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SPECIAL ISSUE

# COVID-19 pandemic and African innovation: Finding the good from the bad using Twitter data and text mining approach

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**Abstract**

This study investigates public sentiments and the essential topics of discussion on Africa's innovation amidst COVID-19. Web scraping techniques were used to collect and parse data from Twitter platform using the keywords "Africa Innovation COVID-19". A total of 54,318 cleaned English tweets were gathered and analysed using Twint Python Libraries. Our sentiment analysis findings revealed that 28,084 tweets (52 per cent) were positive, 21,037 (39 per cent), and 5197 (9 per cent) of tweets were neutral and negative, respectively, for Polarity sentiments. Notably, Healthcare, Imagination, Support, Webinar, Learning, Future, Rwanda, and Challenge were the most discussed topics on Africa's innovation during COVID-19. The topic labelling sentiments on the themes identified were positive, neutral, and negative, respectively. The study also revealed a cluster relationship between all identified topics. The relationship among these themes divulged how COVID-19 is positively shaping social and technological innovation in Africa. The study further presented practical implications to better position African leaders and policymakers to capitalise on the current innovation ecosystems and institutional capacities to transform the continent into a digital and innovation hub. The research concludes with theoretical recommendations and study limitations that will guide researchers and academicians in conducting future research in the subject area.

## 1 | INTRODUCTION

The current disruptive and radical technological innovation caused by the COVID-19 pandemic has led to new and improved technologies for business processes and operations within the workplace and

  

society. Technological innovation during the pandemic has been a critical success factor in supporting global public health in response to COVID-19. Besides, the rapid responses to controlling the virus have leveraged billions of technologies such as big data, artificial intelligence, connected devices, and low-cost computing resources within various sectors (Budd et al. 2020). The introduction of these risk-mitigating technologies and strategies has sustained most businesses and enhanced customer and employee safety by mitigating the menace of contagion (Luo and Alberto 2020).

Palpably, the effective use of digital technologies for online teaching and learning, e-health, remote working, digital contactless payment, online shopping, and robotic deliveries continue to play significant roles in building a resilient society in times of lockdowns and quarantines (Xiao and Fan 2020). Undoubtedly, these digitisations and innovations will have a massive potential in making the post-COVID-19 world a better place (Chearavanont 2020).

## 1.1 | Crisis leading to innovation

The quest to find solutions to combat the novel COVID-19 pandemic worldwide has led to significant disruptions within businesses, governments, and various international bodies. Though the future is uncertain, many are stepping up and finding innovative ways to carry out regular activities to fight against this deadly global pandemic. This has compelled scientists, innovators, and business communities to work collaboratively and frantically in a global context to support emergency responses and government actions (Angelelli et al. 2020). To stay afloat amid COVID-19, most businesses repurposed their production processes to meet the current changes and consumer demand. Several restaurants converted their space to sell groceries and staple items. Most auto dealerships and related businesses also adopted the home delivery model (BBC 2020a; Desai 2020; Gorzelany 2020; Morrison 2020).

In a move to reduce the spread of the virus and promote digitisation across the globe, most African countries such as Ghana, Nigeria, Rwanda, Kenya, South Africa, and Uganda have collaborated with technological innovators, leading to a wide range of inventions across the continent. These inventions include plasma-derived therapy, solar-powered handwashing machines, and other tech solutions to curb the spread of the virus (BBC 2020b; Harrisberg 2020; Tih 2020). Undoubtedly, this is leading to a new wave of African innovation and discoveries in the twenty-first century. Hence, despite the socio-economic challenges caused by COVID-19, "we can still find the good from the bad."

Historically, significant innovations in the last two centuries, such as lightbulbs, steam turbines, refrigeration, drones, DNA, vaccines, car radio, computers, canning, and superglue, were inspired by global crises (Coughlin 2020). Though the dot.com bust in 2001 was unfortunate for most businesses and investors, this led to many innovations such as VoIP, eCommerce, big data, and the web (MARTIN 2013). The SARS (Severe Acute Respiratory Syndrome) epidemic in 2002 also accelerated the penetration of the internet and eCommerce in China, which served as a turning point for eCommerce giants like Alibaba and JD.com in China (Zheng 2020).

Further, the great recession in 2008 also produced successful companies like Credit Karma, Venmo for digital cash exchange, and Groupon, a website that offers deals on companies' promotional products and services to consumers. In addition, the recession also saw the growth and spike in most social media platforms such as WhatsApp, Instagram, Pinterest, and slack (Conklin 2020).

Although most of these innovations have come from Western and Asian countries amidst global crises, there is little to write about on the African continent concerning innovation during global crises. Nevertheless, the current COVID-19 pandemic has spiked new waves of innovation within the African continent, with most of them gaining international recognition, hence the need to examine public sentiment on the current wave of innovation on the continent.

| | Country Names | All COVID-19 Innovations | COVID-19 Recognized Innovations |
|---|---|---|---|
| 1. | Korea, South | 48 | 46 |
| 2. | Kenya | 119 | 20 |
| 3. | India | 96 | 16 |
| 4. | Uganda | 83 | 15 |
| 5. | Singapore | 18 | 13 |
| 6. | Tanzania | 55 | 13 |
| 7. | United States | 78 | 11 |
| 8. | Malawi | 25 | 9 |
| 9. | Bangladesh | 34 | 9 |
| 10. | Nigeria | 60 | 9 |

**FIGURE 1** Coronavirus innovation chart (Hub 2020) [Colour figure can be viewed at wileyonlinelibrary.com]

## 2 | LITERATURE REVIEW

### 2.1 | A new wave of innovation in Africa

The pandemic times have drawn various stakeholders together in the healthcare industry to find solutions to the global COVID-19 pandemic which have led to numerous social and technological innovations. As seen in Figure 1, a Coronavirus Innovation chart created by COVID-19 Innovation Hub as of July 23rd, 2020, revealed innovative solutions from over 100 countries worldwide to aid combat the virus and help people adapt and cope with life during these challenging times. Among these countries are Kenya, Uganda, Tanzania, Malawi, and Nigeria, among the first 10 countries with COVID-19, recognised innovations (Hub 2020). This illustrates a positive indication of how the continent is striving to create an innovative niche for itself during these hard times.

One of the outstanding recent innovations on the continent is the manufacturing of five anti-pandemic robots in Rwanda – namely, Akazuba, Ikirezi, Mwiza, Ngabo, and Urumuri. These robots are mainly used to administer temperature checks, monitor patient status, and keep medical records of 50 to 150 COVID-19 patients per minute (Tih 2020). This is not different from a multifunctional "Doctor car" robot equipped with cameras and remotely controlled by an app built by a group of Senegalese students designed to lower the risk of COVID-19 infection from patients to healthcare caregivers (BBC 2020b).

In countries like Kenya, Ghana, Nigeria, Rwanda, and South Africa, a team of engineers built autonomous drones for the fast delivery of medical supplies to and from health facilities such, hospitals, clinics, testing centres, laboratories, and isolation centres to help combat the virus (Arone 2020; Bailey 2020; Knott 2020; León 2020). In pursuit of improving the quality of medical decisions to save lives, Benin and South Africa developed a medical app called REMA, and Signapps which helps connect medical doctors and experts in Africa to collaborate remotely and resolve patient cases in real-time (REMA 2020; Signapps 2020). Kenya moved one step ahead of its technological innovation by operating a vast network of COVID-19 ambulances throughout Kenya. These ambulances are placed on a real-time map similar to Uber, with a dispatch team who connect patients to care in minutes (Flare, 2020).

In Nigeria, a 20-year-old engineering student in an attempt to help meet the shortage of ventilators on COVID-19 wards, built a portable and E-vent automatic ventilator to help people with respiratory problems. This invention gained the Nigerian federal government's recognition, with plans to collaborate with the students to produce more ventilators (BBC 2020b; Ososanya 2020). At the Wellvis hospital in Nigeria, a team of engineers developed a free online COVID-19 triaging self-assessment

app to help individuals self-assess their coronavirus risk category based on their symptoms and exposure history. Based on the results, users who might be at risk were offered remote medical advice or redirected to a nearby healthcare facility by the app (Paul 2020).

Similarly, the South African government created a WhatsApp interactive chatbot that answered common queries on Coronavirus, its symptoms and treatment. The app had over 3.5 million users with five different languages since it was first launched in March 2020 (Paul, 2020). South Africa, which accounts for around half of the continent's reported COVID-19 cases, adopted 3D designing and printing for a medical mask, which were used in some major hospitals in Johannesburg (BBC, 2020b; Paul, 2020).

A team of engineers in the North African country of Tunisia built web-based X-ray scans using Artificial Intelligence systems. The system scanned lung X-rays to detect coronavirus infection signs with "90 percent" effectiveness after an X-ray scan has been uploaded to the platform. This invention gained the applause of researchers at the National Institute of Applied Science and Technology in Tunis (Medicalxpress, 2020). Although the platform was at its early stages when introduced, thousands of lung X-rays of both healthy people and COVID-19 patients were uploaded onto the platform embedded with artificial intelligence and a machine learning system to learn and detect the impact of the virus on lungs (Medicalxpress, 2020).

Further in Tunisia, the authorities in the capital city, Tunis, in April 2020, turned to sophisticated surveillance state tactics to enforce quarantines by deploying police surveillance robots on the streets. The surveillance robots equipped with thermal-imaging cameras, light detection, and ranging technology served as spies on people on the street during the lockdown who were not observing the lockdown protocols. The robots approached and questioned people about their reasons for being on the streets. Offenders were asked to show their ID and other documents to the robot's camera (BBC 2020b; Guardian 2020; Meisenzahl 2020). These robots were similar to police-operated drones of Chinese state authorities that confronted citizens in public, warning them to take better precautionary measures against the virus (D'Amore 2020).

Furthermore, during the pandemic, there was a spread of misinformation and a lack of data to make informed decisions. To better deal with this situation, a team of 20 innovative persons in Ghana created an artificial intelligence and machine learning real-time tracker of COVID-19 cases across Africa. The real-time information collected and analysed data to assist policymakers and relevant parties in decision-making to effectively plan the distribution of medical supplies and enforce social distancing measures (Paul 2020).

There were over 297 million students out of school in Africa due to the pandemic. Countries such as Kenya, Ghana, South Africa, Nigeria, Rwanda, Namibia, and Egypt reimagined their educational systems by launching e-learning platforms at the post-secondary level. This initiative attracted the support of international bodies such as UNICEF, UNESCO, and the World Bank (Kuwonu 2020). The support included helping these countries adopt traditional mass communication tools such as radio and television to promote remote teaching and learning for primary, secondary, and vocational schools (Kuwonu 2020).

The above innovations in the global south make it imperative to examine public opinions and sentiments on innovation in Africa during COVID-19 on social media. The affluence of publicly available data shared through social media platforms such as Twitter has encouraged many researchers to examine public sentiments on several COVID-19-related topics (Sharma et al. 2020). Given the surge in innovation in Africa in the wake of the COVID-19 pandemic, there is great content to study on this contemporary phenomenon. Hence, this study examined public sentiment and opinion on the current level of innovation in Africa amidst COVID-19. The finding from this study will better position African leaders and policymakers to capitalise on the current innovation ecosystems and institutional capacities to transform the continent into a digital and innovative hub.

Stemming from the study background, the research objectives examined are:

1. The most frequent words (used in tweet posts) on COVID-19 and Africa's innovation.

2. Public sentiments on COVID-19 and Africa's innovation.
3. The major topics of discussion on Africa's innovation during COVID-19.
4. The relationships between the major topics of discussion on Africa's innovation during COVID-19.

# 3 | RESEARCH METHODOLOGY

## 3.1 | Data collection

Twitter is one of the world's biggest social media platforms, with an average of 330 million daily active users as of 2019 using the platform to disseminate public information (Jagdale, Shirsat, and Deshmukh 2019; Abd-Alrazaq et al. 2020; Blog 2020; Chan et al. 2020; Sharma et al. 2020). In 2020, the average number of active users on the platform increased from 330 million to 500 million users with roughly 200 billion tweets per year. The rapid growth of information sharing by users on the Twitter platform has encouraged many researchers to use the platform for data gathering and examining public sentiments on a wide range of topics (Ravikumar 2015; Wang and Taylor 2018; Jagdale, Shirsat, and Deshmukh 2019; Adu 2020a). To capitalise on these, this study scraped data on the Twitter platform using Python Twint libraries (Twitter 2020). Although there are several widely used social media platforms in Africa, Twitter was selected since it appears more elitist with more enlightened and informed opinions than other social media platforms.

The data collection was conducted on November 10th, 2020. The data scraped from Twitter platform were from March 1st, 2020, to November 11th, 2020. These dates were selected since, as of March 3rd, 2020, 11 cases were reported in the African continent (Culp 2020). As of November 11th, 2020, the continent has reported a total of 1,983,616 cases (Worldometers 2020). Also, during the first week of November 2020, the continent started to witness an increase of 3 per cent of COVID-19 cases after the drop in mid-July 2020 (Worldometer 2020b). These dates helped the researchers gain insight into public opinion on risk mitigation technologies during the early and peak stages of the virus.

The researchers used Python programming language, which is a multipurpose tool for data collection and analysis for this study. Python supports applications such as mathematical computation and lines of code. Unlike CSS, HTML, and JavaScript, Python can be used for programming, software, desktop app development, processing big data, writing scripts, and web development. Python Libraries such as Twint, Pandas, NumPy, Matplotlib, pyLDAvis, and Seaborn were used in the data collection, cleaning, and analysis.

The datasets gathered corresponded to the sharing of news, articles, and tweets on innovation in Africa during COVID-19. The keywords used in collecting relevant data were "COVID-19", "Africa", and "Innovation". These keywords were selected based on the study objectives and extensive literature review. The researchers then installed and imported Twint module from its repo. A filter was then created in Python to search and concatenate all tweets that contain ONLY the three keywords identified. The filter includes, keywords = ["Africa, Innovation", COVID-19], search_concatenation = keywords, config = twint.Config() and then, twint.run.Search(config). These machine learning techniques isolated and collected tweets that contained these three keywords. The researchers further manually reviewed the dataset to ascertain this process. A total of 54,318 English tweets were retrieved for further analysis. The next section presents the data cleaning process applied in the research methodology.

## 3.2 | Data cleaning process

The data cleaning process and analysis were conducted on November 14th and 16th 2020, respectively, after obtaining the complete dataset. The dataset was noisy and unstructured. The researchers, therefore, applied several machine learning techniques to clean the dataset by removing unnecessary

content. This content include white spaces, punctuations, stopwords, deduplication, URL, mentions, retweets, and non-ASCII characters to highlight the key attributes suitable for the machine learning model.

## 3.3 | Removing HTML

Since the data was scraped online, the unstructured dataset contained much noise; hence, the researchers used lambda functions to remove unnecessary HTML tags and embedded JavaScript from HTML strings.

## 3.4 | Tokenisation

Tokenisation technique was employed to split up given texts into a set of individual words based on a specified pattern using Regular Expressions aka RegEx. (r'\w') pattern was used to remove punctuations and numbers from the tweets. Some other examples of RegEx used are: '\w+|\$[\d\.]+|\S+' = which was used to split up spaces or periods that are not attached to a digit. '\s+', gaps = True, was also employed to grabs everything except spaces as a token. '[A-Z]\w+' was also employed to only words that begin with a capital letter.

*Remove stop words*:

In addition, we imported a list of the most frequently used words from tweets from the Python natural language toolkit stopwords corpus. Stopwords.word (insert language) was run to get a full list of every language. In total there were 10 English words including "i", "me", "my", "myself", "we", "our", "ours", "ourselves", "you", and "you're". These words were removed since they occur everywhere in the tweets and may impede the effort of the text analysis process to better identify terms that distinguish different texts. Also, these words were removed since they have a low predictive impact. The strip case method was also used to make all letters lower case so that all words with or without caps, for example "COVID-19", "covid-19", and "Covid-19", are handled as the same word. This was done by adding word.lower() in the lambda function to make everything lowercase.

## 3.5 | Term normalisation

The term normalisation process was applied to unify identical or similar words that are written slightly differently (Brantner and Pfeffer 2018). The two types of normalisation, which are stemming and lemmatisation, reduce words to their root form in order to reduce variations of the same words to reduce the corpus of words in the model (Koenig 2019; Raghunathan 2020). The difference between stemming and lemmatising is that stemming removes the ending of words to enable singular, plural, and different verb forms to map the same term without taking into account the context of the word (Porter 2006; Raghunathan 2020). Lemmatising, on the other hand, takes into account the context of the word and shortens it into its root form based on a dictionary definition (Porter 2006; Raghunathan 2020). The researchers adopted the lemmatising process for the term normalisation process since the stemming process can reduce words to their stems, resulting in hard-to-understand terms and can sometimes change the meaning.

## 3.6 | Deduplication

The deduplication technique was applied to remove multiple occurrences with the same text or texts that are identical. Interestingly there were no duplicates found in the tweets since the Twint package

was coded to eliminate all retweets during the data scraping process. Retweets or deduplicated text were not considered by the researchers since the goal was to analyse the importance of certain topics and not users' tweets occurring multiple times, which could be counterproductive in the analysis process. After the data cleaning process, a total of 54,318 tweets with dates were ready for further analysis. The next section of the data presentation presents data analysis that includes word frequency, sentiment analysis, topic modelling, correlation, and cluster analysis.

# 4 | DATA ANALYSIS

## 4.1 | Word frequency

The first phase of the analysis discusses frequent tweets organised in word cloud using intelligent smart search algorithms. This was used to list the most frequently occurring words or concepts from the dataset. Further, this analysis technique gives a quick insight or first-hand findings within a dataset. In most cases, using word frequency can reveal some hidden information with a dataset that could prompt further investigation. This pattern-based analysis helped the researchers to answer the research questions by identifying essential elements of the data (Braun and Clarke 2013).

Although digitalisation, ecosystems, solution, and robot themes did not frequently appear in the word cloud, these words were meaningful in answering our research questions. Therefore, the frequency and the importance of topics in answering the research questions were taken into consideration during the stages of identifying patterns in the data (Damayanthi 2019).

Q1: What are the most frequent words pertaining to COVID-19 and Africa innovation?

As illustrated in Figure 2, words like "Africa", "Innovation", and "COVID-19" had the highest word frequency since these were the search terms used for our tweet collection, hence this could be found in every tweet. Since these words were used as keywords, the researchers did not consider them in the analysis process to avoid research bias. Besides, words like Webinar, Student, Youth, Technology, Entrepreneurship, Learning, Challenge, Robots, Healthcare, Digital, Collaboration, Government, and future got a considerable number of words used. This relates to the fact that most of the tweets were related to the current innovation initiatives and development in the African continent due to the COVID-19 virus.

Furthermore, words like Rwanda got a substantial number of tweets. This is evident in the fact that the East African country is currently among few African countries with the number of daily cases reducing from more than 100 in mid-August to 45 cases in late October (Worldometers 2020). The current catastrophic situation left nothing for the Eastern country to do but come up with innovative artificial intelligence-enabled solutions such as robots, step-and-wash handwashing facilities, and drones to raise awareness (Iliza 2020a). Rwanda is among the top ten leading African countries leading global innovation in fighting COVID-19 (Olalele 2020). Words like South, which presumably relates to South Africa, also got a considerable number of tweets. This is evident in the fact that South Africa recorded the highest number of COVID-19 cases in the continent, with a total of 298,292 cases as of July 15th, 2020 (Worldometer 2020a). As part of the country's innovative solution is the development of an intuitive web-based COVID-19 dashboard that shared real-time updates on the pandemic in South Africa compared with other countries. Hence, it was not surprising to see countries like Rwanda and South Africa as among the top African countries of discussion relating to innovation.

The virus kicked millions of African youths out of schools, aggravating an existing education crisis. The search for COVID-19 solutions tapped into the innovative ideas of the youth of the continent. This disrupted the traditional thinking and ways of tackling the virus and other technological solutions. The youth in Africa, especially in Sub-Saharan Africa, were given the platform and support to showcase their talent, creativity, and innovative ideas. The development of a solar-powered hand-washing basin, doctor car, artificial intelligence for X-rays, portable ventilators, online learning platforms, and mobile apps were all launched as a result of youth-led innovations (Sidibay 2020; UNICEF 2020). In

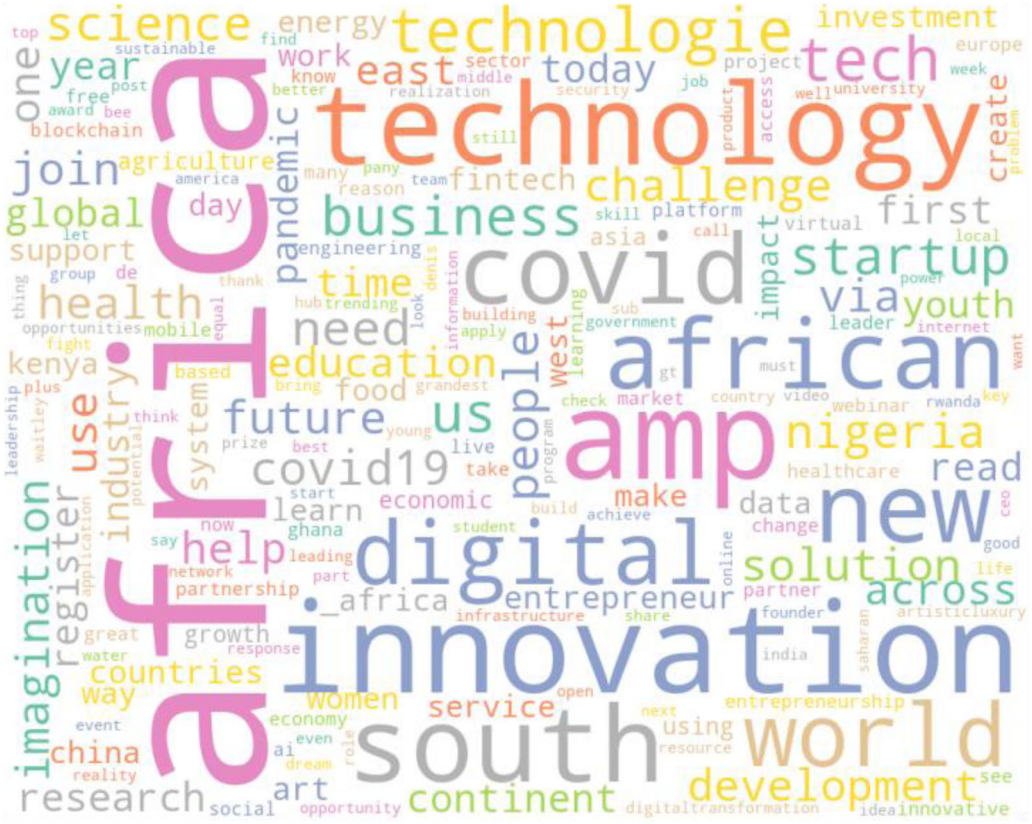


**FIGURE 2** Word Cloud frequent words used in the Tweets [Colour figure can be viewed at wileyonlinelibrary.com]

promoting youth-led innovations, UNICEF organised a COVID-19 Design Innovation challenge program that brought together more than 80,000 inspirational young innovative leaders aged 14 to 35 from Burundi, Malawi, Nigeria, and Tanzania. This innovative challenge gave birth to e-commerce platforms, e-learning platforms, digital platforms for accessing PPE and factual COVID-19 information, automatic hand sanitisers, and disinfectants (UNICEF 2020). Obviously, these innovative solutions will go a long way in the sustainable and long-term solution to the current and post COVID-19 pandemics times. Hence the youth were among the major topics of discussion, as shown in the word cloud in Figure 2.

## 4.2 | Sentiment analysis

In the search for answering research question 2, sentiment analysis was performed to unearth the general perceptions, opinions, and relationships related to the themes identified.

Sentiment analysis is the interpretation and categorisation of people's emotions commonly grouped into positive, negative, neutral, and mixed sentiments within text data (Bogle and Potter 2019; Adu 2020b). The application of machine learning techniques in Python libraries such as Textblob, Seaborn, Pandas and Matplotlib.pyplot were used to detect and separate subjectivity and polarity to identify the polarity of opinion and the subjectivity in the dataset.

Q2: What are the public sentiments on COVID-19 and Africa innovation?

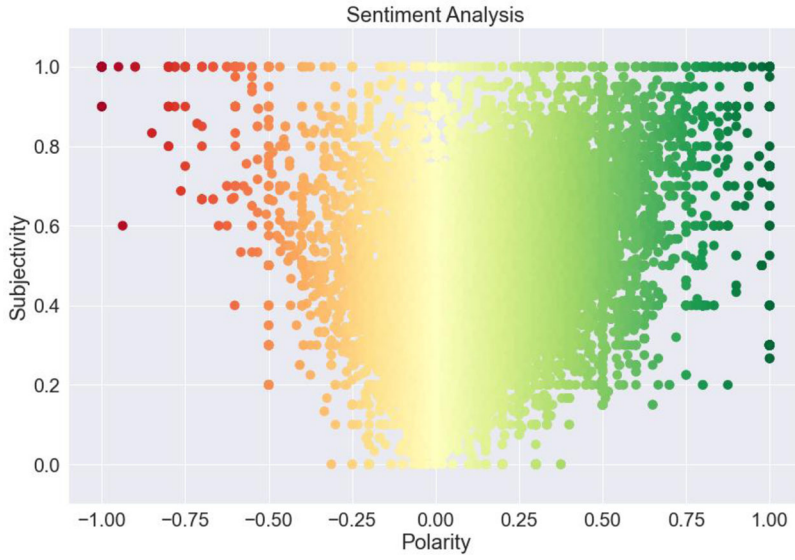


**FIGURE 3** Polarity and subjectivity float [Colour figure can be viewed at wileyonlinelibrary.com]

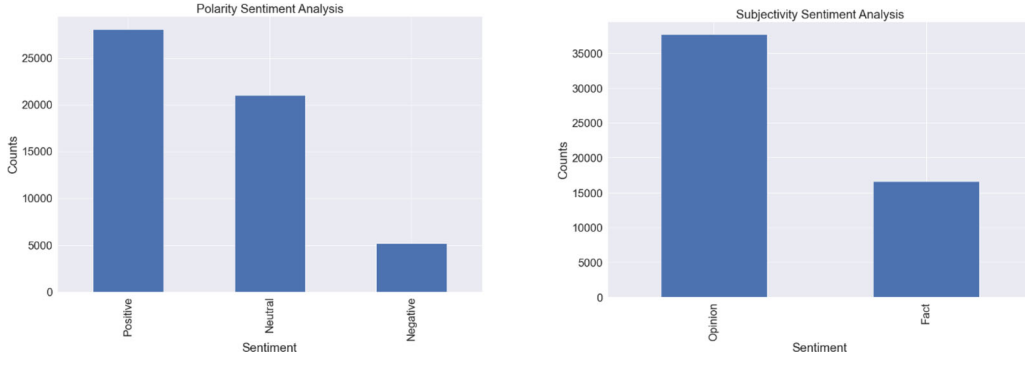


**FIGURE 4** Polarity and subjectivity sentiment analysis [Colour figure can be viewed at wileyonlinelibrary.com]

As illustrated in Figure 3, the polarity float lies in the range of [–1, 1] where 1 means a positive statement and –1 means a negative statement. Subjectivity float refers to opinion, emotion, or judgment that lies in the range of [0, 1].

Further sentiment analysis, as depicted in Figure 4, reveals that 28,084 tweets (52) were positive, 21,037 (39 per cent), and 5197 (9 per cent) of tweets were neutral and negative, respectively, for polarity sentiments. Subjectivity sentiment, on the other hand, recorded 37,693 (69 per cent) opinion tweets and 16,625 (31 per cent) fact tweets from the dataset. Sentiment analysis enabled the researchers to gain insights into the polarity and subjectivity of public perception of the study subject.

## 4.3 | Topic modelling

The third phase of the analysis discussed the coded themes, which were the topics of discussion from the tweet dataset based on percentages to identify the data's broader patterns to help answer the research questions. Latent Dirichlet allocation (LDA) and Python pyLDAvis package, which is the most commonly used topic modelling technique, was used to find out the relevant topics to produce

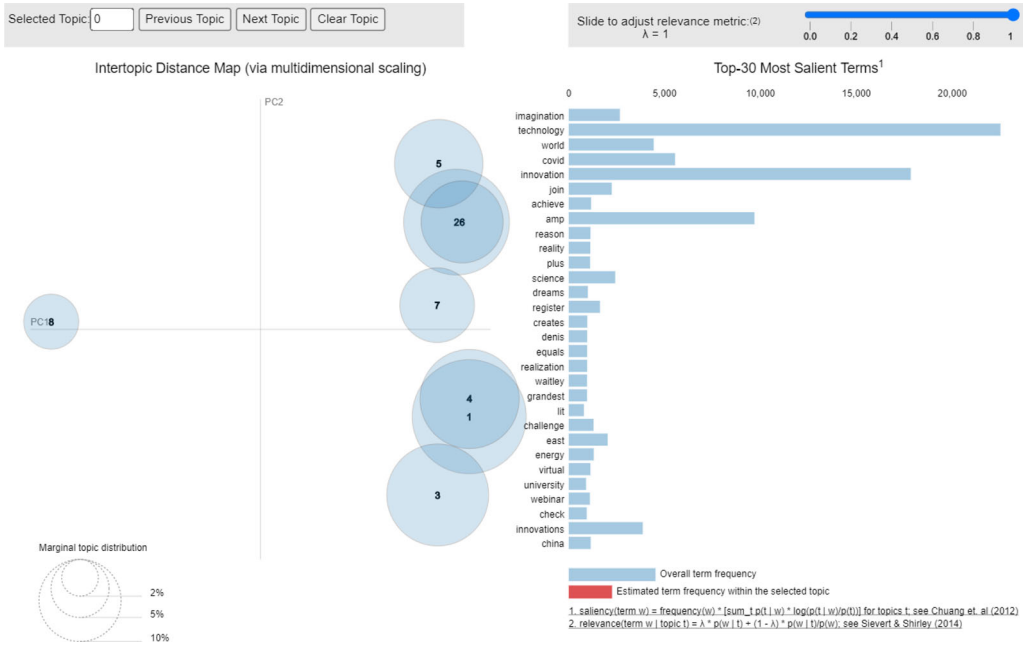


**FIGURE 5** The results of the LDA topic model based on eight relevant topics [Colour figure can be viewed at wileyonlinelibrary.com]

an interactive visualisation (Blei, Ng and Jordan 2003). Auto topics were generated using a natural language process (NLP). Topics were identified by analysing the content and the sentence structure within the dataset into a predefined number of groups and probability using an unstructured machine learning algorithm. The NLP algorithm then assigned significance to some topics over others based on how frequently each topic occurred in the tweet dataset being analysed. The relevant contents coded to the topic nodes were then combined into groups, in other words, clusters, and presented as a summarised node for each broad idea, with child nodes for each topic within that group (Brantner and Pfeffer 2018; NVivo 2020). In other words, the LDA algorithm transformation is performed from bag-of-words counts into a lower dimensionality topic space (Kabir and Madria 2020). The topics and the result of the LDA unstructured machine learning calculation show the top words with the highest probability for every topic, which helped the researchers to interpret the topics. Figure 6 shows the top 30 most relevant terms for eight topics identified.

Despite the robustness of this LDA technique, the researchers critically analysed the topics that were generated to avoid any topic allocation errors (Guo et al. 2016). The researchers assigned topic labels based on the literature review, word cloud generated the relevance and frequency of each of the most salient terms in the corpus (Kazmaier and van Vuuren 2020; Medford et al. 2020). As illustrated in Table 1, Topic 0 is related to Healthcare, Topic 1 includes subtopics that relate to Imagination. Topic 2 includes subtopics that define Support. Topic 3 on the other hand related to Webinar, whereas Topics 4, 5, 6, and 7 relate to Learning, Future, Rwanda, and Challenge, respectively.

Q3: What are the main topics discussed in respect to Africa innovation during COVID-19?

The topics captured represented pattern responses and meanings within the dataset (Braun and Clarke 2013). Figure 6 shows the patterns in the main topics. The study topics comprised of the collection of perceptions on innovations in Africa during COVID-19 that were recorded under auto-generated using machine learning techniques. These topics consist of Healthcare, Imagination, Support, Webinar, Learning, Future, Rwanda, and Challenge. As shown in Figure 5, it may be deduced that all eight identified topics are relatively well connected except Topic 8.

**TABLE 1** The results of the LDA topic model based on eight topics relevant topics

| Possible topic label | Top 10 words for topic #0: |
|---|---|
| Healthcare | ['health', 'post', 'response', 'coronavirus', 'video', 'key', 'read', 'sector', 'change', 'impact', 'industry', 'food', 'continent', 'Saharan', 'sub', 'challenges', 'learn', 'solutions', 'help', 'African', 'check', 'pandemic', 'new', 'south', 'digital', 'technologies', 'innovations', 'technology', 'innovation', 'covid'] |
| | **Top 10 words for topic #1**: |
| Imaginations | ['evidence', 'technology', 'trending', 'paste', 'Nigeria', 'success', 'clean', 'south', 'trends', 'copy', 'twitter', 'water', 'free', 'use', 'amp', 'lit', 'grandest', 'waitley', 'realization', 'equals', 'denis', 'creates', 'dreams', 'plus', 'reality', 'reason', 'achieve', 'innovation', 'world', 'imagination'] |
| | **Top 10 words for topic #2**: |
| Support | ['platform', 'access', 'financial', 'leading', 'read', 'social', 'science', 'women', 'global', 'group', 'African', 'program', 'support', 'company', 'research', 'services', 'solutions', 'tech', 'south', 'new', 'development', 'health', 'east', 'technologies', 'data', 'business', 'digital', 'innovation', 'technology', 'amp'] |
| | **Top 10 words for topic #3**: |
| Webinar | ['online', 'week', 'future', 'new', 'apply', 'use', 'link', 'research', 'click', 'conference', 'summit', 'tech', 'youth', 'day', 'free', 'event', 'today', 'innovations', 'digital', 'covid', 'african', 'south', 'technology', 'webinar', 'virtual', 'challenge', 'register', 'amp', 'join', 'innovation'] |
| | **Top 10 words for topic #4**: |
| Learning | ['companies', 'crisis', 'help', 'forum', 'amp', 'green', 'new', 'innovations', 'entrepreneurship', 'world', 'president', 'coronavirus', 'fight', 'India', 'use', 'health', 'learning', 'power', 'technologies', 'middle', 'Europe', 'women', 'African', 'south', 'china', 'east', 'energy', 'innovation', 'covid', 'technology'] |
| | **Top 10 words for topic #5**: |
| Future | ['china', 'don', 'help', 'look', 'economic', 'make', 'future', 'growth', 'Africans', 'tech', 'technologies', 'African', 'think', 'just', 'making', 'resources', 'innovations', 'continent', 'country', 'south', 'way', 'new', 'countries', 'like', 'need', 'world', 'people', 'amp', 'innovation', 'technology'] |
| | **Top 10 words for topic #6**: |
| Rwanda | ['come', 'won', 'best', 'Rwanda', 'think', 'woman', 'good', 'work', 'old', 'love', 'great', 'academy', 'win', 'like', 'make', 'year', 'time', 'want', 'just', 'don', 'let', 'know', 'world', 'south', 'people', 'prize', 'engineering', 'news', 'innovation', 'technology'] |
| | **Top 10 words for topic #7**: |
| National Challenge | ['national', 'students', 'covid', 'platform', 'book', 'life', 'using', 'Ghana', 'based', 'visit', 'America', 'focus', 'giant', 'need', 'currently', 'talking', 'industry', 'development', 'like', 'today', 'education', 'information', 'Nigeria', 'west', 'fintech', 'African', 'university', 'science', 'south', 'technology'] |

To answer research questions 2 and 3 of the above research question, the sentiment analysis for each identified topic was examined. Noticeably, the majority of the public sentiments on the eight themes identified were positive, neutral, and negative sentiments, as vividly shown in Figure 6. This indicates a strong sense of confidence and optimism in the current surge in innovative activities across the continent.

## 4.4 | Correlation analysis

Further, in the exploration data analysis process, correlation analysis in the form of a heatmap was performed using the Seaborn library in Python to unveil the correlation level in the dataset.

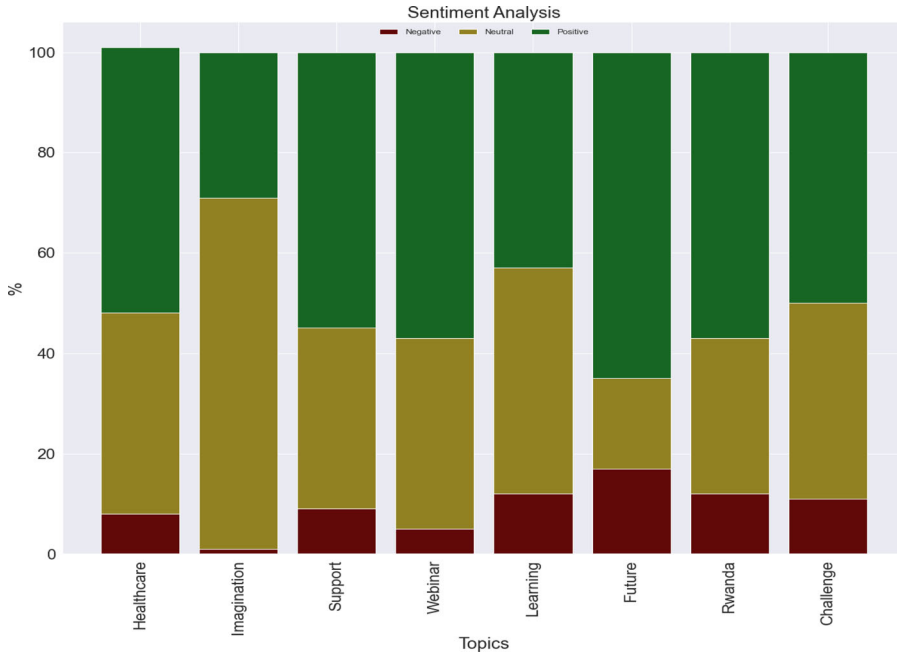


**FIGURE 6** Polarity sentiment analysis of identified topics [Colour figure can be viewed at wileyonlinelibrary.com]

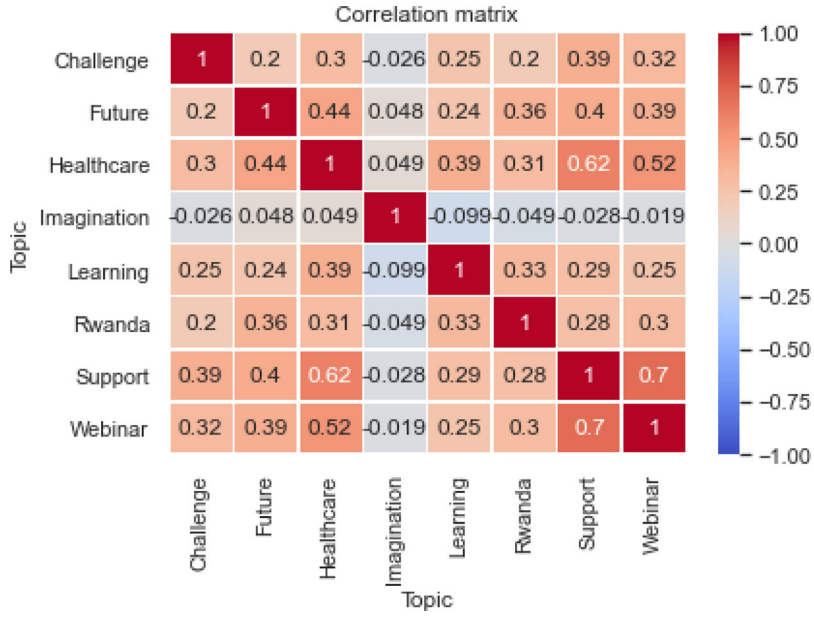


**FIGURE 7** Correlation matrix of identified topics [Colour figure can be viewed at wileyonlinelibrary.com]

For much easier interpretation, an annot = True argument was passed to help display the correlation coefficient on the coloured cells. Figure 7 indicates a strong correlation among variables with a degree level of –0.1 to 1.1, except imagination, which had a weaker correlation –0.014 to –0.05.

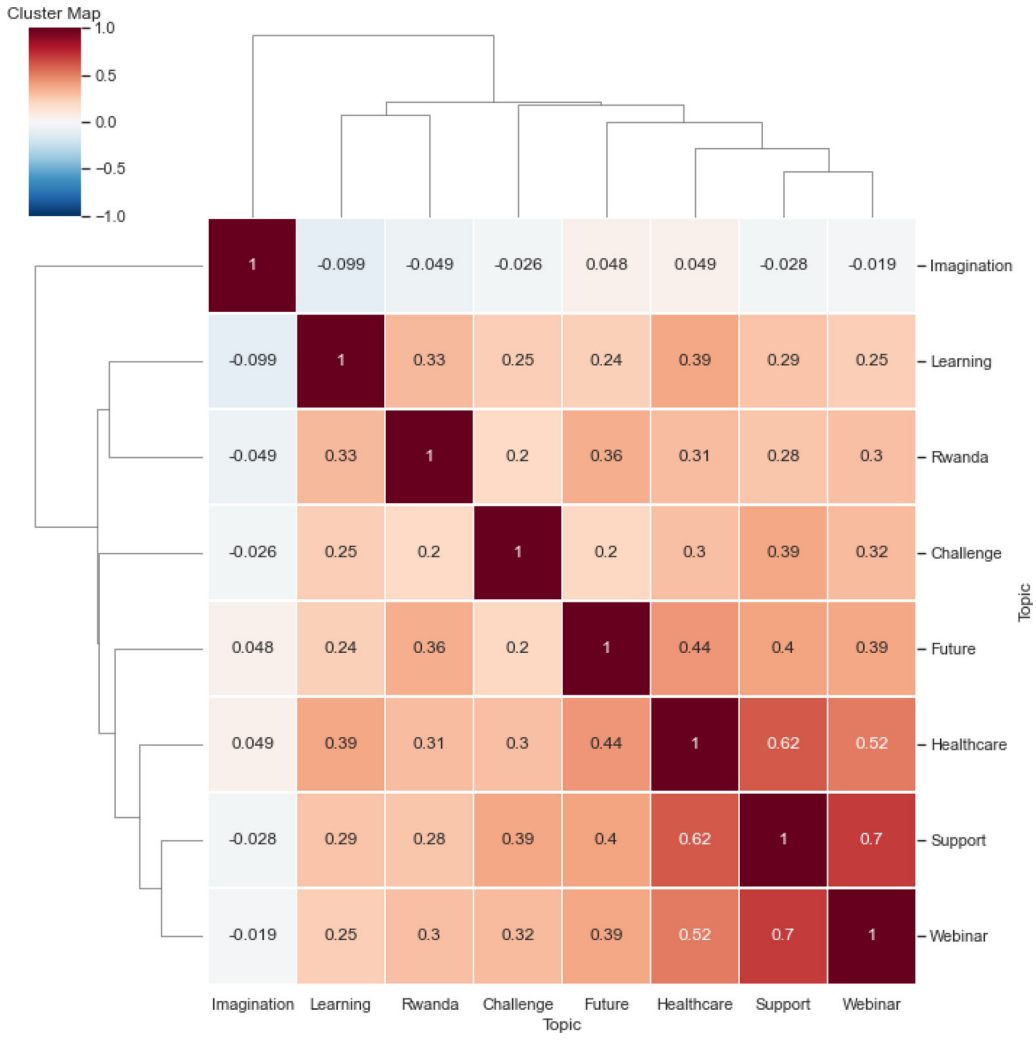


**FIGURE 8** Hierarchical cluster analysis [Colour figure can be viewed at wileyonlinelibrary.com]

## 4.5 | Cluster analysis

Data analysis in this section focused on a heatmap cluster analysis which is a class of techniques used to classify the themes or topics identified in this study into related groups represented as colours as shown in Figure 8.

Cluster analysis was conducted by taking into consideration the research problems. Using Seaborn python library, the selected themes were clustered using code similarity and similarity metric of Pearson correlation coefficient to gauge the datasets' similarity and diversity. This algorithm treated each theme as a singleton cluster. The pairs of themes or clusters were successively merged into one cluster containing all the themes.

Q4: What are the relationships between the main topics discussed in African innovation during COVID-19?

As depicted in Figure 8, there is an overall relationship between imagination and all identified topics from the cluster analysis. The fact can never be disputed that the chase to find solutions to the novel virus and its related issues has led to the ability to produce and simulate novel objects, sensations,

and ideas spearheading the growth of learning innovative ways of living the "new normal" across the globe, and Africa is not an exception. From the design and development of 3D mask printing, robots, surveillance, contact tracing apps, drones, chatbots, self-diagnostic tools, portable ventilators, laboratory systems, solar-powered automatic handwashing tools, and rapid testing, the continent is obviously finding the good from the bad.

Likewise, through the wave of innovation, most African countries have not limited themselves to their traditional constraints such as poor infrastructure and economic challenges. They have made changes for a better African continent by supporting and empowering the youth to work with some of the amazing emerging technologies and to prototype their ideas. As discussed in the literature review (Angelelli et al. 2020; BBC 2020b; Chearavanont 2020; Harrisberg 2020; PAUL 2020), as the number of coronavirus cases continues to increase, so does the level of innovation across the continent. Hence the relationship between learning and the identified topic brought together the importance of innovative learning, solutions, and collaboration by African countries to combat COVID-19.

Further analysis revealed a connection between Healthcare, Support, Webinar, Challenge, Future, and the remaining topics. Evidently, the effect of COVID-19 on global healthcare has shaped digitisation across the globe, putting a new impetus on the need for innovation and technological investment, as well as the implementation of policies and strategic frameworks to unleash African ingenuity. With the paradigm shift in the delivery of healthcare services such as e-health, telehealth, and healthcare webinar during COVID-19, these technologies will continue to transform the healthcare delivery systems around the world.

Seemingly, the current pandemic situation demands agility and strategic initiatives to respond to healthcare needs during the new and the next normal. This has led to an enormous demand in healthcare and health informatics to connect with local communities, gather information, share ideas, and make informed healthcare decisions that improve patients' conditions and healthcare operations. Leveraging health intelligence, big data, artificial intelligence, and machine learning systems has never been more critical. Hence, the surge in emerging healthcare technologies such as diagnostics, 3D printing marks, drones, medical delivery services, chatbots, and robots in Africa during the pandemic period has accelerated changes in the healthcare systems (BBC 2020b; Harrisberg 2020; PAUL 2020; Sidibay 2020). Proactively, healthcare practitioners in Africa in collaboration with various medical and health partners across the globe are using information and communication technologies such as online platforms and webinar series to cross-fertilise ideas on infectious control and preventive topics.

In the face of Africa's healthcare difficulties, the technological and economic advancements, especially in the sub-Saharan region, have also enhanced opportunities for the continent to develop sustainable e-health systems such as mobile health solutions to foster healthcare delivery for a more effective response to COVID-19. An example is a mobile health platform in South Africa, which was rapidly expanded to more than 28,000 trained community health workers across nine provinces for community screening, testing referral, and communicating results (Mogotsi and Bearak, 2020).

In Ghana, Cognate Systems, which is a software engineering company, has created Opine Health Assistant Platforms that record and track the frequency of COVID-19 symptoms from different parts of the country. This is done by dialling a short Unstructured Supplementary Service Data USSD code (*920*222#) by users on their mobile phones to generate an electronic response to questions about their symptoms, contact tracing, and travel history. The app then visualises the results into charts for easy understanding, monitoring, and sharing (Ghanaweb 2020; Owusu 2020).

Similarly, SMS services are being used in Senegal to broadcast acceptable hygiene practices and measures to rural and local communities to reduce the spread of the virus (Purpose 2020). Most African countries are also leveraging on existing social media platforms such as Facebook Live, YouTube Live, and WhatsApp groups to deploy chatbots and self-assessments in local languages (Harrisberg 2020). Seemingly, COVID-19 has compelled governments, organisations, and investors to mirror the indispensable and inevitable role of technology in the continent. Predictably, the current pandemic has accelerated the pace of the digital revolution among various sectors, particularly within the continent's healthcare industry, making it a hot issue to discuss. With the innovation challenge

being promoted in the continent by individual bodies and educational institutions , the innovation landscape in the continent is shifting (UNICEF 2020).

Finally, there was a relationship between Rwanda, Learning, and the remaining topics. Rwanda's service, agriculture, and construction industry were adversely affected by the ongoing pandemic. An interview with the country's Minister of State in Charge of National Treasury with IMF Country focus (IMF 2020) unveiled how his country was learning and leveraging on existing and new technologies and grass-roots networks to combat the spread of the virus. These innovative solutions include the development of a COVID-19 digital health facility surveillance system that is used to monitor influenza-like illnesses and severe acute respiratory infections in real-time to provide an early warning of suspected COVID-19 cases. He further mentioned that the country had developed human-sized robots which were used in healthcare facilities to carry out simple tasks, such as temperature screens, reading vital signs, and monitoring patients, to reduce exposure of the virus to healthcare workers. He also shed light on the country's Geographic Information System (GIS) that monitors COVID-19 cases at the household level. This system helps policymakers evaluate the need for issuing lockdown measures and focus on the need for public health measures at locations with evidence of community transmission and monitoring at-risk populations.

In the capital city of Kigali, the Rwanda National Police deployed drones to high-risk and densely populated areas to raise public awareness about COVID-19 and remind the public to observe preventive measures (Iliza 2020b). Further, an anti COVID-19 spraying booth that automatically sprays disinfectants on people who walk through the booth was launched by Rwanda Biomedical Centre in mid-August 2020. These booths were placed on public place entrances and performed other functions such as hand sanitising, temperature checking, and automated collection of information from individuals (Iliza 2020b). Undeniably, the COVID-19 pandemic has galvanised technological innovations in the East African country, which is uniquely adapted to the African context. Hence, it is a major topic for discussion.

# 5 | PRACTICAL AND THEORETICAL RESEARCH IMPLICATIONS

## 5.1 | Practical implications

The study indicated that social media platforms continue to be an excellent platform for sharing information related to COVID-19 issues. The research revealed a more neutral and positive sentiment of Africa's innovation with four identified themes: Innovation, Solutions, Global Economy, and Digital. This shows a promising future for Africa's innovation in the twenty-first century. Consequently, more efforts and resources are needed by African leaders, governments, organisations, businesses, and individual bodies to continuously build and maintain strong digital and social innovation programs at regional and national levels among African countries. Precisely, governments should promote partnership programs to unearth innovative capacity and evolving technologies across various private and public sectors to boost local innovation. This study further elaborates on five recommendation policies to rebrand the African continent through innovation and strategic decisions.

Businesses, public sectors, governments, investors, and other organisations should seize the current opportunities of innovation in the continent to unlock the next stage of Africa's digital transformation. Businesses and public sectors should leverage the current appetite for technology by customers and the public to expand their online presence and digital contributions. Since the timing is perfect for businesses and the public sector to undergo digital transformation, governments of African countries should make available all key enablers that promote innovative empowering environments for swift digitisation. Businesses, governments, investors, and other organisations should pace up their country's infrastructure investments and development to promote broader digitisation and major infrastructure expansions during this period. Businesses should also scale up their workforce's technological and innovative skills to equip them for the "new normal" and post COVID-19 pandemic life.

Governments and businesses should make available innovation and digitisation education and training for both private and public sector employees across various countries to ensure that a country's workforce is on the same page about its digitisation initiatives.

In addition, this study draws strategic policies for governments and African institutions in transforming Africa's healthcare systems by leveraging on the current surge of innovation in the continent, institutionalising healthcare facilities, and healthcare supply chain. Governments should also promote public sector investment in primary healthcare infrastructure and technology such as locally manufactured ventilators, drones, robots, mobile applications, and healthcare technologies. These would see the contribution and establishment of sustainable, innovative activities across the continent.

Further, to avoid living in a maxim, SMEs in Africa should adopt agility and flexibility strategies to help repurpose their range of products and services as well as business operations to adapt to the changing environment. Organisations should, therefore, continuously try new effective and efficient ways and processes to run business operations, to promote innovation rather than being comfortable and reliant on old ways of doing things.

Undeniably, the COVID-19 pandemic has exposed the educational systems in Africa which call for transformation. Educational transformation across the continent should be built on innovation, research and development (R&D), and the resilience to help develop the skill set of the youth within the continent. With most of the innovations in the continent been championed by the youth, governments, businesses, and individual organisations should harness an innovative conducive environment for the youth, by promoting innovation challenges, scholarships, developing practical innovative programs across junior and tertiary institutions, national recognition programs, and any other programs that will motivate and build the African youth's interest and skill. This would not just lead to creativity among the youth, it would also eliminate fear and the stigma of making errors.

Since the youth in Africa are the asset and future of the continent, governments and policymakers should also transform and revolutionise "the Guggisberg type of education" in Africa, which encourages white colour jobs. To address this, vocational, technical, and information communication technology programs must be enshrined in the academic curriculum right from the basic school level in the formative years of youth.

Given the wide presence of internet connectivity, mobile phone, and smart devices in the continent, governments of African countries should form strategic partnerships with technology and telecommunication industries to provide affordable telecommunication services to remote and vulnerable communities. This would enable healthcare professionals to collect and disseminate health information and cases in real-time.

Furthermore, the study findings call for a shared vision and strategy on research and development for African countries that will put into practice research funding mechanisms to convert the continent into a digitisation hub. Having a shared vision among Africa countries would also strengthen economic integration, human capital development, and cooperation in the continent.

## 5.2 | Theoretical implications

The novel coronavirus has led to a wide range of research on healthcare, finance, education, service delivery, and tourism in developed countries with little emphasis on Africa's innovation. This study contributes to the existing knowledge of innovation in Africa during these pandemic times by exploring word frequency, discussed topics, public sentiments, relationships between topics, correlation, and cluster analysis of identified topics. This study fills the gap in the literature with empirical results of some significant and intriguing findings. Thus, this study serves as a benchmark for future qualitative research on Africa's innovation during a crisis.

### 5.3 | Study limitations and future research considerations

This research analysed only English language tweets, on a single social media platform, which limits the generalisation of the study findings. Therefore, care must be taken to generalise the research findings. Considerably, since Africa is dominated by English, French, and Arabic-speaking countries, future research related to Africa's innovation during an emergency crisis should consider different language (French, Arabic, and Swahili) sentiment analysis on multiple social media platforms.

Also, since this study focused on the entire African continent, it is limited to findings to the level and growth of innovation in specific African countries. Hence, a country-level analysis that could be linked with the country-related literature review discussed in this study is recommended for future research.

Further, there are many innovations in local communities that have been made but not picked up by mainstream media. In Africa, where social media is common amongst the elites, rural innovations are usually transmitted on radio stations, and these innovations would easily have been missed out since information shared on radio stations or traditional media was not included in this study. Therefore, future related studies should consider data or information from both mainstream and traditional media to expand the discourse of Africa's innovation during the COVID-19 pandemic.

Finally, future research studies should consider investigating the types of emerging African technology business setups and entrepreneurship during the current public emergency crisis.

## 6 | CONCLUSION

This research aimed at analysing public sentiments and the significant topics of discussion on Africa's innovation during the current COVID-19 pandemic using tweets from the Twitter platform. The study revealed words like webinar, technology, learning, challenge, Rwanda, healthcare, digital, challenge, robots, and youth as the most considerable number of words used. Most of the public sentiments on the themes identified were positive neutral and negative sentiments. Notably, Healthcare, Imagination, Support, Webinar, Learning, Future, Rwanda, and Challenge were the most discussed topics on Africa's innovation during COVID-19. The study also revealed a cluster relationship between all identified. The relationship among these themes revealed how COVID-19 is positively shaping social and technological innovation across the continent. The study further presented practical implications to better position African leaders and policymakers to capitalise on the current innovation ecosystems and institutional capacities to transform the continent into a digital and innovation hub. The study concluded with theoretical recommendations that guide researchers and academicians in conducting future research on the subject area.

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#### CONFLICT OF INTEREST

The authors declare no conflicts of interest.

#### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. The researchers would like to report no conflict of interest.

#### PEER REVIEW

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