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Leading optometry research institutions and countries in Africa: Lessons for building synergy and resilient education

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Background: Optometry training is shaped by institutional frameworks, with their professional orientation influenced by the academic pedigree of affiliated scholars. An institution's research defines the standards of clinical practice, the quality of training and the societal perception of the profession.

Aim: To identify the leading optometry institutions, the countries at the forefront of optometry research and the most influential academics contributing to institutional rankings in the field of optometry in Africa.

Setting: The study was conducted at the University of Cape Coast.

Methods: A bibliometric search was performed using Scopus, employing a comprehensive set of optometry-related search terms and a list of all African optometry training institutions. The retrieved publications were subjected to a two-stage screening process to identify studies related to optometry and authors affiliated with African optometry schools who are professional optometrists. Identified institutions were ranked based on the h-index, research productivity, citation metrics and publication rate of affiliated authors of the top 50 scholars.

Results: The University of KwaZulu-Natal was identified as Africa's leading optometry research institution. South Africa emerged as the continent's foremost contributor to optometry-related research output, with Kovin S. Naidoo being the most influential contributor. Kwadwo O. Akuffo, Godwin O. Ovenseri-Ogbomo and Sofonias A. Fekadu led Ghana, Nigeria and Ethiopia, respectively.

Conclusion: Africa hosts nine institutions across seven countries advancing research excellence in optometry, thereby contributing to evidence-informed practice.

Contribution: The study identified institutions, countries and researchers within the field of optometry to facilitate collaboration and strategic partnerships. It offers a platform to celebrate these entities' contributions, fostering motivation and encouraging the sustained pursuit of research excellence.

Keywords: optometry institutions; citation index; h-index; publication rate; Africa; bibliometric analysis.

Introduction

In celebrating Optometric academics globally, Efron acknowledged that the institutions and countries these scholars reside in are integral to their recognition and impact.[1] The research output produced by these individuals significantly informs evidence-based clinical practice and shapes the academic standing of their academic institutions and, by extension, the reputational profile of their host countries. Consequently, institutional rankings are inextricably linked to the scholarly contributions made within these environments.

These dimensions may be examined from multiple perspectives, including teaching excellence, student outcomes, student perceptions, completion rates, research productivity, peer evaluations, staff qualifications, innovation and societal impact.[1,2] Evaluating an institution based on a single, well-defined parameter within this multi-dimensional framework is often more straightforward

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Note: Additional supporting information may be found in the online version of this article as Online Appendix 1.

than employing a complex combination of these factors, which may be mutually exclusive.[2]

Accordingly, this study aims to evaluate optometry training institutions in Africa by assessing the research influence of their academic staff, research productivity, publication output and the span of publishing years.

Such rankings significantly influence prospective students' choice of institution, thereby playing a crucial role in shaping their academic trajectories. Consequently, institutions, regardless of their socio-cultural contexts, are compelled to enhance their capabilities to remain competitive and sustainable.[3] This dynamic can potentially influence the broader landscape of higher education in Africa by fostering institutional competitiveness and advancing disciplinary excellence.[3]

Research methods and design

The Scopus author profile records of the top optometric academics in Africa were obtained in comma-separated values (CSV) format, using the list of the top 50 optometric academics,[4] which ranked African optometric academics based on h-index, publication rate, prolificity and citation counts. Because Scopus updates regularly, the authors' Scopus records containing article titles, co-author lists, institutional affiliations, publication years, citation counts, language of document, document type, access model, indexed keywords and abstract were extracted on 30 July 2025.

Ranking institutions and countries

All author-specific files from the same country and those within the same institutions (Online Appendix 1) were merged and deduplicated to remove co-authored overlaps, resulting in a final list of unique publications for each institution and country. For each institution and country, aggregate metrics including total citations, total number of documents and group h-indices, which is the largest h such that at least h articles have each been cited ≥ h times,[5] were evaluated to assess their overall contribution to optometry research across Africa. Publications from all constituent authors were pooled per group, either country or institution and ordered by descending citation count. Another column was added to rank the citations from highest to the document rank number cited at least h times to obtain country specific or institutional specific, as demonstrated by Jorge Hirsch[5] and Efron et al.[6] In cases of a tie, institutions or countries with the same h-indices were further ranked according to the duration between their first and last publication, with fewer years being ranked higher to demonstrate high productivity. When multiple institutions or countries have the same h-index and publication span, the total number of citations and documents, sorted in descending order, was used as a tiebreaker.

Data analysis

The data were manipulated using Microsoft Excel.

Ranking authors contributing within countries

All data sheets provided by research collaborators were merged into a single sheet. All authors were ranked in descending order based on their h-index, a widely recognised metric for assessing research impact, as introduced by Jorge Hirsch.[5] The ranking was arranged in descending order, as a high h-index indicates greater research influence. In cases of a tie, authors with the same h-indices were further ranked according to the duration between their first and last publication, with authors who published over fewer years but had more documents ranked higher. When multiple authors had the same h-index and publication span, the total number of citations and documents, sorted in descending order, was used as a tiebreaker. Using this ranking system, the leading academic optometrists were identified and shortlisted for each institution and country.

Ethical considerations

This article followed all ethical standards for research, without direct contact with human or animal subjects. The analysis was based exclusively on secondary data obtained from the Scopus database, which is publicly available and does not contain personal identifying information. No consent was applicable, and the confidentiality of data was not compromised.

Results

The University of KwaZulu-Natal ranked as the leading optometry institution in Africa, achieving an h_{IN}-index of 63 (total sum of h-index from authors of the institution) from 14 academic optometrists ranked among the top 50 academic optometrists in Africa. The university is cited 81343 times from 611 documents and has a publication rate of 24.44 articles per year from the institution. The University of Cape Coast followed, attaining an h_{IN}-index of 28 from 12 optometry researchers, producing 34 articles per year, yielding 442 articles and documents and 4301 citations. Asmara College of Health Sciences recorded an h_{IN}-index of 6 with 24 publications, 139 citations and a publication rate of 1.85 articles per year (Table 1). The h_{CO}-index, the cumulative sum of authors' h-index within a country, was used to rank the leading country in optometry research.[6] South Africa emerged as the frontrunner in optometry research on the continent, with an h_{CO}-index of 65 and 83167 citations, gathered from 806 articles and 16 academic optometrists. Ghana ranked second with 21 optometric researchers contributing 397 articles, 20.89 articles per year and 4746 citations, yielding an h_{CO}-index of 31. Eritrea ranked lowest, with a publication rate of 1.85 articles per year and an h_{CO}-index of 6, based on the work of a single academic optometrist who had published 24 articles and received 139 citations. Notably, national journals were present in only two countries (Table 2).

Top 10 optometry researchers in South Africa

In South Africa, Kovin S. Naidoo emerged as the leading researcher with an h-index of 54 from 166 documents

and 68 883 citations over 25 years of publishing. Uchechukwu L. Osuagwu ranked second with an h-index of 29 from 170 documents cited 10 337 and a publication rate of 12.14 articles per year. The years of publication of top optometry researchers in South Africa range from 3 to 25, with an average of 13.7 years. Most of the top researchers in South Africa were affiliated with the University of KwaZulu-Natal. Among the top 10 in South Africa, only 20% were female – Bernadine N. Ekpenyong and Rekha Hansraj. Prasidh Ramson has 16 articles in only 3 years (2013–2016), yielding 304 citations and an h-index of 11 (Table 3).

Top 10 optometry researchers in Ghana

Kwadwo O. Akuffo, emerged as the topmost-ranked optometry researcher in Ghana and at Kwame Nkrumah University of Science and Technology, with an h-index of 15 from 50 documents in 11 years, yielding a publication rate of 4.55 articles per year and 896 citations. Samuel Kyei, who placed second in Ghana, was the lead at the University of Cape Coast, with an h-index of 15 from 102 documents cited 933 times in 12 years. Kyei has been the most prolific, with 8.50 articles yearly since 2013. University of Cape Coast researchers accounted for 60% of the top researchers in Ghana (Table 4).

Top researchers in Ethiopia

Only the University of Gondar optometry researchers were among the top researchers in Ethiopia. Sofonias A. Fekadu emerged as the leading researcher in Ethiopia, with an h-index of 8 from 19 documents and 243 citations in 5 years, yielding a publication rate of 3.8 artices per year. With a publication rate of 3.75 articles per year, Abel S. Assem ranked second, with an h-index of 6 from 15 documents and 91 citations over 4 years (Table 5).

TABLE 1: Top optometry research institutions in Africa based on bibliometric indicators.

Rank	University	Optometrists	$Citations_{IN}$	h_{IN}-index	$Documents_{IN}$	Year of first publication	Year of last publication	$Pub\ rate_{IN}$
1	University of KwaZulu-Natal	14	81 343	63	611	2000	2025	24.44
2	University of Cape Coast	12	4301	28	442	2012	2025	34.00
3	Kwame Nkrumah University of Science and Technology	9	2315	27	141	2006	2025	7.42
5	University of Johannesburg	2	2518	26	194	1970	2025	3.53
4	University of Benin	5	977	18	107	2002	2025	4.65
6	University of Gondar	5	601	14	57	2016	2024	7.13
8	Mzuzu University	1	179	9	15	2020	2023	5.00
7	Al-Neelain University	1	187	8	51	2016	2025	5.67
9	Asmara College of Health Sciences	1	139	6	24	2012	2025	1.85

$Citations_{IN}$, citations of institution; h_{IN}-index, h-index of institution; $documents_{IN}$, documents of institution (articles only); $Pub\ Rate_{IN}$, Publication rate of institution.

TABLE 2: Leading countries in optometry research.

Rank	Country	Population (in million)	Optometry schools	Num of optoms	h_{co}-index	$Citations_{co}$	$Articles_{co}$	Year of first publication	Year of last publication	$Pub\ Rate_{co}$	National journal	Sub-region
1	South Africa	64.75	4	16	65	83 167	806	1970	2025	14.65	African Vision and Eye Health	Southern Africa
2	Ghana	35.06	2	21	31	4746	397	2006	2025	20.89	None	West Africa
3	Nigeria	237.53	14	5	18	977	107	2002	2025	4.65	Journal of the Nigerian Optometric Association	West Africa
4	Ethiopia	135.47	2	5	14	601	57	2016	2024	7.13	None	East Africa
5	Sudan	51.66	1	1	8	187	51	2016	2025	5.67	None	North Africa
6	Malawi	22.22	1	1	8	179	15	2020	2023	5.00	None	East Africa
7	Eritrea	3.61	1	1	6	139	24	2012	2025	1.85	None	East Africa

h_{co}-index, h-index of country; $citations_{co}$, citations of country; $articles_{co}$, articles of country; $pub\ rate_{co}$, publication rate of country.

TABLE 3: Top researchers in South Africa.

Rank	Author name	Affiliation	Citations	Documents	h-index	Year of first publication	Year of last publication	Publication years	Publication rate
1	Kovin S. Naidoo	University of KwaZulu-Natal	68 883	166	54	2000	2025	25	6.64
2	Uchechukwu L. Osuagwu	University of KwaZulu-Natal	10 337	170	29	2011	2025	14	12.14
3	William F. Harris	University of Johannesburg	2274	166	26	1996	2019	23	7.22
4	Khathutshelo P. Mashige	University of KwaZulu-Natal	1112	121	15	2003	2025	22	5.50
5	Bernadine N. Ekpenyong	University of KwaZulu-Natal	347	38	12	2015	2025	10	3.80
6	Rekha Hansraj	University of KwaZulu-Natal	421	65	12	2014	2025	11	5.91
7	Samuel O. Wajuihian	University of KwaZulu-Natal	384	28	12	2012	2024	12	2.33
8	Prasidh Ramson	University of KwaZulu-Natal	314	16	11	2013	2016	3	5.33
9	Olalekan A. Oduntan†	University of KwaZulu-Natal	196	17	9	2012	2020	8	2.13
10	Alvin J. Munsamy	University of KwaZulu-Natal	180	40	8	2015	2024	9	4.44

†, Author is deceased.

TABLE 4: Top researchers in Ghana.

Rank	Author name	Affiliation	Citations	Documents	h-index	Year of first publication	Year of last publication	Publication years	Publication rate
1	Kwadwo O. Akuffo	Kwame Nkrumah University of Science and Technology	896	50	15	2014	2025	11	4.55
2	Samuel Kyei	University of Cape Coast	933	102	15	2013	2025	12	8.50
3	Emmanuel K. Abu	University of Cape Coast	585	58	15	2012	2025	13	4.46
4	Kofi Asiedu	University of Cape Coast	629	45	12	2016	2025	9	5.00
5	Samuel B. Boadi-Kusi	University of Cape Coast	426	49	12	2014	2025	11	4.45
6	Stephen Ocansey	University of Cape Coast	547	46	12	2014	2025	11	4.18
7	Samuel Abokyi	University of Cape Coast	407	31	10	2014	2024	10	3.10
8	David B. Kumah	Kwame Nkrumah University of Science and Technology	202	19	10	2011	2025	14	1.36
9	Emmanuel Kobia-Acquah	Kwame Nkrumah University of Science and Technology	347	29	10	2018	2025	7	4.14
10	Edmund Arthur	Kwame Nkrumah University of Science and Technology	327	25	9	2016	2025	9	2.78

TABLE 5: Top researchers in Ethiopia.

Rank	Author name	Affiliation	Citations	Documents	h-index	Year of first publication	Year of last publication	Publication years	Publication rate
1	Sofonias A. Fekadu	University of Gondar	243	19	8	2019	2024	5	3.80
2	Abel S. Assem	University of Gondar	91	15	6	2020	2024	4	3.75
3	Betelhem T. Yibekal	University of Gondar	141	11	6	2019	2023	4	2.75
4	Abiy M. Alemayehu	University of Gondar	136	13	6	2018	2024	6	2.17
5	Haile W. Alemu	University of Gondar	139	14	6	2016	2023	7	2.00

TABLE 6: Top researchers in Nigeria.

Rank	Author name	Affiliation	Citations	Documents	h-index	Year of first publication	Year of last publication	Publication years	Publication rate
1	Godwin O. Ovenseri-Ogbomo	University of Benin	464	39	14	2011	2025	14	2.79
2	Jennifer A. Ebeigbe	University of Benin	139	12	8	2006	2025	19	0.63
3	Mutali Musa	University of Benin	199	42	8	2022	2025	3	14.00
4	Onyekachukwu M.-A. Amiebenomo	University of Benin	140	11	7	2015	2024	9	1.22
5	Eghosasere Iyamu	University of Benin	110	10	6	2002	2015	13	0.77

TABLE 7: Top researchers in Sudan, Malawi and Eritrea.

Author name	Affiliation	Country	Citations	Documents	h-index	Year of first publication	Year of last publication	Publication years	Publication rate
Saif H. Alrasheed	Al-Neelain University	Sudan	187	51	8	2016	2025	9	5.67
Chikasirimobi G. Timothy	Mzuzu University	Malawi	179	15	9	2020	2023	3	5.00
Rajendra Gyawali	Asmara College of Health Sciences	Eritrea	139	24	6	2012	2025	13	1.85

Top researchers in Nigeria

The University of Benin stands out in Nigeria's optometry research landscape. Godwin O. Ovenseri-Ogbomo emerged as the leading optometry researcher in Nigeria, with an h-index of 14 from 39 documents and 464 citations over 14 years, yielding a publication rate of 2.79 articles per year. Jennifer A. Ebeigbe ranked second, attaining an h-index of 8 from 12 articles and 139 citations over 16 years with a publication rate of 0.63 documents per year. The top Nigerian optometry researchers' publication spans 4–19 years (Table 6).

Top researcher in Sudan, Malawi and Eritrea

Only one optometry researcher from Sudan, Malawi and Eritrea was featured in the top 50 (Table 7). From Al-Neelain University, Saif H. Alrasheed has led the Sudanese Optometric research with 51 publications, 187 citations and an h-index of 8 since 2016, with a publication rate of 5.67 articles per year. At the University of Mzuzu, Chikasirimobi G. Timothy has led optometry research with 15 publications, 179 citations and an h-index of 9 in just 3 years, a remarkable 5 articles per year. Rajendra Gyawali represents Asmara College of Health Sciences as the only optometry researcher from Eritrea who made the list of the top 50 optometric researchers in Africa with an h-index of 6, 139 citations, 24 documents and a publication rate of 1.85 articles per year.

Discussion

Optometry, recognised as one of the fastest-growing healthcare professions globally, has evolved beyond its traditional focus on spectacle dispensing and basic vision testing.[6] It is now regarded as a comprehensive field of eye and vision care, essential in detecting, diagnosing, treating and managing ocular diseases and visual impairment.[7] The role of optometry in achieving Universal Health Coverage and reducing visual impairment caused by uncorrected refractive errors by 2030 is of critical importance.[8] The profession is gaining significant traction in Africa, with an increasing number of young Africans pursuing optometry as a career. This trend is often influenced by students' preference for educational institutions, which are linked to the institution's academic reputation.[9,10]

According to research impact metrics, the University of KwaZulu-Natal in South Africa is Africa's most prestigious optometry institution, followed by the University of Cape Coast in Ghana (Table 1). South Africa has been training optometrists since 1924,[11] and its long history has likely contributed to developing robust structures and resilience in optometric research and postgraduate training. Although Ghana has a relatively shorter history in optometry training, it has made significant progress, becoming the second institution, after Sudan's Al-Neelain University, to establish a full-fledged school of optometry.[11,12]

South Africa has made significant strides in developing a local and/or national journal, the *African Vision and Eye Health Journal*. This publication has become a prominent platform for scholarly contributions from optometric academics across Africa and internationally.[13] Not only is this well established, it is also the only national optometry journal in Africa currently indexed in major databases such as Scopus, with a Q3 rating in Scimago (www.scimagojr.com). Nigeria also maintains a national journal, the Journal of the Nigerian Optometric Association, which has facilitated the dissemination of research findings from Nigeria and the surrounding region. In contrast, Ghana and several other African countries lack a dedicated national optometric journal. As a result, Ghanaian scholars are compelled to publish in international, regional or other local journals, which limits opportunities for promoting research of national relevance. To foster scholarly discourse and advance optometry and vision science in these countries, it is essential to prioritise establishing and developing national optometric journals. Both local and international funding bodies should support this effort. South Africa's success in creating a reputable optometry and vision science literature platform can serve as a model. Furthermore, the African Council of Optometry (AFCO) could play a pivotal role in championing this initiative, which would not only enhance the profession but also position the region as a central hub for knowledge generation in optometry.

To achieve the 17 sustainable development goals (SDGs) by 2030, the seventeenth goal emphasises the means of implementation to revitalise global partnerships for sustainable development.[14,15] This partnership is pivotal for advancing the scholarly standing of optometry in Africa, particularly when fostered within and beyond national borders. South Africa's long-established optometric educational infrastructure offers an opportunity for mentorship and support to neighbouring countries, facilitating significant progress in the field. Notably, institutions such as the University of Johannesburg (UJ), which ranks among the top African universities (Table 1), and the University of KwaZulu-Natal (UKZN), a continental leader, are positioned to exchange knowledge and collaborate in strengthening optometric education.

Moreover, comparisons between the Doctor of Optometry and BSc training models offer valuable insights for enhancing educational standards. High-ranking institutions and countries in optometric scholarship should partner to develop robust training systems that meet national and continental needs. The University of Al-Neelain in Sudan, the first African institution to establish a school of optometry at the standard of developed countries such as Australia, was notably omitted from the recent survey mapping optometry education in the subregion.[16] This exclusion may be attributed to the political instability stemming from ongoing conflict in the country.[17] Strengthened collaboration and partnership are crucial to supporting and revitalising Sudan's optometric standing. Despite the conflict, the institution was ranked among the top 10 optometric institutions, with faculty member Saif H. Alrasheed leading the way (Table 7).

The shortage of qualified academics is frequently cited as a significant barrier hindering the progress of optometric education across Africa and in many of its countries. The challenge of attracting and retaining distinguished optometry scholars persists in the region.[16] As such, it is essential to recognise and celebrate the scholars, institutions and nations that serve as the cornerstone of optometric knowledge. The scholarly contributions of these entities have had a direct or indirect impact on Africa's 1.5 billion people. UKZN and UJ are recognised in South Africa for their significant contributions to optometric scholarship (Table 1).

Among the top-ranked researchers in South Africa, nine are affiliated with UKZN, with only one from UJ. Notably, UKZN is distinguished by having female optometrists among the top 10, with Bernadine N. Ekpenyong and Rekha Hansraj serving as inspirational role models, especially for young women in the field. Kovin S. Naidoo, is the leading optometry scholar in South Africa, with William F. Harris of UJ ranked third (Table 3). In Ghana, Kwadwo O. Akuffo of KNUST, is recognised as the most esteemed optometry researcher, with Samuel Kyei, leading in productivity (Table 4). Despite optometry's relatively recent establishment in Ethiopia, the University of Gondar has remarkably impacted optometry research, with five of its scholars ranked among the top 50 in Africa. Sofonias A. Fekadu, stands out as the most notable researcher in Ethiopia (Table 5).

Among the 14 optometric institutions engaged in optometry scholarship in Nigeria,[16] the University of Benin produced all five scholars ranked in Africa's top 50 highly regarded optometry academics (Table 6). Godwin O. Ovenseri-Ogbomo is widely acknowledged as the foremost scholar in this cohort (Table 6). The University of Benin, recognised as the oldest institution for optometry training in Nigeria and the first in Africa to introduce the O.D. programme, bears a significant responsibility in fostering and supporting the academic development of its counterpart institutions to further the advancement of optometry scholarship. A notable observation regarding the academic staff profile within the Optometry Department at the University of Benin is the predominance of PhD qualifications in disciplines outside of optometry and vision sciences, namely Pharmacology,

Microbiology and Biochemistry. This disciplinary misalignment may partly explain the limited research output in core optometry and vision science fields.

With its 14 optometry schools, all offering the O.D. programme, Nigeria remains the leading nation in optometry institutions. In comparison, Sudan, Malawi and Eritrea each contributed a scholar to Africa's top 50 optometry academics.[16] Notable scholars include Saif H. Alrasheed of Al-Neelain University, Chikasirimobi G. Timothy of the University of Mzuzu and Rajendra Gyawali of the Asmara College of Health Sciences (Table 7). This underscores the importance of collaboration and partnership within the African academic community, wherein distinguished African researchers such as Kovin S. Naidoo could serve as mentors, and institutions could share best practices to enhance the scholarly development of their researchers and institutions. Although the study is bibliometric in nature, it has important clinical implications. Institutions that produce high-impact research often train the next generation of clinicians influence curriculum development and support evidence-based practice. As such, academic productivity serves as a proxy for broader clinical and educational excellence in optometry.

Limitations

The data synthesised were as per Scopus records as of 30th July 2025. The reliance on the Scopus database as the sole database presents potential bias, as Scopus does not index all journals. This may affect the publication metrics and ranking of researchers who publish in non-Scopus-indexed journals. There could have been changes in institutional affiliations after this date, which this study could not have captured. There is the possibility of scholars who might not have updated their affiliations, and, therefore, their information is still assigned to their previous institutions. The study did not account for multiple affiliations outside Africa and non-optometry training institutions. It could not fully account for the up-to-date record of deceased scholars. All these said, the study provides valuable information for stakeholders in optometry education and practice, which only requires updates occasionally.

Conclusion

The findings of this study indicate that Africa has cultivated a growing cadre of optometric scholars who are making significant contributions to both clinical training and academic literature. Key institutions including the University of KwaZulu-Natal, University of Cape Coast, Kwame Nkrumah University of Science of Technology, University of Benin, University of Johannesburg, University of Gondar, Al-Neelain University, Mzuzu University and Asmara College of Health Sciences alongside respective host countries such as South Africa, Ghana, Nigeria, Ethiopia, Sudan, Malawi, Eritrea have been identified as pivotal in fostering collaboration and enhancing the scholarly profile of African optometry institutions.

While progress is evident, challenges such as limited funding, insufficient mentorship and an over-reliance on foreign journals impede the full development of optometry research in Africa. Targeted strategies are essential to ensure the sustainability and expansion of these academic achievements. These include promoting national journals, enhancing mentorship programmes, strengthening institutional collaborations and active involvement of organisations such as the AFCO in supporting capacity-building initiatives. Implementing these strategies will contribute to advancing optometric scholarship in Africa, improving eye care outcomes and reinforcing the continent's position within the global optometry community.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article. The author affirms that this submission complies with ethical standards for secondary publication, and appropriate acknowledgement has been made of the original work.

CRediT authorship contribution

Pious T. Amoako: Methodology, Formal Analysis, Writing - Original Draft, Visualisation, Software, Data Curation, Writing - Review & Editing. Samuel Kyei: Conceptualisation, Methodology, Formal Analysis, Writing - Original Draft, Visualisation, Project Administration, Validation, Resources, Writing - Review & Editing, Supervision. Paul Owusu: Formal Analysis, Visualisation, Software, Data Curation, Resources, Writing - Review & Editing. Joseph M. Sa-Ambo: Methodology, Formal Analysis, Investigation, Project Administration, Data Curation, Writing - Review & Editing. Gideon Owusu: Investigation, Writing - Original Draft, Visualisation, Validation, Data Curation, Writing - Review & Editing. Randy Asiamah: Software, Data Curation, Writing - Review & Editing, Supervision. Patrick Evans Agyiri: Formal Analysis,

Investigation, Visualisation, Data Curation, Writing - Review & Editing. Samuel Ankamah: Methodology, Visualisation, Software, Validation, Writing - Review & Editing, Supervision. Khathutshelo P. Mashige: Methodology, Investigation, Visualisation, Project Administration, Validation, Resources, Writing - Review & Editing, Supervision.

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Data availability

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