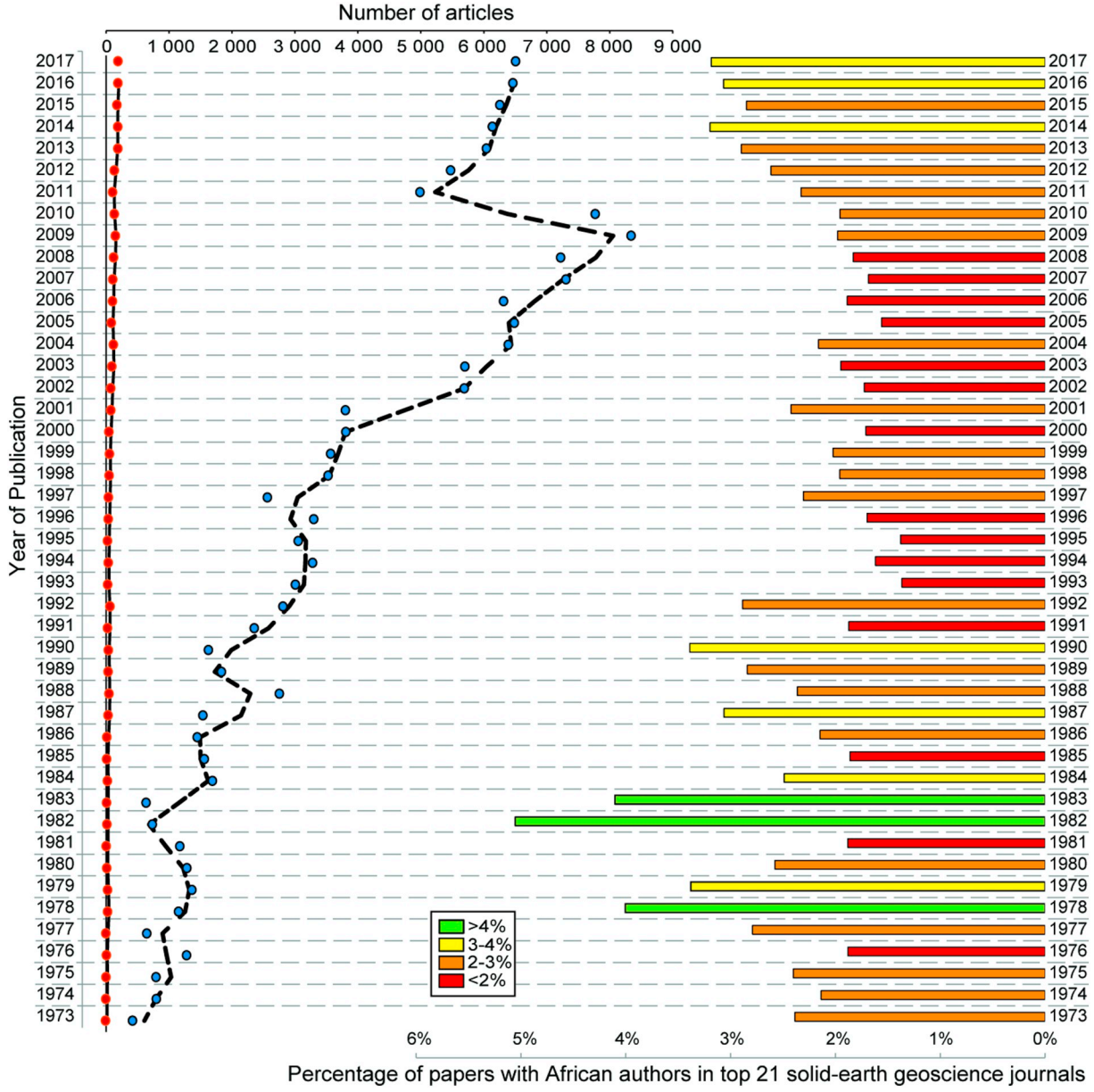

Fig. 5. Temporal distribution of articles published in the 21 high-impact geoscience journals between 1973 and 2017. Note the difference in moving average trends between African-authored articles (containing at least one author with an African affiliation) (solid black line with orange points) relative to the trend in total numbers of articles in the same journals (dashed line, blue points). The histogram plots the percentage of African-authored articles within these journals per annum. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the most highly-cited geoscience articles—only 13 of 2744 authors of such are African, five of whom have primary affiliations outside of the continent.

We have also demonstrated that the total percentage of geoscience articles on African topics, written by African authors, is ~2% in the high-impact journals (see Table SI.2), a figure similar to that of Atickem et al. (2019) who found that only 2.6% of all peer-reviewed scientific journal articles in 2013 included at least one African. We have also compared the generation of high-impact geoscience articles between Africa as a whole and other nations on a per capita basis. For example, China has a similar population to Africa, but produces twice as many publications, and a country as small as Australia (by population), generates 71 times as many.

The African authors that are present on high-impact articles are highly cited and have prolific research profiles (Fig. 6), demonstrating that Africa has the capacity to produce high-impact research. Similarly, some of the African authors publishing in the local African journals have above median *h*-indexes and high publication counts, indicating that these researchers are impactful in the global geoscience arena (Fig. 6). Why then is there so little representation of African authors in high-impact articles? Firstly, African geoscientists may choose to submit their work to Africa-centric journals, to serve those most likely to be impacted by their work, such as the *South African Journal of Geology* or *Journal of African Earth Sciences*. Secondly, African researchers may be reluctant to collaborate on high-impact work because of high teaching loads, or a lack of institutional incentive and financial support (Sawyerr, 2004). Even at the intra-African level collaborations are almost non-existent. For example, most African authors collaborate with non-Africans as their main first collaborator on publications, and only Lesotho, Namibia, Somalia, Eswatini and Zimbabwe collaborate internally (mostly with South Africa) (UNESCO, 2015). Note that we could not determine this for the geosciences only. African geoscientists

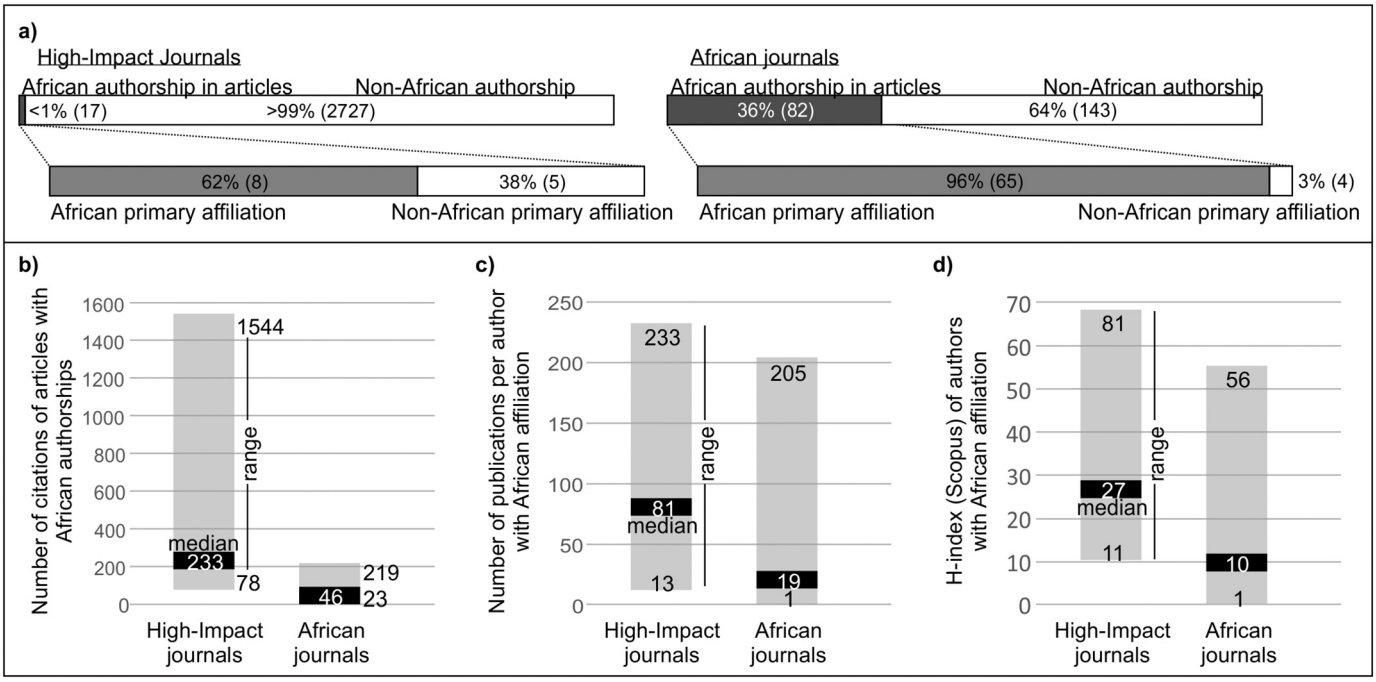

Fig. 6. Categorization of (a) African authorship in the 21 high-impact journals relative to the African journals (*South African Journal of Geology* and *Journal of African Earth Sciences*), based on author affiliation, and comparative histograms showing (b) the number of citations received by African-authored articles in the 21 high-impact journals relative to the African journals; (c) the number of articles published by African authors and (d) the h-index of African authors.

may also fear that submitting their research to high-impact journals will result in rejection, hence they opt for journals of lower impact which they perceive to be more receptive to their work (Ondari-Okemwa, 2007; Tarkang and Bain, 2019); and/or these journals may have high rates of rejection, resulting in limited work from Africa being published (Beaudry et al., 2018; Tarkang and Bain, 2019). Historically, Waast (2002) also showed that research in Africa has been market-driven (e.g., contract-based consulting-type research) rather than prestige-driven (e.g., aiming for high-impact research) with the obvious result of declining quality and no significant pressure to publish. Teasing out these specific issues would require background knowledge from authors and journals regarding how many articles are submitted and rejected, not just published, which is beyond the scope of this paper. We also acknowledge that some African geological research may not be stored in online repositories. For example, the work of Kay et al. (2013) showed that 25 of the 54 geological surveys in Africa do not store publications online; the same countries shown in this study to contribute little (or not at all) to geoscience article output (viz. Fig. 4c).

A clear dominance in geoscience research output (authorships, article output, impact) exists within Africa. The countries most researched in the geoscience articles are (in descending order) South Africa, Egypt, Namibia, Morocco, Ethiopia and Zimbabwe (Fig. 4a). The largest number of authorships are from South Africa, Egypt, Morocco, Ethiopia, Algeria and Cameroon (Fig. 4b), a list that largely coincides with the countries that produce the highest number of publications in all sciences in Africa (South Africa, Egypt, Tunisia, Nigeria, Algeria and Morocco) (Sooryamoorthy, 2018). South African geoscience publications has historically totalled ~6% of the national publication output (1993–2003), a substantial contribution to a non-dominant science field and proportionally higher than contributions from geosciences in the USA (~3%), the UK (~4%) (Schulz and Manganote, 2012) and Africa generally (1.8%) (Sooryamoorthy, 2018). There are established links between collaboration and research impact (Cimini et al., 2016), which suggests that this dominance may be related (at least in part) to these nations sharing strong collaborative links with their previous colonial countries (apart from Ethiopia which was never colonised). For example, the top two international collaborators with South Africa (a former British colony) are English-speaking (USA and UK) and the former French protectorates and colonies of Morocco, Algeria and Cameroon collaborate most frequently with French researchers (UNESCO, 2015). However, Egyptian authors are less influenced by this factor and collaborate most frequently with Saudi Arabia, the USA and Germany (UNESCO, 2015).

Economic drivers must certainly contribute to the apparent inability of Africa to compete with global research output. Tijssen (2007) showed that the share in world scientific articles by sub-Saharan Africa declined from 1.0% to 0.7% between 1987 and 1996, apparently as a result of African output not keeping pace with the rest of the world (e.g., Fig. 5). This is likely a manifestation of the fact that 33 countries in Africa meet the criteria for being “least developed” by the United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States. These Least Developed Countries, none of which occur in North America, Europe or South America, are economically vulnerable, have low school and university enrolment rates, and have an average annual income per person of < US$1025 (as of 2018). A more detailed discussion of the reasons behind these trends are presented in the next section.

4.2. African challenges

The publication of African-authored articles has been stagnant since the 1970s (Fig. 5), with only a marginal improvement since the early 2000s linked to an increase in funding to the continent (World Bank, 2008). With this increase in expenditure, it is surprising that the increase in articles published is not higher. Indeed, it is also concerning that the five years of highest relative output of African-authored geoscience were more than 25 years ago (1978, 1979, 1982, 1983, 1990) and that two of the lowest years of output are relatively recent (2005 and 2007). This trend may be linked to years of relatively low global output (e.g., 1982, 1990, and post-2009), but it may also be related to the well-documented ‘brain drain’ from Africa. King (2004) showed that a net outflow of 100,000 scientists from Africa to other countries occurs every year, and Capuano and Marfouk (2013) showed

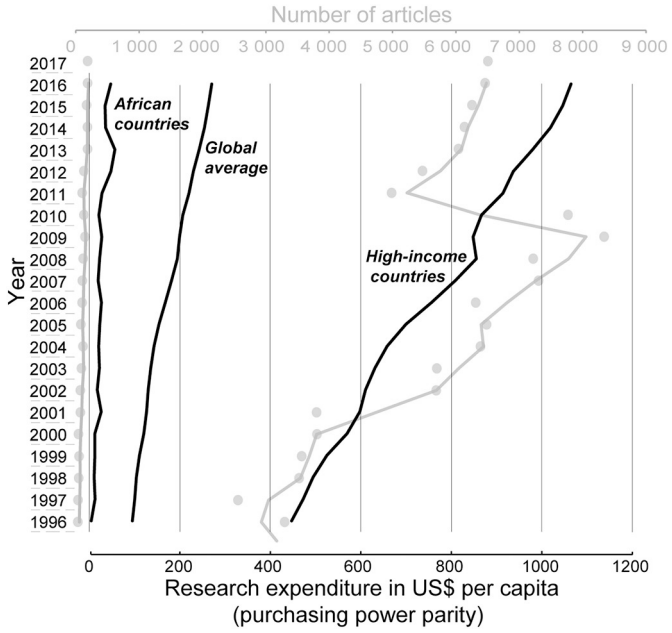

Fig. 7. Trends in average research expenditure in US$ per capita (normalized for purchasing power) for African countries, globally and for high-income countries (see Supplementary Information SI.3.2. for list of high-income countries) overlain on the data measured for article output (in grey—this study) (research expenditure data from the UNESCO Institute for Statistics, 2018).

more recently that, between 1990 and 2000, the number of highly-skilled immigrants from Africa to OECD countries increased by 90% (OECD = Organization for Economic Co-operation and Development; countries listed in SI.3.1).

For those scientists remaining on the continent there has been a history of difficult conditions. For example, at the Ahmadu Bello University in Nigeria it was found that, in 1999, 75% of all teaching staff had a second job from which most of their income was derived, and that at the time, a professor in Nigeria earned an average salary of US$170 per month (Waast, 2002). By comparison, an associate professor in the USA earned an average of US$4381 per month in 1999 (U.S. Department of Education National Center for Education Statistics, 2010).

The stagnation in literature output from Africa may also be related to government spending on research and development in a more general sense. To this end we have examined research expenditure data from the UNESCO Institute for Statistics (2018). When normalized for purchasing power in US$ currency terms, the differences in expenditure between high-income countries (listed in SI.3.2), the global average and the African average is clear (Fig. 7). Global average expenditure on research has been between US$100 and US$300 per capita since 1996, while that in Africa has increased from US$4 (1996) to US$42 (2017) per capita, with a maximum of US$56 in 2013.

When plotted and overlain on geoscience article output trends (i.e., from Fig. 5), there is an apparent parallelism (Fig. 7). The average expenditure on research in high-income countries was less than US$500 per capita in 1996 but has more than doubled over the past 20 years to US$1064. Interestingly, this trend tracks parallel to the trends in total numbers of geoscience articles in the high-impact journals, suggesting a clear mechanism for how the wealthiest nations are able to produce the largest share of articles. It is also noteworthy that the average global expenditure line is closer to the African trend than to the high-income countries, again indicating the disproportionate share of article output from the wealthiest nations.

Salager-Meyer (2008) points out that one of the reasons for relatively poor scientific output from developing countries is related to how these countries perceive basic scientific research (and the publication thereof) as a marginal activity. Such work requires significant resources (laboratories, specialized equipment, funding, research assistants, technicians), which cannot always be prioritized over more basic human needs. This is evident in the tertiary education enrolment rate in Africa, which is the lowest globally at 6% (Teferra, 2014) and is clearly linked to the economic investment into research, as illustrated in Fig. 7. Beaudry et al. (2018) recently completed an in-depth study of higher education and research in Africa. In general, they found that the main challenges affecting tertiary education are high demand for higher education coupled with lack of institutional preparedness for large student enrolments; lack of support for young doctoral students; lack of preparedness to cope with international demands for increased quantity and quality of research output; and mismatches in governmental support (funding) required by tertiary institutes for teaching and research intensity. This has resulted in poorly developed or maintained essential services, shortages in academic and technical staff and deterioration of infrastructure. Even if foreign funding is sought (or obtained) there is often a requirement of co-funding by the host country or host institution, a condition that frequently cannot be met by developing African nations (Bendana, 2019; Waast, 2002).

In-country geoscience resources also appear to be problematic. A recent study of geological surveys in Africa by the United Nations Economic Commission for Africa has revealed that: "*most African geological surveys are deficient in capacity and geological information*" (African Minerals Development Centre, 2018). In this report the work of Geoscience Australia was examined, as they undertook a desktop-based study of all geological surveys in Africa in 2012 (Kay et al., 2013). They used the availability of geology, geophysics, marine, hydrogeology, risk/hazard, remote sensing, mapping, mining and energy data, along with publication output and English language capability to make the assessment. It was found that only six countries were able to actively undertake major geoscientific surveys (South Africa, Egypt, Ethiopia, Morocco, Namibia, Tanzania). These countries are within the top seven producers of articles (apart from Namibia, which ranks 12th in Fig. 4c), indicating a link between an actively functioning national survey and article output. If one considers that a country's geological survey is a connection point for interested foreign geoscience researchers, any lack of capabilities has obvious consequences for meaningful collaborations. This may also explain why, despite 46 African nations receiving geoscience-specific World Bank funding (Kay et al., 2013), there is a dearth of article output—because money itself cannot conduct the research when technical and human resources are lacking in-country.

Lastly, we consider the fact that most (~70%) high-impact geoscience articles published about African topics do not involve a single African geoscientist (Table 2). This results from a practise, often referred to as 'parachute' science, which is typically carried out by researchers from developed nations conducting field work and sample collection in a developing nation, after which they return home to begin generating publications, without involving in-country scientists in their work (at least not as co-authors) (Harris, 2004). In some fields, mainly the medical and health sciences, practitioners are becoming increasingly aware of the negative impacts this can have, and it is largely frowned upon. Indeed, the editors of the prestigious medical science journal *The Lancet* expressed an "extremely unfavourable" outlook held for those articles submitted by authors who have not included collaborators from the nation in which the work was done (The Lancet Global Health, 2018). However, in geoscience there does not seem to be any established requirements or etiquette for international researchers to work with local scientists. We can see evidence of this even on the intra-Africa level, given that near-neighbouring countries to South Africa (Botswana, Namibia, Zimbabwe, Mozambique) have authorship numbers much lower than article numbers (Fig. 4a and b) and some such articles are known to have been authored by South Africans. It is perhaps then prudent for geoscience journals to become more vigilant about articles which stem from this type of 'parachute' science. Funding agencies could also enforce transparency about article authorship for

those studies conducted between high-income and developing countries to ensure equity.

4.3. African opportunities

One of the main aims for any researcher is to gain recognition of one's work in high-impact academic journals. Given that now, and for the foreseeable future, high-impact journals are in the English language, it is obvious that proficiency in English will be the gatekeeper for such recognition. It is in this area that African academics can leverage the existing English language abilities on the continent. Currently, 26 of the 54 African countries use English exclusively or as a second language, and 53 countries use English to some degree for communicative purposes. As recently as 2008, Rwanda introduced English as the language of instruction in school systems and its use is increasingly emphasized in politics and academia. The newest nation in Africa, South Sudan, has in fact adopted English as its official language (Plonski et al., 2013). This suggests that, notwithstanding other serious challenges (socio-economic, political, conflicts, readiness of geological surveys), Africa should be able to make its research globally accessible and collaboration should increase.

There are fewer single author articles produced in the scientific literature each year, resulting from an increase in scientific collaboration globally. Along with strong links to language commonality between collaborating nations (Cimini et al., 2016; Mêgnigbêto, 2013), these trends could have a positive effect in Africa. For example, previous studies have shown that international collaboration and funding produces research with higher impact (Adams, 2013; Cimini et al., 2016), suggesting that increases in collaborative project proposals can translate into more funding for Africa-based studies.

International engagement in the earth and environmental science programmes in Africa has also been increasing in the last 15 years. For example, the Africa Array program, which began in 2004 and initially focussed on southern and central Africa, has now spread to Ghana, Nigeria and Ethiopia (Nyblade et al., 2011). The mission statement of the Africa Array program is: "*To create new geoscientific research and training programmes and rebuild existing ones in Africa with Africans and for Africans*". More recently, Jessell et al. (2018) examined two linked initiatives: The West African Exploration Initiative (WAXI) which uses industry and partner government financial support to provide graduate and professional geoscience training in West Africa, and GEOLOOC, which is a UNESCO-supported online training program aimed at linking several West African universities to Earth Science resources. The work of Gill et al. (2019) is also an example of such initiatives in East Africa, wherein the British Geological Survey is developing collaborations in Africa. These projects ultimately aim to use the earth and environmental sciences to address social challenges in the region.

Despite its underrepresentation and significant challenges, Africa already has some capacity, and is building more, to participate in modern, high-impact geoscience research. However, if African economies wish to build geoscience capacity, they must accept that an increase in the percentage of their gross domestic product (GDP) spent on research is necessary (Sooryamoorthy, 2018). South Africa is an example of this, given that it has a long history of institutionalised research grant management (since 1918), and introduced performance-based funding to universities in 1985 (Luruli and Mouton, 2016). South Africa also enjoys a strong presence in all publication fields since receiving a boost to research and development funding through the BRICS collaboration (Brazil, Russia, India, China, South Africa) which began in 2010 (Chen and Chen, 2016). Furthermore, South African universities have been able to attract and retain highly productive researchers, probably as a result of competitive salaries: on a normalized purchasing-power basis, academic salaries in South Africa are second only to Canada (Altbach et al., 2013).

Foreign researchers (i.e., outside of Africa) also need to make serious efforts to develop collaborators in Africa when pursuing or developing their research programmes on the continent, which will bolster the impact of research and researchers in Africa. It may even be necessary for institutes and universities in high-income countries to re-evaluate their funding and reward policies in a way that promotes working with developing countries in an equitable way (Jeffery, 2014). Indeed, the same is needed in African institutions and universities—to reward meaningful geoscience research and international collaboration. African geoscientists should also make significant efforts to pursue international collaborations, attracting foreign researchers and investment into their areas of study on the continent.

Declaration of Competing Interest

The authors declare no known conflicts of interest, whether personal, financial, academic or otherwise in the research presented. The authors have no affiliation whatsoever with the initiatives and programs described herein. No funding was provided for this study.

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Appendix A. Supplementary data

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