Nigerian Journal of Technology (NIJOTECH)
Vol. 42, No. 3, September, 2023, pp.389 - 398
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v42i3.12

COVID-19 CRISIS ERA; ENGINEERING INTERVENTIONS IN SUB-SAHARAN AFRICA

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ARTICLE HISTORY:
Received: 05 May, 2023.
Revised: 06 June, 2023.
Accepted: 28 June, 2023.
Published: 01 November, 2023.

KEYWORDS:
Artificial Intelligent, COVID-19 Pandemic, Engineering Innovation, Health care, Manufacturing, Robotics, Sub-Sahara Africa

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITOR:
Patrick Akpan

FUNDING:
None

HOW TO CITE:
Oyejide, A. J., Akinlabi, A., Atoyebi, E. O., Falola, P. B., Awonusi, A. A., and Awolabi, F. "Covid-19 Crisis Era; Engineering Interventions in Sub-Saharan Africa", *Nigerian Journal of Technology*, 2023; 42(3), pp. 389 – 398; https://doi.org/10.4314/njt.v42i3.12

Abstract

Despite numerous notable contributions by Africans during the Corona Virus Disease (COVID-19) outbreak, little effort has been made to document these contributions in a comprehensive publication. Herein this work, an attempt was made to bring together African-based technological interventions proffered in Sub-Saharan Africa during this period. Across Africa generally, different engineering methods were used to develop several contrivances such as ventilators as well as deploying Artificial Intelligence to facilitate contact-free human-human and human-object interactions. Broadly, these approaches center on two key areas which are efforts to mitigate the spread of the infectious disease, and management of the infected, which are the focus of this present work. Indeed, a comprehensive report of these efforts is essential to appraise the contributions of the home-based researchers and to create an archive for future research and decision making across the African continent, thus necessitating the need for this systematic appraisal.

1.0 INTRODUCTION

The sudden outbreak of SARS-COV-2 virus has proven again beyond reasonable doubts that "necessity is the mother of invention." The COVID-19 outbreak, which stared the whole world in the face, took away loved ones unplanned, imposing serious socio-economic and health implications [1-3, 9]. This global crisis revealed current weaknesses in the Sub-Saharan African (SSA) region's health, connectivity and communications infrastructure, in addition to disadvantage of excessive dependence on importation of manufactured goods. Due to restriction ofmovement, traditional fields such as electrical, mechanical, civil, chemical engineering and others that rely on work by on-site teams were negatively impacted [1]. On the other hand, disciplines including AI, robotics, ICT, computer engineering, medical and biomedical engineering witnessed unprecedented growth being at the fore of supporting efforts towards mitigating the effects of the crisis and will continue to gain grounds in the era of the "new normal" [1]. These numerous challenges thus forced the necessity of several innovations in Africa which are aimed at curbing the spread of the pandemic as well as to aid its management. It is believed that many more innovations are still underway to completely flatten the curve of the infection [4]. While looking forward to these, it is imperative to showcase the several notable pandemic-inspired inventions by African

Engineers developed towards tackling the crisis that deserve worldwide attention and acknowledgement.

The significant outcomes of some of the technologies and engineering approaches to limit the severity of the COVID-19 pandemic across Africa have been published in some reputable journals. For instance, [5] provided a comprehensive overview of the utilization of addictive manufacturing for ventilator components in South Africa during the COVID-19. Also, [6] provided a rapid review on utility of telemedicine in sub-Saharan Africa during the COVID-19 pandemic, exploring the benefit and challenges. Furthermore, a comprehensive review was published by [7] to reveal the accuracy of utilizing big data analytics, artificial intelligence and nature-inspired computing models to detect COVID-19 infection and contact tracing in Africa. Also, a system review was done by [8] to explore the deployment of digital technology in Africa during the first wave of the COVID-19 pandemic. The authors attest that African countries employed technology and creative approaches to effectively handle patients, track cases, and communicate vital information in order to combat the transmission of the COVID-19 virus. While appraising the advancement in robot and drone applications to ease the negative effect of the COVID-19 pandemic in developed countries of the world, [9] noted that such technologies were not only adopted by researchers and scientist in Sub-Saharan Africa, but there were also attempts to develop them.

Several documented and undocumented efforts were made in line of engineering, technology and innovation across Africa, particularly Sub-Saharan Africa, and while the above-cited literature and many more have published a few of the innovations, none, to the best of the authors' knowledge, has provided an overview of the contribution of African home-based researchers and innovators to several core aspects of engineering and technology that were conceptualized, developed, implemented and deployed during the COVID-19 pandemic waves in Africa.

It is against this backdrop that the different interventions proffered, their outcomes and how they helped to shape SSA healthcare system were mapped out in this present work.

2.0 METHODOLOGY

This study was a mix of desk review of extant literature and inductive analysis of research and non-research innovative engineering activities across Sub-Saharan Africa during the COVID-19 pandemic. To achieve a comprehensive appraisal, published journals and articles available on the Internet on COVID-19 pandemic in Africa between 2019 and 2022 were considered since this was the period when the outbreak began and peaked. The initial search was limited to uploads on Google Scholar and ResearchGate. The second approach was to access pre-publication and not yet peer-reviewed publications from reliable sources such as University press, BBC documentary and random Internet search, which was then filtered by the authors for quality, and interest to the current article. Besides, the different materials were addressed by the co-authors based on their areas of teaching and research expertise and were finally addressed holistically by all authors before developing the entire article.

3.0 DISCUSSION

3.1 Engineering and Technological Interventions in Sub-Saharan Africa during COVID-19 Pandemic

3.1.1 Artificial intelligence and robotics

A. Artificial Intelligence

Throughout history, an effective epidemiologic approach towards safeguarding lives during any pandemic is to put in place measures that assure control and prevention of disease transmission. The COVID-19 was no exception, with many countries implementing physical distancing. AI was applied to COVID-19 in the areas of medical image acquisition, image segmentation and diagnosis, and the quick identification, classification, screening, and quantification of COVID-19 patients [10, 11]. However, tracking and predicting COVID-19 occurrences in affected regions like Africa has been challenging due to the lack of huge amounts of historical local data to train AI models [12]. Generally, lack of data is a big limitation to AI technologies [13]. This led to the development of AI forecasting models. The majority of the social media and noisy data used in the training of the forecasting models are in multiple data formats, lacks data standardization and interoperability, and missing values, which can be erroneous and unreliable [14]. This often times affects the performance and accuracy of the models.

In developed countries like Europe, COVID-19 outbreak forecasting helped in developing appropriate procedure in developing vaccine and therapy plans and to concentrate on areas that need more attention and implementing precautionary measures to stop the pandemic from spreading [15]. In Africa, it is noteworthy that some forecasting models were also developed using Artificial Intelligence. For instance, [16] used Ensemble Kalman Filter (EnKf) approach, a deep learning model for short forecasting of COVID-

19 pandemic using Cameroon as a case study. The authors sought to know the COVID-19 trend in Cameroon. The investigation was able to state the significance of efficient control measures in preventing the spread of the pandemic. Likewise, [17] proposed an online forecasting system of COVID-19 cases in Nigeria. In order to update the ensemble model's parameters, which in turn produced updated COVID-19 forecasts every 24 hours, data was streamed from the Nigeria Center for Disease Control (NCDC). This gave policymakers the push they needed to deploy containment strategies and/or evaluate containment interventions in order to stop the spread of COVID-19 in Nigeria. An artificial neural network (ANN) model was used in Seychelles between January 2020 and July 2021 to forecast COVID-19 confirmed cases [18].

There were other ways through which AI was employed by Africans in combating the pandemic, such as the effective control of physical distancing by implementing cashless, Internet-based transportation payment service in Ethiopia [19]. Also, [20] proposed an Artificial Intelligence-based technical framework to aid effective diagnosis and treatment of the COVID-19 and its associated comorbidities in resource-limited settings, focusing specifically on Sub-Saharan Africa. This AI-framework enables harnessing of diagnostic data from different point of care units using evaluations from radiological images, polymerase chain reaction and information provided by end-users so as to detect and manage COVID-19, thereby limiting the spread of the disease. Further work includes the proposed low-cost block chain and artificial intelligence-coupled self-testing system and tracking system for COVID-19 and other emerging infectious illnesses by [21]. The proposed technology, which is adaptable for use in communities with infectious diseases awakened the involvement of relevant stakeholders for the development and implementation of the technology. Furthermore, [22] developed a dynamical epidemic model for the estimation of vital epidemic parameters of COVID-19's early-stage transmission as well as to forecast the evolution of COVID-19 in Algeria.

According to UNESCO, radio is the most reliable and cost-effective way to acquire and share information throughout the majority of the developing world. On radio, people frequently provide first-hand accounts of situations that are not otherwise documented and express their personal opinions without being influenced by research questions or fear of judgment [23]. As a result, UN Global Pulse deployed a speech-to-text technology, an AI-based application to extract public radio content in real time using keywords related to COVID-19 for decision making in Uganda and Tunisia [24]. The analysis of the public radio discourse is of benefit in tackling COVID-19 through rapid identification of affected locations and intensity of possible outbreaks in the community. This also helps to support public health professionals to hasten investigation and respond faster to communities infected.

According to Euro News, Dr. Mustafa Hamdi and his students at the National Institute of Applied Sciences and Technology (INSAT) in Tunisia developed an online open access platform that aids in the detection of COVID-19 in the lungs of suspected patients in order to save time and have a diagnosis other than the standard test kit. The platform operates by comparing the x-rays of a COVID-19 patient with that of a person who is thought to be infected with the virus. The accuracy of the algorithm used was 92% [25].

In South Africa, a mobile and web application, EMGuidance which used AI technology was used by medical professionals for medicines and treatment [26]. Chatbots implemented using AI, HealthAlert Virtual assistant provided useful health information to people [26]. In Kenya, M-Pesa (a mobile application) was developed to make social distance easier with its mobile payment technology [27]. There was also development of an electronic pass to implement physical distancing between essential workers and travelers in Sierra Leone [28] and design and deployment of FAIR digital health infrastructure in Uganda, Ethiopia, Liberia, Nigeria, Kenya, Somalia, Tanzania, Zimbabwe, and Tunisia for COVID-19 reporting and genome research [29].

B. Robotics

In the aspect of robotics, students from Senegal Advanced School of Engineering in Dakar created a robot named Dr. Car—a car equipped with mechanical arms and a mounted camera [30]. Hospital workers may remotely engage with patients through Dr. Car, bring them food and medical supplies, monitor their temperature and take their blood pressure. Similarly in Rwanda, humanoid robots perform some medical staff tasks in COVID-19 isolation centers, such as taking body temperatures of patients in order to reduce human contact and transmission [31]. The creation and use of robots, the costs associated with provision of protective equipment for medical staff and the risk of spread of COVID-19 virus from patients to the front-line health workers were significantly reduced.

https://doi.org/10.4314/njt.v42i3.12

Another interesting application of AI and robotics during the pandemic was the use of drones. Drones equipped with a loudspeaker developed by a firm called Zipline were used in Rwanda and Ghana to convey pandemic prevention strategies as well as to monitor and manage containment and quarantine measures [32]. In the shortest time possible, drones deliver drugs, test samples, COVID-19 tests, and packages of blood to several hospitals or isolation centers since they do not require to use roads that are most likely in poor shape in the SSA countries. Sprayer drones developed in Botswana have the capability of disinfecting 3,000 cubic meters of air in 30 minutes in public places like hospitals, supermarkets, petrol stations, and isolation facilities [31]. Doctors and healthcare facilities were able to track shipments of PPE, vaccines, and blood after placing orders via an app [33]. Drone flight times range from 15 to 30 minutes, and they can be launched 5 to 7 minutes after an order is received. This innovation was slated for export to the United States (US).

While researchers worked independently from their countries, it is also important to mention that a collaboration between experts from 11 African countries (Botswana, Cameroon, Canada, Eswatini, Mozambique, Namibia, Nigeria, Rwanda, South Africa, Zambia and Zimbabwe) and researchers from York University implemented Big data and AI-based techniques in nine (9) African countries to provide data analysis strategies to aid informed public health decision making and COVID vaccination rollout approaches [25].

3.1.2 Medical and molecular engineering

The Africa Higher Education Center of Excellence for Genomics of Infectious Disease (ACEGID) located in Redeemer's University, Nigeria in collaboration with Center for Disease Control (CDC) is the first institution in Africa to successfully sequence Genomes for SARS-COV-2 [33]. Since 2020 after the outbreak of COVID-19, ACEGID has identified 55 variants of the virus including the B.1.1.7 (UK) variant [33]. As at 2021, ACEGID has tested more than 42,000 samples from Nigeria alone.

As measures to combat the spread of the SARS-COV-2, ACEGID has been helpful in training for CDC frontline health personnel in Polymerase Chain Reaction (PCR) diagnostic technique. Because of her laudable achievements towards mitigating the negative health implications of COVID-19 pandemic, ACEGID situated in Nigeria, Western Africa Region has been named by WHO as a specialized continental reference sequencing research laboratories for emerging pathogens, including the SARS-COV-2. In January 2021, [34] presented detailed phylogenetic analysis of genome sequenced in six SARS-CoV-2 positive samples from the first major infection wave in the Union of Comoros. Other researchers in this category include evaluation of reinfection with SARS-CoV-2 in Libya [35] and cross-sectional, nationally representative, age-stratified sero-survey study in Sierra Leone by [36].

3.1.3 Software, electrical and electronics applications

The software industry was not left out in the creation of countermeasures to combat the spread of corona virus. This is evident in the several software tools that were created to facilitate real time tracking and visualizations of the spread of the virus. For example, by using an online platform that is powered by an Unstructured Supplementary Service Data (USSD) protocol, Ghana citizens can self-report their corona virus symptoms and locations [31]. Ushahidi (which means 'testimony' in Swahili) is a mobile application developed in 2008 by a community of Kenya cyber activist. Ushahidi was developed initially to locate precisely on an interactive map any act of violence in the aftermath of a highly contentious election. In fact, this particular invention was the first 'crisis-mapping' application in the world and the first open-source software in Africa. Fast forward to mid-March 2020 (12 years later), Ushahidi became a worldwide tool used in fighting COVID-19. Italian humanitarian NGOs employed this Kenyan invention on a regular basis to report vulnerable and isolated people in northern Italy and Sardinia. This has helped elderly people in unstable situations gain access to medicine and food supplies during the lockdown. [27]. This same App gained relevance in other countries such as Nigeria, Peru and Japan during the pandemic. A similar App called Hackcovid App was developed by The Moroccan Federation of IT Technologies (APEBI) to digitize citizen solidarity to mitigate the social consequences of the COVID-19 virus [27].

One of the effective guidelines specified by the World Health Organization (WHO) to limit the spread of COVID-19 is by avoiding direct contact with the mouth, eyes and nose. However, these parts of the body are essential to humans and touching them is often by reflex action, for instance when itching. To address this, two students of Electrical and Electronics Engineering, Federal University of Technology, Owerri, Nigeria collaborated to develop a wrist contrivance which alerts the wearer when the hand on which it is worn is taken towards the face [41]. A similar device called personal health monitoring device (PHMD) was designed by [42] in Nigeria which allows people to continuously monitor their health, thereby reducing the need to visit a hospital during the pandemic. The portable, mobile, low-cost and energy efficient device was equipped with capabilities to display electrocardiograph (ECG), to measure oxygen saturation (SpO_2) and pulse rate (beat per minute).

Although instrumental in addressing the outbreak, maintaining physical distancing could not completely prevent the spread of the disease due to its airborne nature. Surfaces such as clothing materials, bags, wrist watches, skin and others are medium through which the COVID-19 can be transferred. A scientific evaluation revealed different stabilities of the disease on skin (96hrs at 22° and 8hrs at 37°C), bank notes (8hrs at 22°C and 4hrs at 37°C) and clothing (96hrs at 4°C and 4hrs at 22°C) [43]. One of the technologies developed in this regard was disinfecting chamber equipped with pumps and piping that deliver alcohol-based sanitizers in form of fumes to the body of a person passing through it. Throughout Africa, different kinds of the disinfecting chambers were developed, which includes in Ghana [44] and DICovid Disinfectant Booth in Nigeria [45]. Other devices include; Police robots in Tunisia, automated hand sanitizers dispensers, Google assistant automatic home control device/switch, infrared-based thermometers [30, 46, 47].

3.1.4 Manufacturing: Mechanical tools and protective equipment

Mechanical tools such as the ventilator were crucial to the management of COVID-19 outbreak. At some point worldwide, there was a shortage of ventilators needed to savage the lives of infected patients [48, 49]. In fact, the United States Food and Drug Administration (FDA) listed ventilators as one of the essential tools inadequate in number for the management of the disease [50]. Innovators and experts in Africa also rose to the challenge of developing low-cost, effective and affordable ventilators in Ethiopia, Nigeria and Sierra Leone to bridge the gap created by the shortage [49, 51]. For instance in Kenya, engineers of the Kenyatta University situated in Nairobi successfully developed a prototype ventilator that costs just 10% of the cost that the ventilator machine will be imported [37]. In addition, engineers from different universities in SSA collaborated to develop a ventilator that will only take about one hour to install. Besides, the first ventilator made in Rwanda was successfully created by biomedical engineers from the Integrated Polytechnic Regional College Kigali (IPRC) [38]. Also, for the first time, the Jomo Kenyatta University of Agriculture and Technology (JKUAT) created a portable solar-powered ventilator during the peak of the COVID-19 season [33]. The importance of stepping in to manufacture ventilators locally is evident when considering the low numbers of ventilators available in SSA compared with the need estimates. As revealed by [39], South Africa had the lowest shortfall of about 40% while Nigeria had the highest percentage shortfall of about 98% in terms of needed ventilators at the peak of the pandemic [31].

Similarly at the peak of the outbreak, contrivances such as; face shields and nose masks were in considerable demand leading to innovators seeking alternative ways of producing them. 3D printing technology was deployed across Africa to achieve this. For instance, in places such as Cameroon, Egypt, Kenya and Gambia, affordable personal protective equipment was produced for frontline healthcare providers during the pandemic using 3D printing technique [37, 52]. This technique was also employed in additive manufacturing of motorcycle shields in Uganda [40] as well as ventilator masks adaptable for two to four patients' use in Kenya, thereby allowing the management of multiple COVID-19 patients simultaneously [53].

Other personal protective equipment made by African Engineers include: first, the self-sanitizing mask developed by Uganda engineers which is a mask with in-built sanitizer. Second, the medical oxygen station that enables hospitals to generate their own oxygen for a fraction of the cost of making use of a ventilator. This was an innovation by engineers of the National Advanced School of Engineering of Yaoundé. Third, a porch that has the ability of disinfecting people that enters public places was created at the National Advanced School of Engineering by a group of Cameroonian engineers. Fourth, in Uganda, engineers created an automatic disinfectant sprinkler system that were installed in public buses to mitigate against the spread of corona virus. As well, Kenya engineers were able to develop an automated solar powered hand-washing machine, taking advantage of the abundance of solar energy in their region [31].

Furthermore, one of the biggest challenges during the COVID-19 pandemic was managing paraplegic patients in isolation centers and home. In cases of emergency, they would often need a caregiver to move them from the conventional wheelchairs to a bed, which sometimes is time demanding. To overcome this challenge, authors of [37, 40] in Nigeria

https://doi.org/10.4314/njt.v42i3.12

developed a dual purpose, battery-powered wheelchair that is adaptable as a wheelchair as well as a bed, thereby eradicating the need to transfer paraplegic patients from isolation bed to wheelchair and vice-versa.

3.1.5 Educational tools

As with many other places in the world, the COVID-19 outbreak forced quite a number of SSA universities to carryout teaching activities and examinations online for the first time due to compulsory lockdown of schools. Numerous challenges accompanied this policy decision including the risks of students cheating and falsifying answers to examination questions. It was against this backdrop that engineers in African Institute of Informatics in Cameroon developed an application that can monitor students' computers during online exams including using a facial recognition system. At the time when the trial version of the application was released, more than twenty (20) cases of cheating were detected. Interestingly too, several tertiary institutions in Nigeria succeeded in their efforts to move education and training online during the COVID-19 global crisis. Some of these private universities include Babcock University (BU), Covenant University (CU), Elizade University (EU), and Afe Babalola University (ABUAD). BU and CU had their convocation ceremonies online during the crisis. In addition, with the funding from the Royal Academy of Engineering, the Nigerian Institution of Mechanical Engineers (NIMechE) moved all its activities to an online bootcamp. This enabled them create a virtual School of Engineering and Entrepreneurship called ENGentrepreneur [31]. Authors of [54] also confirmed that technology saved education in Lybia during the peak of the pandemic.

3.2 Summary of Significant Innovations by African-based Researchers during the COVID-19 Pandemic

Table 1 presents a summary of published creative inventions by Africans, reported by British Broadcasting Corporation (BBC), the Federal University of Technology (FUTA) news magazine and Scientific Africa [30].

Table 1: Significant Innovations by African-based Researchers during the COVID-19 Pandemic

S/N	Invention	Inventor	Country of Origin	Description of Invention
1.	PGuards	Tunisia Engineers [30]	Tunisia	Police surveillance robots used to enforce lockdown measures. Makes use of thermal-imaging cameras, light detection and ranging technology.
2.	Web based X-ray lung scanner	Engineers in Tunisia [30]	Tunisia	Detects signs of a possible COVID-19 infection. Recognizes the impact of COVID-19 on lungs. Adjudged 90% effective in reporting the probability of infection.
3.	Solar-powered hand washing basin	Richard Kwarteng and Jude Osei [30]	Ghana	On detection of hand by the sensor, it automatically releases soapy water followed by clean water for hand washing within a time frame of 25 seconds.
4.	Doctor car robot	Students from Dakar polytechnic [30]	Senegal	A multifunctional robot equipped with cameras and remotely controlled to deliver drugs and food as well as take the temperatures of quarantined patients in a bid to lower the risk of COVID-19 contamination from patients to caregivers.
5.	Respire-19 portable ventilator	Usman Dalhatu – a students of engineering [30]	Nigeria	The prototype automatic ventilator was built to tackle the shortfall in availability of ventilators in Nigeria during the COVID-19 pandemic.
6.	Nose masks	Notalie Raphil (founder of Robots Can Think) [30]	South Africa	Design and printing of 100 node masks per day with 3d printer during the heat of the pandemic.
7.	Wooden hand-washing machine	Stephen Wamukota – a 9-year-old school boy. Received a presidential award for this innovation [30]	Kenya	Mechanical draining of water from a bucket to was hands using foot pedal.
8.	Positive pressure ventilator prototype	Team of researchers at the Federal University of Technology Akure (FUTA) [55]	Nigeria	A portable Continuous Positive Airway Pressure (CPAP) non- invasive mechanical ventilator that has the ability of delivering constant and steady pressure. The device runs on DC and can be configured to be powered by solar energy.
9.	Dual purpose sanitizer	FUTA through Technology Park and Incubation Center (Tech-PIC) empowered 4 Faculty members and 2 students to develop the device [56]	Nigeria	The device makes use of a pedal mechanical system for dispensing soap, water and sanitizer. The device also makes use of sensors and other electronics components to detect hands and then dispenses soap, water and sanitizer. The total time programmed for hand washing is 25 seconds in accordance with WHO's recommendations.
10.	Dual-purpose wheel chair	Michael Kanisuru Adeyeri, Sesan Peter Ayodeji, and	Nigeria and South Africa	The inventors developed an ergonomically correct and safe dual-purpose wheel chair to be used by

	Abimbola Omotayo Orisawayi [40]	paraplegics in the under developed countries. This wheel chair powered by a battery and proposed to be used by the paraplegics in their homes, hospitals as well as rehabilitation centers is expected to ease sitting and lying positions of the patients which is desirable in reducing contacts of caregivers with infected paraplegics' patients. The system can switch between sitting mode and sleeping/relations modes and vice versa.

4.0 CONCLUSION

The sudden outbreak of the COVID-19 pandemic created a wide range of gaps that needed to be urgently filled, especially in area of health. This consequently necessitated the creation of many technological innovations across Sub-Saharan Africa. Many of these African-based innovations were instrumental in helping to curb the spread of the outbreak as well as the management of the recorded cases. The deployment of robots and AI significantly reduced human-human contact, consequently reducing the costs associated with provision of protective equipment for medical staff and the risk of spread of COVID-19 virus from patients to the front-line health workers. In the area of manufacturing, the scarcity of imported goods and essential equipment like the ventilator, face shield led to local manufacture of alternatives in Nigeria, Ghana, Rwanda, South Africa and many other African Countries.

In all, the various gaps created by the COVID-19 pandemic helped to push African innovators to put to good use their engineering and technological knowhow which ultimately helped to shape the health sector in Sub-Saharan Africa. As African nations bounce back from the negative impact of COVID-19, the African continent must be proactive by swinging straight into plans for possible future pandemic. It is hoped that the inspiration will be sustained post-pandemic to create more economically viable products and alternative devices, thus, reducing dependence on importation and improving healthcare delivery in Sub-Saharan Africa.

5.0 RECOMMENDATION

Although the initial intention was to carry out a survey across the entire African countries about the documented and on-going research and innovations that were employed during the COVID-19 pandemic, we could not achieve this because of the large scope. Hence, this review analysis is not a representative of the whole African continent. Consequently, an elaborate systemic review is recommended for future studies of this kind in order to inclusively applaud the intellectual efforts of home-based African researchers, policy makers and innovative individuals across the continent.

6.0 DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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