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RESEARCH ARTICLE

Africa's response to the COVID-19 pandemic: A review of the nature of the virus, impacts and implications for preparedness [version 1; peer review: awaiting peer review]

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Abstract

Background: COVID-19 continues to wreak havoc in different countries across the world, claiming thousands of lives, increasing morbidity and disrupting lifestyles. The global scientific community is in urgent need of relevant evidence, to understand the challenges and knowledge gaps, as well as the opportunities to contain the spread of the virus. Considering the unique socio-economic, demographic, political, ecological and climatic contexts in Africa, the responses which may prove to be successful in other regions may not be appropriate on the continent. This paper aims to provide insight for scientists, policy makers and international agencies to contain the virus and to mitigate its impact at all levels.

Methods: The Affiliates of the African Academy of Sciences (AAS), came together to synthesize the current evidence, identify the challenges and opportunities to enhance the understanding of the disease. We assess the potential impact of this pandemic and the unique challenges of the disease

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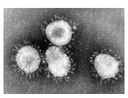
on African nations. We examine the state of Africa's preparedness and make recommendations for steps needed to win the war against this pandemic and combat potential resurgence.
Results: We identified gaps and opportunities among cross-cutting issues which is recommended to be addressed or harnessed in this pandemic. Factors such as the nature of the virus and the opportunities for drug targeting, point of care diagnostics, health surveillance systems, food security, mental health, xenophobia and gender-based violence, shelter for the homeless, water and sanitation, telecommunications challenges, domestic regional coordination and financing.
Conclusion: Based on our synthesis of the current evidence, while there are plans for preparedness in several African countries, there are significant limitations. Multi-sectoral efforts from the science, education, medical, technological, communication, business and industry sectors as well as local communities is required in order to win this fight.

Keywords
COVID-19, SARS-CoV-2, Africa, Preparedness, Pandemic, Resurgence, Drug discovery, Diagnostic testing



This article is included in the Coronavirus (COVID-19) collection.

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Introduction

As the world continues to experience climatic and ecosystem changes and increased human migration, there has been a surge of novel and re-emerging pathogens. Over the past three decades, up to 30 new human pathogens have been detected, 75% of which have animal origin (Jones *et al.*, 2008). Rift Valley fever, Severe Acute Respiratory Syndrome coronavirus (SARS-CoV-1), Pandemic influenza H1N1 2009, Yellow fever, Avian Influenza (H5N1 and H7N9), West Nile virus, Middle East Respiratory Syndrome Coronavirus (MERS-CoV) and the current Severe Acute Respiratory Syndrome CoV-2 (SARS-CoV-2) are a few among many (Jones *et al.*, 2008; Mourya *et al.*, 2019).

COVID-19 triggers respiratory difficulties for which the SARS-CoV-2 virus is responsible. The virus was first reported in the city of Wuhan, Hubei Province, in China on December 31st 2019 (WHO, 2020). Since then, the virus has wreaked havoc in different countries at an alarming pace, claiming thousands of lives. As of late March 2020, Africa had not yet recorded as many mortalities as Europe, North America and Asia. However, the economic impact of the pandemic will not spare the continent. It is predicted that the disease will cost the world economy at least \$1.1 trillion in lost income due to forced quarantine, as businesses, schools and factories would have to be closed (Oxford Economics, 2020). While high income countries and some emerging countries have responded with varying stimulus packages for example; United States \$2 trillion, France \$49 billion, Australia \$11 billion, United Kingdom £350 billion, and India \$54.2 billion (see Mervis, 2020), Africa, and especially the sub-Saharan region, has limited capacity to marshall up such stimulus packages. Therefore, there is an urgent need for African governments to invest in resilient health systems to ensure robust response and post-pandemic economic rejuvenation (Kruk *et al.*, 2015).

As the global scientific community works assiduously to limit the spreading of COVID-19, the Affiliates of the African Academy of Sciences (AAS) have synthesized current evidence on the biology and epidemiology of the disease, and identified the challenges and opportunities in combating the global pandemic. This paper aims to enhance understanding of COVID-19, assess Africa's preparedness and determine operational challenges of disease control.

Methods

Recognizing the threat of COVID-19 on the continent, 13 scientists from eight African countries conducted research on COVID-19, in an effort to understand the biology and epidemiology of the virus as well as its impacts on and the preparedness of Africa. The scientists are from Ghana (n=2), South Africa (n=2), Namibia (n=1), Nigeria (n=3), Uganda (n=1), Mauritius (n=1), Kenya (n=2) and Egypt (n=1) and their expertise ranged from virology, clinical science and medicine, polymer chemistry, public health, behavioural science, computational biology, statistics, medical statistics, health monitoring and evaluation, environmental science, human geography, and engineering.

Three brainstorming sessions via Zoom were conducted. Following email exchanges and meetings, four main sub-themes were highlighted: (1) nature and biology of the virus, (2) potential impact of the pandemic on the continent, (3) health systems preparedness, and (4) challenges, knowledge gaps and research opportunities. The scientists aggregated within sub-groups and worked on the identified sub-themes. A consolidation of these sub-themes paved the way for recommendations for policy and research avenues for the scientific community.

To identify studies, the following sources were used: Scopus and Web of Science biographic databases, peer review journals of the BMC, Proceedings of the Royal Society of London, Lancet, Oxford Academic, medRxiv, National Library of Medicine; organizational websites of the World Health Organisation, National Centre for Biotechnology, National Institute for Communicable Diseases, the World Economic Forum, Government websites and Google Scholar. Keywords included: "COVID-19", "nature of virus", "biology", "genome impacts", "Africa", "preparedness", "impacts", "responses", among others. Overall 300 articles were retrieved out of which 135 were considered to be relevant for this paper. Inclusion criteria: articles had to be directly related to the sub themes i.e., coronavirus, potential impact, preparedness and knowledge gaps as well as being current. We excluded articles that were not directly related to our sub themes.

Nature and biology of the virus

Biology of the virus

Coronaviruses consist of a lipid envelope containing a positive single stranded RNA and are generally characterized by club-like spikes projecting from their surface (Phan, 2020). They commonly result in respiratory diseases with mild to severe outcomes in humans. However, they are particularly complex due to their ability to infect multiple host species (Fung & Liu, 2019). Coronaviruses are divided into four main sub-groups namely; alpha, beta, gamma and delta-coronaviruses. These groups can be found in wildlife such as bats (bats coronaviruses) and livestock species such as cattle (bovine coronaviruses), goats and sheep (Phan, 2020). Although several coronaviruses are zoonotic in nature, their wide genetic diversity, frequent genomic recombination, and increasing human–animal interfacial contact, novel coronaviruses capable of human infection (human coronaviruses) are likely to periodically emerge.

Within the family of coronaviruses, COVID-19 is the seventh known member infecting humans. Since November 2019, six coronavirus species were known to cause human diseases with four of them in particular: HCoV-229E, HCoV-OC43, HCoV-NL63, and HCoV-HKU1 being prevalent and known to cause mild illness such as common colds in immunocompetent individuals. The two other strains namely SARS-CoV-1 and MERS-CoV, both zoonotic in origin, attracted worldwide attention, by causing severe respiratory disease outbreaks and fatalities in 2003 and 2014–15 respectively (Lo *et al.*, 2005; Oboho *et al.*, 2015). COVID-19 has a closer resemblance to SARS-CoV-1 than MERS-CoV. Both SARS-CoV-1 and MERS-CoV epidemics subsided following much less drastic measures than those being currently implemented in the fight against COVID-19, which is evidently highly transmissible and more virulent.

The length of the genome of coronaviruses ranges from approximately 26,000 to 32,000 bases with varying numbers of open reading frames (ORFs) (from 6–11) (Song *et al.*, 2019). Non-structural proteins (NSPs) comprise approximately 67% of the entire genome, while the remaining ORFs encode accessory and structural proteins (Cui *et al.*, 2019). The four major structural proteins of coronaviruses are the spike surface glycoprotein (S), small envelope protein (E), matrix protein (M), and nucleocapsid protein (N).

In late 2019, viral metagenomics analysis that was conducted on bronchoalveolar-lavage specimens from early infected Chinese adult patients confirmed the mismatch with known pathogenic coronaviruses (HCoV-229E, HCoV-NL63, HCoV-OC43, and HCoV-HKU1) (Zhu *et al.*, 2020). This confirmed that the disease was caused by a novel coronavirus. Genomic sequencing showed that the novel virus shared more than 85% similarity with a bat SARS-like CoV (bat-SL-CoVZC45 and bat-SL-CoVZXC21) with the majority of the contigs matching the genome from lineage B of the genus betacoronavirus (Zhu *et al.*, 2020). This was confirmed by real-time RT-PCR assay matching the viral RNA to a consensus RdRp region of pan β-CoV. The COVID-19 genome has 14 ORFs encoding 27 proteins. Found at the 5′-terminus of the genome, the *orf1ab* and *orf1a* genes encode the pp1ab and pp1a proteins, respectively. Together, they consist of 15 nsps including nsp1 to nsp10 and nsp12 to nsp16. The 3′-terminus of the genome contains four structural proteins (S, E, M, and N) and eight accessory proteins (3a, 3b, p6, 7a, 7b, 8b, 9b, and orf14) (Figure 1). Recent COVID-19 genomic sequence data from multiple patients from different countries shows multiple variants with mutational differences indicating that the virus continues to evolve in human hosts (Li *et al.*, 2020).

The organization of the genetic material of the COVID-19 virus resembles that of bat-SL-CoVZC45, bat-SL-CoVZXC21, and SARS-CoV-1. In particular, the lengths of the majority of

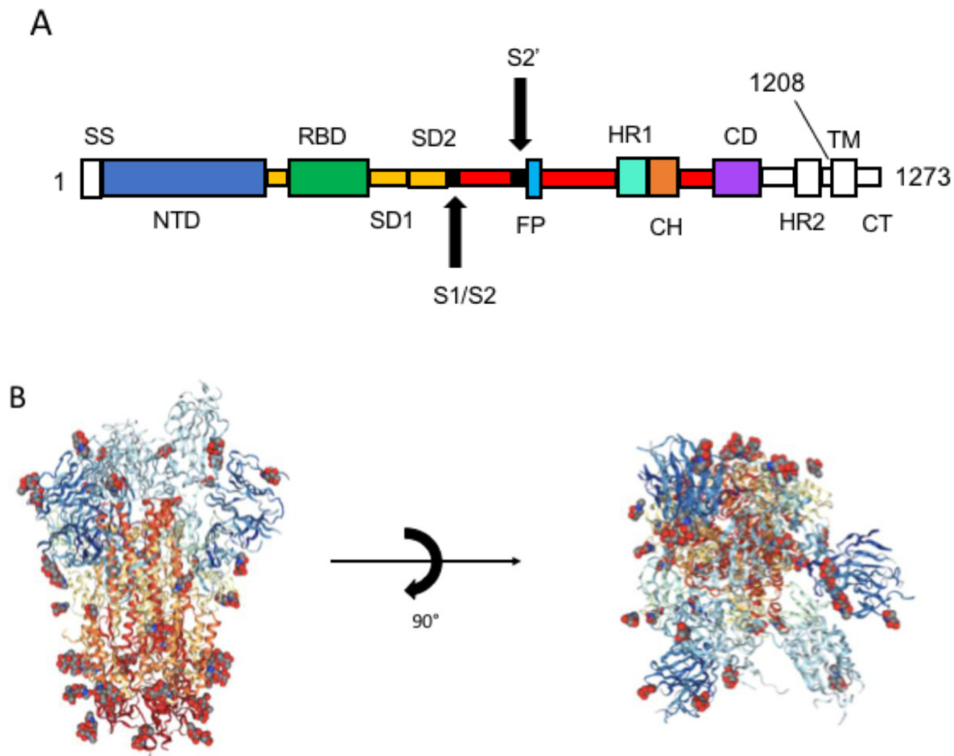

Figure 1. Structure of 2019 n-CoV in the prefusion conformation. (**A**) Schematic of 2019n-CoV primary structure colored by domain. Domains that were excluded from the ectodomain expression construct or could not be visualized in the final map are colored white. SS= signal sequence, NTD= N-terminal domain, RBD= receptor-binding domain, SD1= subdomain 1, SD2= subdomain 2, S1/S2= S1/S2 protease cleavage site, S2′= S2′ protease cleavage site, FP= fusion peptide, HR1= heptad repeat 1, CH= central helix, CD= connector domain, HR2= heptad repeat 2, TM= transmembrane domain, CT= cytoplasmic tail. Arrows denote protease cleavage sites. (**B**) Side and top views of the prefusion structure of the 2019-nCoV S protein with a single RBD in the up conformation. The prefusion 2019-nCoV spike glycoprotein structure (Accession ID 6VSB) was obtained from the publicly available RSCB Protein Data Bank [Reference 1: RCSB Protein Data Bank: Enabling biomedical research and drug discovery (2020) *Protein Science* 29: 52–65 doi: 10.1002/pro.3730]. The 3D structure figure was generated using NGL, a web application for molecular visualisation [Reference 2: AS Rose and PW Hildebrand. *NGL Viewer: a web application for molecular visualization.* Nucl Acids Res (1 July 2015) 43 (W1): W576-W579 first published online April 29, 2015. doi:10.1093/nar/gkv402].

proteins encoded by COVID-19, bat-SL-CoVZC45, and bat-SL- CoVZXC21 were found to be identical with few minor insertions or deletions. COVID-19 encoded a longer spike protein compared to the bat SARS-like coronaviruses, SARS-CoV-1, and MERS-CoV (Lu *et al.*, 2020).

In terms of amino acid sequences, the COVID-19 virus is close to SARS-CoV-1, but there are significant differences. For instance, the 8a protein found in SARS-CoV-1 is absent in COVID-19; the 8b protein is made up of 84 amino acids in SARS-CoV-1, but was found to be longer (121 amino acids) in COVID-19; the 3b protein in SARS-CoV-1 consists of 154 amino acids, but is shorter in COVID-19, with only 22 amino acids (Wu *et al.*, 2020). The overall structure of the spike protein (S) in COVID-19 is very similar to that of SARS-CoV-1, with a root mean square deviation (RMSD) of 3.8 Angstrom over 959 Cα atoms. The main distinctive feature between COVID-19 and SARS-CoV-1 is the position of the receptor binding domains (RBDs) in their respective down conformations. Indeed, the RBD in SARS-CoV-1 packs tightly against the N-terminal domain (NTD) of the neighbouring protomer in the down conformation. On the other hand, the RBD in COVID-19 in the down conformation is angled closer to the central cavity of the trimer. The spike protein of the COVID-19 shares 98% sequence similarity with that of the bat coronavirus RaTG13 (Coutard *et al.*, 2020). Furthermore, the spike protein of both COVID-19 and SARS-CoV-1 possess a similar host-cell receptor namely angiotensin-converting enzyme 2 (ACE2).

Other unique features of COVID-19 include the insertion in the S1/S2 protease cleavage site resulting in an "RRAR" furin recognition site in COVID-19 in contrast to the single arginine in SARS-CoV-1 (Coutard *et al.*, 2020). Moreover, several key residues responsible for the binding of the RBD of SARS-CoV-1 to the ACE2 receptor were variable in the case of the COVID-19 (including Asn439, Asn501, Gln493, Gly485 and Phe486; 2019-nCoV numbering) rationalizing the difference in their binding affinities (Lu *et al.*, 2020). Indeed, the binding affinity of ACE2 to the COVID-19 ectodomain measured via surface plasmon resonance (SPR) was found to be approx. 15 nM which is about 10-20 times higher than that of SARS-CoV-1 which explains the higher ease of transmission of COVID-19 among humans (Coutard *et al.*, 2020). Amino acid examination of COVID-19 and SARS-CoV-1 helped to shed light on the structural and functional differences of the two coronaviruses. In particular, 380 amino acid substitutions exist between the amino acid sequences of COVID-19 (HB01) and the analogous consensus structure of SARS-CoV-1 and SARS-like viruses. Indeed, 102 and 61 amino acid substitutions were noted in nsp3 and nsp 2 respectively (Wu *et al.*, 2020). Additionally, there are 29 variant residues between the spike protein of COVID-19 and RaTG13 with 17 positions corresponding to RBDs.

Morphological elucidation via transmission electron microscopy (TEM) confirmed that COVID-19 belonged to the *Coronaviridae* family. The virus particles were spherical in general with diameter ranging between 60–140 nm with quite characteristic spikes, about 9 to 12 nm (Cascella *et al.*, 2020). Genomic sequencing of the COVID-19 showed that the genomes clustered together within the sarbecovirus subgenus, with a typical betacoronavirus organization: a 5′ untranslated region (UTR), replicase complex (orf1ab), S gene, E gene, M gene, N gene, 3′ UTR, and several unidentified nonstructural open reading frames.

Pathogenesis of COVID-19

COVID-19 similar to the SARS-CoV-1 binds the ACE2 receptor to gain entry into cells, where it replicates using the cellular machinery (Li *et al.*, 2003; Zhou *et al.*, 2020) leading to cell injury and death. The ACE2 receptor, though abundant in the respiratory system, are also found in other tissues such as gastrointestinal, testis and kidney (Li *et al.*, 2020).

Thus, patients with mild disease present with respiratory symptoms such as rhinorrhoea, sneezing, and sore throat, and with severe disease the lower respiratory tract is involved leading to difficulty in breathing, shortness of breath, coughing and acute respiratory distress syndrome. Gastrointestinal issues, such as diarrhoea and abdominal discomfort, as well as kidney failure have been noted (Worldometer, 2020. Increasingly, different types of clinical and biological evolution have been noted as observed by Lescure *et al.* and Huang *et al.* in patients infected with COVID-19. These include mild, moderate and severe or critical with either persistent worsening or biphasic evolution of the condition (Huang *et al.*, 2020; Lescure *et al.*, 2020).

The severe clinical sequelae of COVID-19, is attributed to immune-inflammatory responses that lead to host tissue injury. Patients infected with COVID-19 showed increased levels of plasma pro-inflammatory cytokines with concomitant pathologies such as lung infiltrates evidenced by ground glass opacities bilaterally on radiological investigation and acute cardiac injury (Huang *et al.*, 2020; Rothan & Byrareddy, 2020). The cytokine storm that correlates with disease severity in many patients is evidenced by significantly high blood levels of IL1-β, IL1RA, IL7, IL8, IL9, IL10, basic FGF2, GCSF, GMCSF, IFNγ, IP10, MCP1, MIP1α, MIP1β, PDGFB, TNFα, and VEGFA. In more severe patients, high levels of proinflammatory cytokines correlated with the need for admission to the intensive care unit. These were IL2, IL7, IL10, GCSF, IP10, MCP1, MIP1α, and TNFα (Huang *et al.*, 2020).

Evidence is cumulatively pointing to the fact that the clinical presentation is heterogeneous in different populations and ages (Heymann *et al.*, 2020; Woelfel *et al.*, 2020). Thus, it is important to document clinical and biological progression and patterns in different populations, ages, and comorbid backgrounds to better guide clinical management and decision making.

Challenges and opportunities of the potential impacts of COVID-19 in Africa

Africa's public health infrastructure and capabilities

As a primary defense, in emergencies regarding infectious diseases, at the center of global health security are national public health infrastructure and capabilities (Sands *et al.*, 2016). Each African country should have crisis management plans in readiness and involve the international community to activate such preparedness when need be. When comparing the aftermath of recent year's pandemics and epidemics in Africa, including H1N1 pandemic, the Ebola virus, SARS, and MERS, preparedness is an area of concern. Prior to the H1N1 pandemic in 2009, the WHO had urged member states to engage in preparedness development as new pandemics emerged, affecting humans. A recent study conducted in 2018 evaluated within the WHO African region the calibre of country preparedness. Out of 47 countries (of all 54 countries in Africa), evaluation of 35 national pandemic preparedness plans occurred. Results revealed that preparedness in South Africa was high at 79%, while Cote d'Ivoire only managed 5%. Across the 35 evaluated countries, the composite score for pandemic plan completeness was 36%. The overall assessment indicated that there were inadequate pandemic preparedness plans on the African continent (Figure 2 and Figure 3, Sambala *et al.*, 2018).

Other challenges in African health systems include: poor coordination, management and leadership, inadequate human resources, and inadequate budget allocations for health (Oleribe *et al.*, 2019). There is a dire need to reinforce public health infrastructure and capabilities, as well as multi-sectoral coordination, human capacity, laboratory testing and surveillance systems in the aftermath of COVID-19 (Gilbert *et al.*, 2020).

On average, risk communication and preparation was 48%, with coordination and partnership having the highest score (49%). Prevention and containment was 35%, while surveillance and monitoring scored 34% (Figure 3). Case investigation and treatment reported 25% and ethical consideration was the lowest across the 35 African countries at 14%. The WHO Head of Emergency operations in Africa has warned that new cases may emerge at any time, but noted that many hospitals would not be able to cope with the increased cases for those requiring intensive care treatment. As of 30th March 2020, a total of 4,832 confirmed cases and 155 deaths in Africa (Figure 4, Table 1) had occurred (Worldometer, 2020). It is an axiom that lack of laboratory reagents and capacity increases turn-around time in mass-testing to confirm COVID-19 cases. This delays case confirmation and thus disease management.

Many countries have limited intensive care facilities. For example, in South Africa, should an outbreak occur, for hospitalized patients, it would be a major challenge for public health care services to provide 90–100% with the required supplemental oxygen, 20–25% of those with severe cases with the required intensive care treatment, and 5–10% of these same severe cases with the required mechanical ventilation (WHO Interim guidance, 2020; WHO Euro region, 2020).

Potential impacts on African economies

The COVID-19 pandemic is likely to have a substantive effect on African economies. Who will be affected? Casual workers and low-wage earners may be the most impacted, including domestic workers, leisure and hospitality workers (Devereux, 2020). In

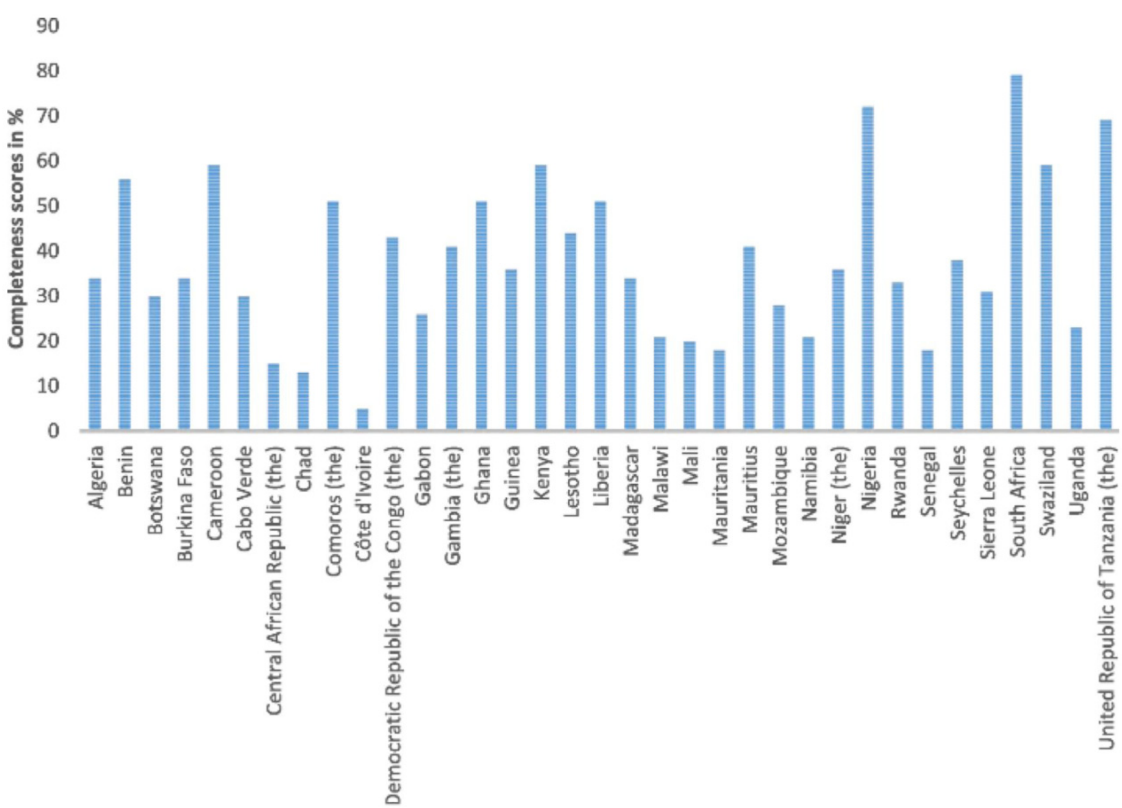

Figure 2. Composite scores of preparedness plans by country (Sambala *et al.*, 2018).

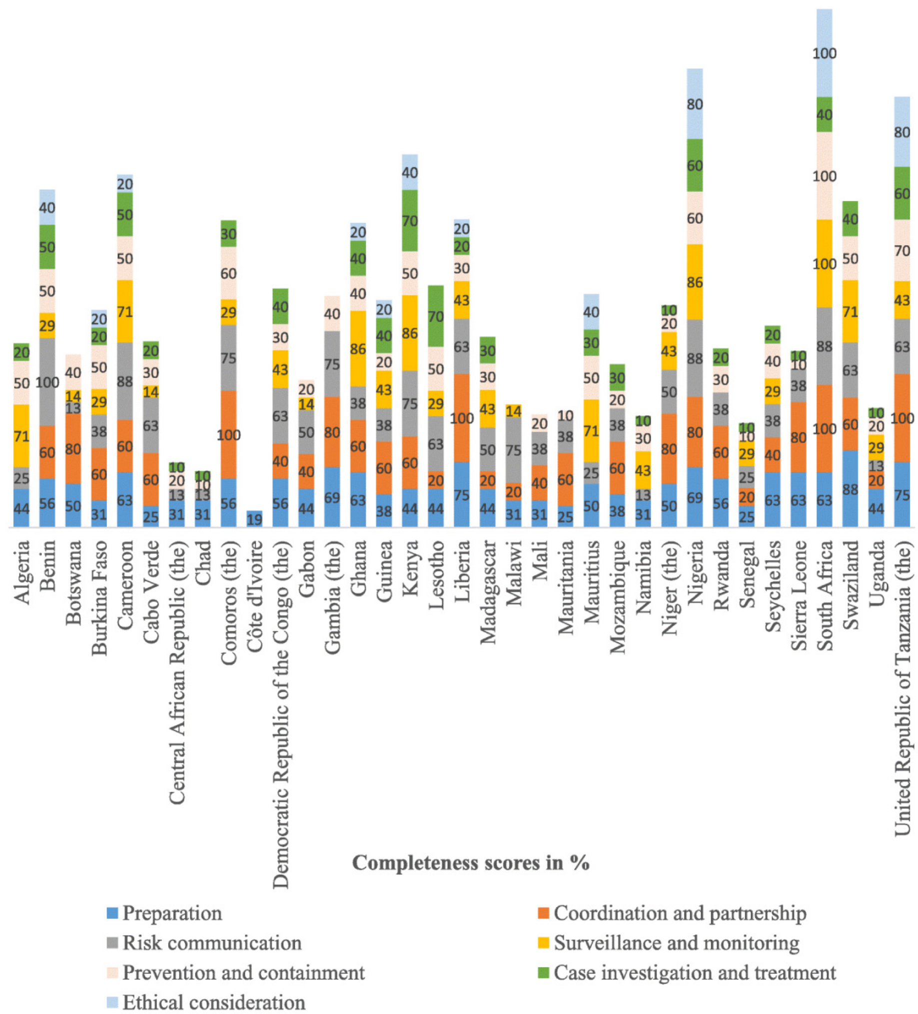

Figure 3. Completeness of the preparedness plans of countries by category (Sambala *et al.*, 2018).

particular, employees in informal sector who do not have access to paid sick leave may be reluctant to take time off - which could put both their families at risk but also lead to the spread of the virus (Fine *et al.*, 2020). As has been seen in the case of China, quarantine directives may lead to the partial and full shut down of factories, plants and daily markets for the manufacture of goods and services and sale of food stuffs. Livelihoods, Small to Medium Enterprises will also be severely impacted (World Bank, 2020). Moreover, restrictions on the free movement of people will disrupt economic activity and the hardest hit will be the urban poor that thrive on daily wage earnings (Africa Insiders, 2020). Universities, schools, colleges, and workplaces have been closed – shifting to online lectures which also have their own challenges (Houlden & Veletsianos, 2020). This may affect teachers, lecturers, graduate student assistants and students especially those from already vulnerable and marginalised communities and income groups (UNESCO, 2020). Most international meetings have been affected for example the 26th Commonwealth Heads of Government Meeting (CHOGM) that was due in June in Kigali, Rwanda has been postponed (Shaban, 2020b), other international and local convenings have been affected (Leone, 2020). Consequently, travel plans have been cancelled affecting many international conferences and tech companies and economies relying on conference-linked tourism. Moreover, many African economies are closely interlinked with China, this will also affect supply chains (African Union, 2020). As such, this may lead to a decline in economic growth for 2020 across Africa with a long haul recovery process. Estimates of global growth were downgraded by forecasts of the Organization for Economic Cooperation and Development (OECD) in 2020 from 3 % in 2019 to 2.4% in 2020. The International Monetary Fund has indicated a similar decline, including a 1% decline in the growth of the Chinese economy due to the pandemic (Boone, 2020).

Importation risks

Due to closed air traffic links between the affected Chinese provinces and African countries, Gilbert *et al.* (2020) evaluated the virus importation risk that each African country may face in the spread of the virus. Countries are required to make mandatory

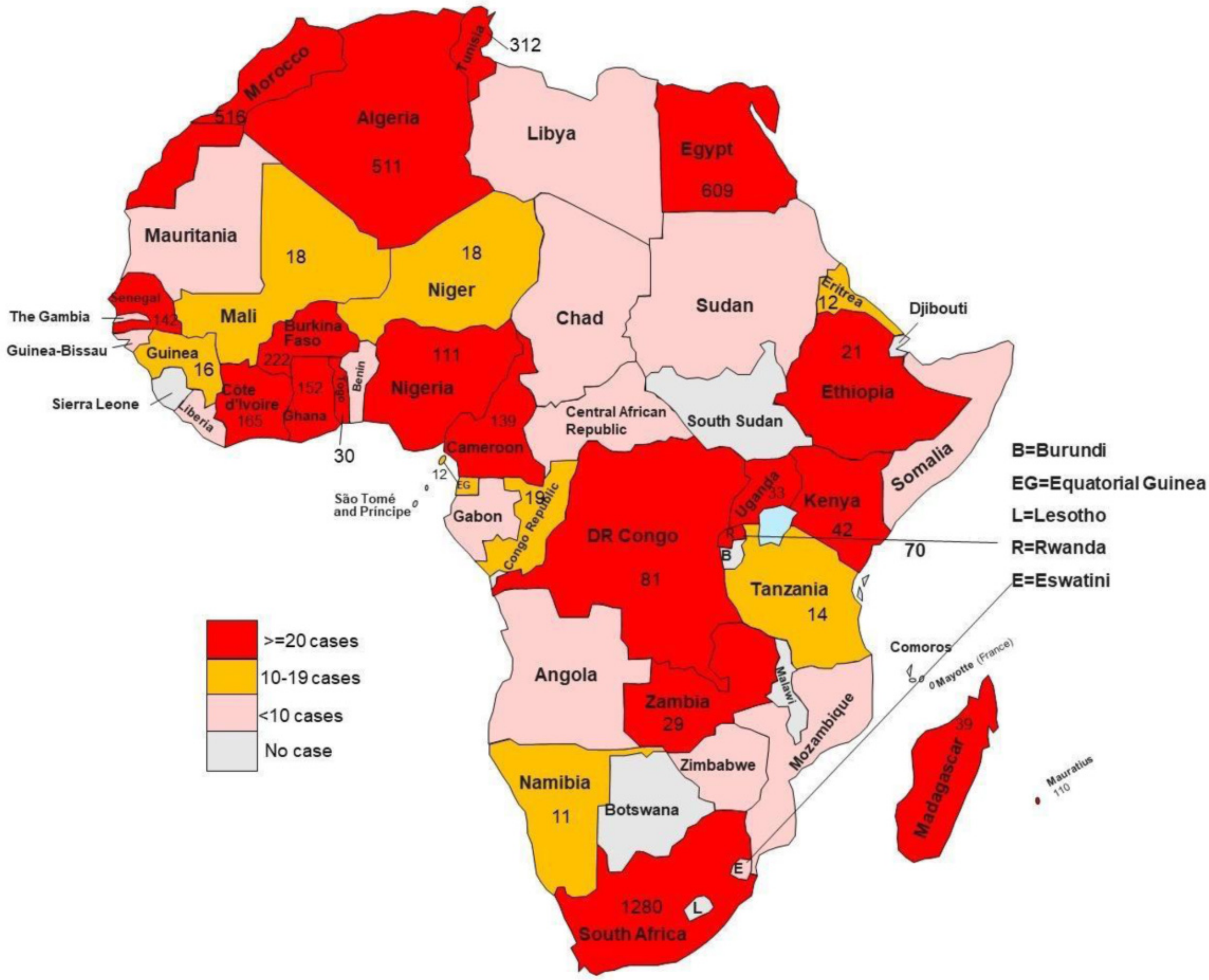

Figure 4. Map of Africa showing the distribution of total cases of COVID-19 in African countries. (Worldometer, as of 0920 GMT March 30th 2020).

declarations to the WHO annually, of the country's resources in the preparedness for encountering an epidemic, known as State Parties self-assessment Annual Reporting (SPAR). The indicator list includes: adherence to WHO standards, medical staff, legislation, laboratory skills, food safety, emergency organization, measure of equipment in healthcare facilities and communication to the public (INSERM, 2020). The Infectious Disease Vulnerability Index (IDVI) was also taken into account as it influences the response to an epidemic, but it is not directly linked to the health system. Both IDVI and SPAR high scores (out of 100 each), can predict efficient virus importation response. Results indicated that South Africa, Algeria and Egypt were most at risk of virus importation due to the high trade exchange volume with China. Ironically, the SPAR and IDVI scores of these three counties were the best on the continent. Kenya, Ghana, Nigeria, Ethiopia, Angola, Sudan and Tanzania have lower virus importation risk, yet they had lower SPAR and IDVI scores. This raises concern of possible non-detection of imported cases or even of local/community and/or national virus spread (INSERM, 2020). This points to limited regional and national systems and capacities for monitoring and coordination.

Overburdened health care workers and their patients

As is the case in many parts of Africa, hospitals have a limited bed capacity to accommodate COVID-19 patients. For example, the Lagos State Infectious Disease Hospital (IDH) in Nigeria has a 100-bed capacity but has to accommodate a state with over 18 million residents. In South Africa, nationally there are 187 beds per 100,000 population (Dell & Kahn, 2017). Similarly, in many African countries, hospitals are understaffed, without enough personal protection equipment (PPE), appropriate equipment, without training to deal with this novel virus, or unable to

Table 1. Distribution of total cases, total deaths, total recoveries, cases and deaths. per one million population and date of first reported cases of COVID-19 in African countries (Worldometer, as of 0920 GMT March 30th 2020).

Country	Total cases	Total deaths	Total recovered	Active cases	Cases / 1m population	Deaths/1m population	Reported 1st case in 2020
South Africa	1,280	2	31	1,247	22	0.03	Mar-04
Egypt	609	40	132	437	6	0.4	Feb-13
Morocco	516	27	13	476	14	0.7	Mar-01
Algeria	511	31	31	449	12	0.7	Feb-24
Burkina Faso	222	12	23	187	11	0.6	Mar-08
Ivory Coast	165	1	4	160	6	0.04	Mar-10
Ghana	152	5	2	145	5	0.2	Mar-11
Senegal	142	NA	27	115	8	NA	Mar-01
Cameroon	139	6	5	128	5	0.2	Mar-05
Nigeria	111	1	3	107	0.5	NA	Feb-27
Mauritius	110	3	NA	107	86	2	Mar-17
DRC	81	8	2	71	0.9	0.09	Mar-09
Rwanda	70	NA	NA	70	5	NA	Mar-13
Kenya	42	1	1	40	0.8	0.02	Mar-12
Madagascar	39	NA	NA	39	1	NA	Mar-19
Uganda	33	NA	NA	33	0.7	NA	Mar-20
Togo	30	1	1	28	4	0.1	Mar-05
Zambia	29	NA	NA	29	2	NA	Mar-17
Ethiopia	21	NA	1	20	0.2	NA	Mar-12
Congo	19	NA	NA	19	3	NA	Mar-14
Mali	18	1	NA	17	0.9	0.05	Mar-24
Niger	18	1	NA	17	0.7	0.04	Mar-18
Guinea	16	NA	NA	16	1	NA	Mar-12
Equatorial Guinea	12	NA	NA	12	9	NA	Mar-13
Eritrea	12	NA	NA	12	3	NA	Mar-20
Namibia	11	NA	2	9	4	NA	Mar-13
Eswatini	9	NA	NA	9	8	NA	Mar-13
Libya	8	NA	NA	8	1	NA	Mar-23
Mozambique	8	NA	NA	8	0.3	NA	Mar-21
Angola	7	2	NA	5	0.2	0.06	Mar-19
Gabon	7	1	NA	6	3	0.4	Mar-12
Zimbabwe	7	1	NA	6	0.5	0.07	Mar-19
Benin	6	NA	NA	6	0.5	NA	Mar-15
Cabo Verde	6	1	NA	5	11	2	Mar-19
Sudan	6	1	NA	5	0.1	0.02	Mar-12
Mauritania	5	NA	2	3	1	NA	Mar-12
Gambia	4	1	NA	3	2	0.4	Mar-16
CAR	3	NA	NA	3	0.6	NA	Mar-14
Chad	3	NA	NA	3	0.2	NA	Mar-18
Liberia	3	NA	NA	3	0.6	NA	Mar-15
Somalia	3	NA	NA	3	0.2	NA	Mar-15
Guinea-Bissau	2	NA	NA	2	1	NA	Mar-24
Total	4,495	147	280	4,079			

handle the number of patients at one time (Finnan, 2020). Limited budgets for emergency spending, complicated national procurement and recruitment processes and systems complicate the potential for quickly bridging the observed gaps in requisite equipment, logistics and staffing (Bruton & Edwards, 2020; Dusseljee, 2020). These inadequacies and challenges have led to protests among health workers in some countries as has been the case in Malawi (Pensulo, 2020). All these issues point to the need for African countries to improve the functionality of their health systems in response to the COVID-19 outbreak to increase their capacity to manage a large number of patients (McVeigh & Boseley, 2020).

Isolation of poor and rural communities with limited access to telecommunications

With the ongoing pandemic, online shopping might increase along with deepening Internet penetration, rise in e-commerce and more smartphones and mobile payment systems across Africa. Nevertheless, many regions remain isolated from internet access with high poverty, illiteracy, a lack of transport infrastructure and logistical inefficiencies. For example, even in one of the continent's strongest economies, the Internet is utilized by only 11.5% of South Africa's population (Makhitha & Dlodlo, 2014). If the world becomes more dependent on teleconferencing facilities for enterprises, those without access to internet infrastructure in many parts of Africa or who have regular interruptions of communications and power cuts could be increasingly isolated.

Adverse impacts on mental health

Rapid implementation of social distancing could cause loneliness and isolation of the elderly, people with disabilities and with underlying health issues. This could lead to the infliction of physical and mental harm, increased anxiety and change daily routines for many vulnerable sections of the population. Senior citizens' centers may also be closed. The banning of public funerals could also be a source of depression for some of African societies, such as in Ghana where these practices are a central component of social life (BBC, 2020). Those living with mental health disabilities, such as depression, anxiety or post traumatic stress disorder (PTSD) may be seriously impacted with a change of behaviour, with the closure of schools, businesses and social distancing measures (Cassata, 2020).

Food insecurity

Many lower-income communities rely on income received daily to survive. The virus could also impact such food insecure populations especially among urban poor and mobile populations such as camp labourers. In eastern and northern Uganda for example, the price of 500 g of salt has been reported to have risen by more than fivefold from UGX 700 ($0.19) to UGX4000 ($1.09) within a period of two weeks from the confirmation of COVID-19 cases in the country (Rashul *et al.*, 2020). The food and agricultural sector may face illness-related labour shortages, transport interruptions, and quarantine measures limiting access to markets. Furthermore, supply chain disruptions could result in food loss and waste. A loss in purchasing power could reduce people's eating patterns, causing nutritional deficits (Beltrami, 2020). With a potential economic downturn globally, residents in poor countries which rely on imports for food and fuel needs may see an increase in costs, with a lower export of primary commodities. Agriculturally dependent economies, especially in sub-Saharan Africa, will likely see a depreciation in their local currencies against the United States dollar and worsening balance of payment regimes as agricultural exports constrict.

High vulnerability of informal settlements

In densely populated informal settlements across Africa, which comprise 59% of urban settlements across Africa (UN-HABITAT, 2019), the risk of contracting and spreading COVID-19 will be very high. Typically, hundreds share communal taps, many rely on open defecation without access to functioning toilets, there are raw sewerage and open drains, congestion and a lack of solid waste management and many diverse nationalities. Physical contact in informal settlements has a pronounced influence on the spread of respiratory diseases, especially in places with a high prevalence of tuberculosis and HIV/AIDs. This will make distancing strategies and control interventions within those communities challenging (Johnstone-Robertson *et al.*, 2011). Further, prevention materials such as hand sanitizers, masks and other detergents have lately seen a spike in prices owing to heightened demand. Persons in informal settlements often have limited disposal income and prioritise to secure household basic needs especially food, this leaves them more exposed to the risk contracting and being agents of COVID-19 spread.

Social services and legal protection

Many services for psychological support, prevention of domestic violence, and actions to initiate new protection orders, will no longer be offered during national lockdowns. Support groups will likely be cancelled, along with home visits, in-person assessment and counselling services. Similarly, educational workshops and other awareness raising activities will be cancelled. This could have particular implications for the increased incidence of domestic and gender-based violence for vulnerable women and children (Mosaic, 2020). Further, countries where restrictions on movement have been imposed (in part or in full) have affected delivery of social services to vulnerable groups for examples, persons living with HIV/AIDs face heightened cases of discrimination and stigma and an increased difficulty in accessing routine services. These incidents have been reported in Kenya, South Africa and Uganda (Human Rights Watch, 2020; Jerving, 2020).

A potential rise in xenophobia and security

Racism and xenophobia related to COVID-19 could rise with the spread of rumors and fake news, fears and stigma, especially on social media platforms. For example, in Kenya, recent cases have been reported against Asian men and women. Similarly, in a Chinese-led hospital in Zambia, suspicion was heightened when people returning from China with the virus symptoms were not quarantined. Other concerns were raised at hospitals, close to the Congo border, where many Chinese companies operate mines (STAT, 2020). It is also interesting to note that even outside Africa, Mr. Matteo Salvini, former Deputy Prime Minister of Italy, wrongly linked COVID-19 to African asylum seekers, calling for border closures (Devakumar *et al.*, 2020). For this reason, in March 2020, Michelle Bachelet, the UN High

Commissioner for Human Rights called on member states to combat discrimination triggered by the virus on people of Chinese and East Asian ethnicity (Shields, 2020).

Ongoing clinical trials

Currently, not many countries (only 1 in the African continent) have joined the Solidarity trial: a large international trial, launched by WHO aimed to determine the most efficient treatment options against COVID-19 (Nature website, Retrieved 21 April 2020). Argentina, Bahrain, Canada, France, Iran, Norway, South Africa, Spain, Switzerland and Thailand. The four most promising COVID-19 drug(s) are under investigation in the trial: (i) Remdesivir, (ii) the combined use of two HIV drugs, Lopinavir/Ritonavir, (iii) a combination of Lopinavir/Ritonavir with interferon beta and (iv) the anti-malarial medications Chloroquine and Hydroxychloroquine (WHO, 20202g). Unlike conventional clinical trials, the Solidarity trial is very simple and does not place additional burden on front line healthcare workers but enables collection of data on patients' response to the drugs.

HIV drugs, serum, stem cells and traditional Chinese medicine

More than 80 clinical trials are ongoing or pending in China on potential treatments for nCov2019. WHO is drafting a clinical trials protocol which researchers around the world could use to help set similar standards for the trials in China. Some of the trials include as many as 600 patients. According to the Chinese Clinical Trials Registry, clinical trials involving the use of an HIV-drug combination (lopinavir and ritonavir) together with another antiviral called remdesivir have already begun (Maxmen, 2020). Lopinavir and ritonavir block enzymes preventing viral replication while Remdesivir is an adenosine analogue developed by the US company, Gilead which incorporates nascent viral RNA chains causing pre-mature termination. Remdesivir was recently shown to possess $EC_{50} = 0.77\,\mu M$ in Vero E6 cells (Wang *et al.*, 2020).

A few clinical trials have also been launched to test the efficacy of the antimalarial drug Chloroquine (ChiCTR2000029609). In particular, it is currently being tested at more than ten hospitals in Beijing and Guangdong province. Another Chinese clinical trial involves using plasma from convalescent patients with the hypothesis of using the antibodies built up by the persons to fight the virus (ChiCTR2000029850). In a stem cell clinical trial listed in the Chinese registry, a research team from the First Affiliated Hospital of Zhejiang University is looking at injecting stem cells isolated from menstrual blood into patients, and comparing results with the placebo group (ChiCTR2000029606). A large number of Chinese clinical trials are looking at the potential of Chinese traditional medicine to treat COVID-19 with *Shuanghuanglian*, being the most popular Chinese medicine under investigation (Maxmen, 2020).

The antiviral drug Favilavir (Favipiravir) produced by Zhejiang Hisun Pharmaceutical has been approved as an investigational therapy in the treatment of COVID-19, reported local media (Clinicals Trials Arena. Accessed 01/04/2020). Favilavir is approved for the treatment of influenza (Wang *et al.*, 2020). COVID-19 infected patients have been recruited in randomized clinical trials to investigate the potential of favipiravir in combination with interferon-α (ChiCTR2000029600) and favipiravir combined with baloxavir marboxil (an approved influenza inhibitor targeting the cap-dependent endonuclease) (ChiCTR2000029544) (Li & De Clercq, 2020) for COVID19 treatment.

So far, Remdesivir, Favilavir and Chloroquine seem more promising. Favilavir was found to be 100% effective in protecting mice against Ebola virus challenge, although its EC50 value in Vero E6 cells was as high as 67μM (Wang *et al.*, 2020). Remdesivir and chloroquine blocked viral infection at much lower concentrations and displayed high selectivity indices (Wang *et al.*, 2020) (Figure 5). A recent clinical trial showed that the combination of azithromycin and hydroxychloroquine resulted in significantly better COVID-19 viral elimination (Gautret *et al.*, 2020). Data from completed and ongoing clinical trials may be used as a guide for COVID-19 treatment strategies.

Environmental impacts

Changes in behavior patterns brought on by COVID-19 could reduce carbon emissions. Changes may reduce the need for long-haul flights, and promote online meetings, working from home and habits which reduce commuting. Similarly, with the closure of certain supermarkets, consumption might decline. Overall, this may mean 2020 will see less CO_2 emissions. For example, in China, compared to previous years, the lockdown led to the 25% reduction in energy use and emissions over a two-week period (mostly electricity use, industrial production and transport) (Myllyvirta, 2020). Meanwhile, coal consumption by the six largest power plants in China has fallen by over 40% since the last financial quarter (Grant & Larsen, 2019). Similar reductions are being observed in Italy and other parts of Europe and across the United States of America. The airline industry, which covers 2.6% of the global carbon emissions will reduce activity, potentially for some period due to the lingering period of the virus. A drop in global emissions of 0.3% in 2020 is still likely, reports researchers at the Climate and Environment Research in Oslo. This is less distinct compared to the crash of 2008–09, but also provides an opportunity for less rebound if efforts to stimulate the economy are focused towards sectors such as clean energy (Henriques, 2020). However, whether these will have lasting positive environmental impacts remains to be seen. For example, the focus on COVID-19 has stalled progress on other policy priorities including liberalisation and environmental policies, and a further delay may be due to a strong fossil-fuel heavy stimulus (Oxford Institute for Energy Studies, 2020).

Recommendations for Africa's preparedness and response

As the COVID-19 cases continue to increase across the world (Zarocostas, 2020) including Africa (Makoni, 2020), governments, scientists, and personnel from the medical fraternity must urgently enhance preparedness. COVID-19 infections in Africa are rapidly rising, with the virus spreading to dozens of countries within weeks, countries are moving from preparedness to response (WHO, 2020a). The already overwhelmed and fragile health systems in Africa may not be in a good position to handle a

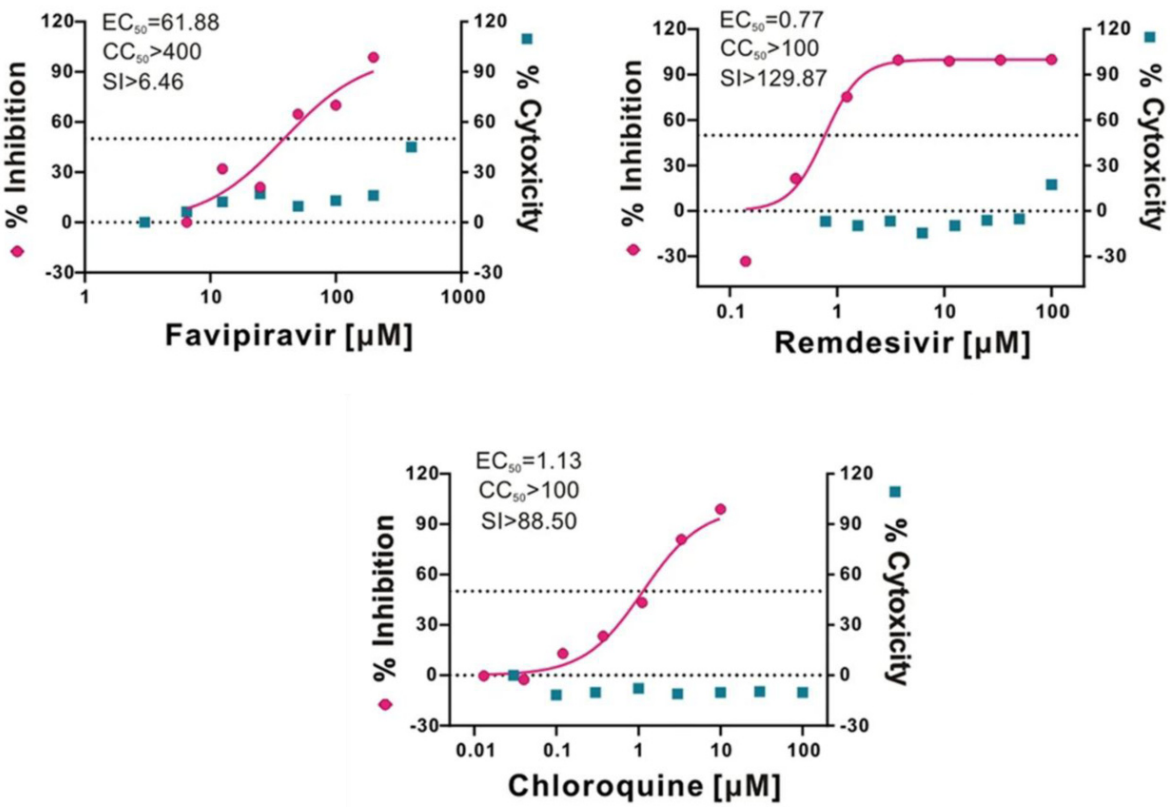

Figure 5. The antiviral activities of the test drugs against 2019-nCoV *in vitro*. Vero E6 cells were infected with 2019-nCoV at an MOI of 0.05 in the treatment of different doses of the indicated antivirals for 48 h. The viral yield in the cell supernatant was then quantified by qRT-PCR. Cytotoxicity of these drugs to Vero E6 cells was measured by CCK-8 assays. The left and right Y-axis of the graphs represent mean % inhibition of virus yield and cytotoxicity of the drugs, respectively. The experiments were done in triplicates. Reproduced under the terms of the Creative Commons CC BY license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (Wang *et al.*, 2020).

severe outbreak of this nature. This section of the paper suggests recommendations and highlights some of the optimistic response that Africa is deploying in response to the virus.

Reinforcing public health infrastructure and capabilities

There is a need for a concerted and multi-sectoral approach to increase the overall level of preparedness of health infrastructure and capacity in Africa. The preparedness should include, well trained sufficient manpower, quick response rates, the availability of critical medical logistics; products, pharmaceuticals, masks, testing kits, hospital beds and protective gear. In addition, laboratories with the needed standardized biosafety levels as well as, available and efficient isolation, referral hospitals and treatment facilities need to be identified and made ready to receive patients (Government of Kenya, 2020). In the case of Kenya, transport and mobile isolation units were expanded into temporary isolation treatment facilities to tackle cases of the virus (Business Insider SA, 2020). There is also a dire need to train doctors and nurses as well as rapidly recruit more to expand the personnel number to manage infected cases, with the support of international organizations and local private entities. The WHO has deployed 40 experts in 10 countries to support treatment, infection, control and prevention, coordination, community engagement, laboratory disease control and surveillance. Further assistance has helped countries in diagnostic capacity building (Business Insider SA, 2020). Prevention and control measures at both the community and healthcare facility levels will be critical (WHO, 2020a).

Early detection of cases

A critical first step is early detection of the virus to limit human-to-human transmission that could ultimately negatively influence treatment capacity (Makoni, 2020). It is also imperative that the African continent prepares to create capacity for isolation and treatment of affected individuals. Early detection in African countries has been supported by the WHO, that have provided COVID-19 testing kits, strengthening surveillance in communities and training dozens of health workers. However, this is by no means sufficient to the need that lies ahead (WHO Euro region, 2020).

In most countries, there are one or two designated centers ‘accredited’ for testing COVID-19 cases. This will mean a lot of samples must be shipped from long distances across the country. It is recommended that national research centers liaise with university molecular laboratories (of which there could be several across the country) and other high level research molecular research laboratories available within their countries to increase their capacity to support testing. This will go a long way to determine the community burden and increase the overall capacity of the country to respond better in subsequent outbreaks.

Health surveillance systems and sample testing services

Tracking and health surveillance systems are important for outbreaks. Before 4 February 2020, the National Institute of Communicable Diseases in SA and the Institut Pasteur in Senegal were the only referral laboratories in Africa capable of COVID-19 sample testing. Currently, 47 countries in the WHO African region have COVID-19 testing and screening facilities in place (WHO, 2020d). The AU's Center for Disease Control, CDC, have also championed efforts to boost the capacity of African member states in testing and screening COVID-19 (Africa News Agency (ANA) Reporter, 2020). Although the WHO African region has donated PPE to the Ministry of Health in Ghana and to some other African countries as part of efforts to support COVID-19 Outbreak Response (WHO, 2020c), much more has to be done. Beyond testing is the capacity of the countries to continue tracking the suspected cases including identifying those who potentially go into hiding due to associated stigma as such cases have potential of escalating the spread of the virus.

Controlling ports of entry

Preparedness should include effective and efficient surveillance at all ports and points of entry into each country. Africa is the leading commercial partner for China, and therefore air travel between China and the continent increases the importation of the virus in Africa (Gilbert *et al.*, 2020). While measures have been put into place for prevention and control of Chinese importation (Le Monde Afrique, 2020; WHO, 2020d), with local transmission, the detection, prevention and control are of concern and requires accelerated identification of doubtful cases, isolation and transfer of individuals, diagnosis, tracing, and potential contact follow-up, as well as increased surveillance (Gilbert *et al.*, 2020; WHO, 2020d). For example, to prevent the outbreak and spread of COVID-19, Kenya has already banned slaughter, the export of donkeys and all flights from China. The Kenya-Uganda land border has been closed to all pedestrians and vehicles, with the exception of cargo trucks. Other countries have drawn lessons from the 2014 Ebola virus, where more than 11 000 people died. For example, the Democratic Republic of the Congo strengthened points of entry screening, partner coordination structures in readiness and upgrading of isolation units in management of suspected cases (Kazeem, 2020).

Importation risk mitigation

Due to the high volume travel links mentioned previously, WHO has prioritized support for 13 African countries, namely South Africa, Uganda, Kenya, Ghana, Nigeria, Zambia, Ethiopia, Algeria, the Democratic Republic of the Congo, Mauritius, Angola, Tanzania and Cote d'Ivoire (Makoni, 2020). Despite Egypt having high risk SPAR and IDVI scores and pinpointed as the airport on the African continent with the highest passenger load from Chinese affected areas, the country was not named among the WHO prioritization list (Lai *et al.*, 2020). In addition, missing from the list was Morocco, despite the country having moderate risk scores (Gilbert *et al.*, 2020). It is recommended that the WHO expand their support to all African nations who need support to deal with the COVID-19 cases.

Regional coordination platforms

Coordination platforms are crucial to ensure contingency and emergency plans are present, operational structures with clear communication channels exist, and resources are adequate and available for impending threats (Ayebare *et al.*, 2020). This can enable timely intervention to mobilize domestic and international resources to operationalise preparedness plans and response efforts. The WHO plays a vital role in coordinating efforts for preparedness of local outbreaks (WHO, 2020a). However, the utilization of existing structures is also critical. For example, as of 3 February 2020, the Africa Task Force for COVID-19 was established by the African Centre for Disease Control and Prevention (African CDC, 2020). Together with WHO, the Africa CDC is working on point of entry screening, prevention and control of infections at healthcare facilities, clinically managing severe COVID-19 infections, engaging communities, providing risk communication and laboratory diagnosis (WHO, 2020b). The Africa CDC coordination body has already been pivotal in establishing testing capacity for SARS-CoV-2 in approximately 40 African countries within one month of declaration of a "Public Health Emergency of International Concern" (PHEIC) (Ayebare *et al.*, 2020). However, the Director of Africa CDC reiterates the growing concern of the COVID-19 threat to Africa at different levels, namely, economic growth, security and social dynamics (Makoni, 2020).

Domestic coordination structures

Domestic examples of coordination have also already been seen. For example, in January 2020, the Federal Government of Nigeria (FGN) approved funds for preparedness for the Federal Ministry of Health (FMoH) for COVID-19. A multi-sectoral Coronavirus Preparedness Group led by the Nigeria Centre for Disease Control and National Emergency Operations Centre (EOC) has been set up by the FMoH to work closely with other stakeholders to respond to COVID cases and implement solid control measures (Federal Ministry of Health, 2020). Similarly, the Government of Kenya (GoK) issued an executive order in February 2020 to establish a framework for upscale and coordinate Kenya's preparedness and national response to the threat of COVID-19. As part of this, Kenya has established the national emergency response committee (Government of Kenya, 2020). The committee's mandate is to coordinate the country's preparedness, prevention and response, coordinate capacity building of medical personnel to respond to the threat, enhance surveillance at all ports and points of entry in Kenya, coordinate preparation of national, country and private isolation and treatment facilities, coordinate the supply of critical medical products/supplies, pharmaceuticals, masks, testing kits, and other protective gears (Government of Kenya, 2020). Similar coordinating entities will need to be set up elsewhere.

Financing

Fast accelerator funding should be made available to strengthen measures to ensure control and containment of an outbreak quickly. The financing would cover the procurement of diagnostic kits, protective gears, building and upgrading of laboratories, hospital beds and payments of personnel. This places a further burden on the already lean purses of most African countries. To date, the WHO has donated Personal Protective Equipment as part of efforts to support COVID-19 Outbreak Response, to the Ghanaian Ministry of Health, including 300 swabs, 500 RNA extraction, 1000 test kits, 9000 surgical masks, 180 goggles, 800 face shields, 350 N95 masks, 9200 examination gloves and 750 gowns. The WHO has also been supporting the Ghana Health Services by providing technical support for preparedness and response to COVID-19. The support included coordination and case management as well as capacity building (WHO, 2020c).

Governments are also starting to put in place financing schemes to support small to medium sized businesses, and funds to cushion the financial shocks experienced particularly during country lockdowns. For example, South Africa has established the Solidarity Fund, Debt Relief Fund, and Business Growth/Resilience Facility as well as 42 million Rand investment in the health sector alone (Dlothi, 2020).

Private philanthropists including the Oppenheimers and the Ruperts, two of the wealthiest families in the country, have each donated R1 billion towards the relief fund. Religious organizations, such as the AwqafSA, the Muslim Judicial Council, Sanzaf and Islamic Relief South Africa, have collectively donated R1million for low-income communities, and particularly those who derive their income from the informal sector. Funds will be used to provide aid via the donations in the form of hygiene and sanitation kits, water and non-perishable food items immediately during the 21-day lock-down and to stimulate recovery afterwards (Thebus, 2020). A unit, called the Vulindlela unit is also being set up in the Ministry of Finance, who will evaluate both the government and the private sector in creating the required structural reforms (Stoddard, 2020). Many more efforts such as these will be needed - with the support of all sectors of society, as millions struggle from impacts of likely economic recessions.

Efficient and constant sensitization and community engagement

Before the emergence of the first cases in Africa, efforts were made to sensitize the general population about the virus, taking personal preventive measures such as avoiding crowded gatherings, preventative hygiene measures, social distancing, self-isolation, regular and thorough hand washing using soap and water, using hand sanitizer (alcohol-based), and wearing face masks. These orientations notwithstanding, a negligible proportion of the population adopted these measures. Awareness raising should be scaled up, using social media platforms and work to curb the misinformation and myths about the virus (Shields, 2020). There will also be a need for increasing the capacity of local disaster risk management committees and youth groups for emergency responses, setting up mobile laboratories and clinics, and increasing the legitimacy of local chiefs or queen mothers and section heads, and religious leaders to disseminate timely information. The efficient and constant orientation of the citizens is needed, including in different vernacular languages, for the non-literate and disabled.

Reducing xenophobia and protecting against gender-based violence

The World Health Organization cautions against "actions that promote stigma or discrimination" when conducting national response measures to the outbreak managed to avoid potential racially aggravated assaults or violence. There is also a need for health officials to speak openly and respond to the concerns of communities to avoid antagonistic attacks (STAT, 2020). Social services will need to develop material and refine existing materials to ensure the safety and wellbeing of women and children against gender-based violence during lockdowns. Telephonic counselling will become more important, along with awareness raising using telephone applications in the court and for justice support. Facilities should be provided for trauma containment counselling. New forms of safety planning will need to be developed (Mosaic, 2020).

Communicable disease hotlines

Communicable diseases hotlines should be put in place in every country, to respond to worried callers, requesting advice on safety and understanding the symptoms. For example, South Africa's largest hospital group, Netcare, has refocused its communicable diseases hotline on COVID-19. In Algeria a call center has been set up in the capital Algiers to improve early detection and help contain the spread of the disease. This can be encouraging to people to avoid the spread of COVID-19 by taking correct measures, and countering false information in the public domain (WHO, 2020e). Strengthening the national capacity for disseminating alerts should also be a priority.

Provision of water and sanitation, particularly in informal settlements

Washing hands regularly or using alcohol-based sanitizers is a challenge for people with limited access to water. Three billion people across the world do not have access to handwashing facilities. Meanwhile, 33 of the top 42 countries that have the least access to hand-washing facilities are found in Africa (Kashiwase, 2020). Municipalities urgently need to prioritize the installation, repair and maintenance of access to clean, affordable water, increase the number of standpipes and install water tankers in informal settlements. Examples have already been seen in some parts of the continent, such as in South Africa, which is planning to assist over 2,000 communities by distributing water tanks at 2,901 water collection points (DeKlerk, 2020).

Temporary shelter for the homeless

Many homeless people will need places to stay during the lockdown events. Temporary shelters will need to be identified to accommodate these people. This has been the response by Cyril Ramophosa, the president of South Africa (Mail & Guardian, April 2020). Incentives must be created so the homeless do not feel forced into those facilities, with concerns of living in close proximity in full boarding homes, with the potential to be exposed to others with drug and alcohol addictions. During this time, authorities should support the development of soft skills to help them integrate back into their families and communities (Daily Maverick Team, 2020).

Increasing access to telecommunications
To ensure the access to telecommunications of poor, rural communities, special thought will need to be given to the benefits of logistically organized, centralized delivery routes with low packaging. Moreover, studies have shown many Africans are apprehensive to purchase online due to fraud and delivery difficulties. This should be preempted and managed through training, along with infrastructure development to scale up internet penetration in marginal communities (Makhitha & Dlodlo, 2014).

Changing behavior patterns in the long term to reduce carbon emissions
Our study has also shown COVID-19 may affect the way economic stimulus affects how emissions will evolve in the coming years. If behaviors preferences persist beyond the pandemic, this may reduce emissions and may contribute to the Africans' decarbonization process. Nations need to take seriously the potential opportunities to change and sustain measures to reduce air pollution, increase the presence for biodiversity, among other activities, as has already been observed in many parts of the world, to potentially mean a turn-around in the long-term trend (Henriques, 2020; Myllyvirta, 2020).

Physical activity and mental health
To ensure public health recommendations for social isolation quarantine should recommend a regular activity, going outside and exercising in unpopulated areas during quiet periods, and ways to maintain social connectivity, such as through computers, affordable internet connectivity, and training in digital training. Physical activity is vital for mental health and protecting the immune system from the effects of stress, arguably more so during self-isolation. Governments must support citizens in lockdown with guidance on how to exercise at home or provide time to exercise outdoors once a day (Cassata, 2020).

Reducing food insecurity
Interventions must be put in place for vulnerable populations, including low-income communities, senior citizens, and disabled populations to receive appropriate healthy and nutritious food assistance and avoid hunger. Distribution centers and supermarkets for fresh produce should also scale up plans to deal with increased demand from 'panicked' shoppers. Moreover, planning across the supply chain is needed to avoid food insecurity. In addition to other health services, countries across Africa must scale up social safety nets that are flexible to shocks (Beltrami, 2020).

Potential targets for the development of therapies
Current treatment options available to healthcare professionals fighting the COVID-19 pandemic are scarce given that the pathogenesis of the virus is not fully understood yet. The CoV spike glycoprotein is a key target for vaccines, therapeutic antibodies and other diagnostics (Wrapp *et al.*, 2020). The presence of the densely glycosylated spike (S) protein facilitates the entry of the SARS-COV-2 into host cells (Wrapp *et al.*, 2020). The S protein is present in a metastable prefusion trimer conformation which undergoes dramatic rearrangement of its structure enabling fusion of the viral membrane with the host cell membrane. Binding of the S1 subunit to the host-cell receptor triggers this process. This destabilizes the pre-fusion trimer causing release of the S1 subunit and transition of the S2 subunit into a stable post-fusion conformation (Walls *et al.*, 2017). Indeed, the S protein plays an indispensable function and thus represents a potential target for antibody mediated neutralization and can further guide vaccine design for the treatment of the COVID-19.

Structural modeling of S protein indicated strong interaction of the human ACE2 molecules with SARS-COV-2 (Xu *et al.*, 2020). Chen & Du (2020) identified 5 active compounds namely Baicalin, Scutellarin, Hesperetin, Nicotiamine and Glycyrrhizin and carried out molecular docking studies to predict their binding capacity to ACE2. As can be noted from Table 2, Scutellarin had the highest binding affinity to ACE2 compared to the remaining molecules.

In general, viruses enter cells through a process known as receptor mediated endocytosis and recent studies suggested that ACE2 in COVID-19 may be the receptor involved in infecting lung cells. The surface protein ACE2 is located on cells in the kidney, blood vessels and importantly in lung AT2 alveolar epithelial cells. AP2-associated protein kinase 1 (AAK1) is a known regulator of endocytosis. Hence a potential way of preventing transmission of the virus into human cells could be via the disruption of AAK1 (Richardson *et al.*, 2020). Amongst the 378 AAK1 inhibitors in

Table 2. Summary of molecular docking of Baicalin, Scutellarin, Hesperetin, Nicotiamine and Glycyrrhizin with ACE2 (Chen & Du 2020).

Compound	Δ G/ (kCal/mol)	Potential binding sites
Baicalin	-8.46	ASN-149 ARG-273 HIS-505
Scutellarin	-14.9	GLU-495 UNK-957 ARG-482
Hesperetin	-8.3	TYR-613 SER-611 ARG-482 GLU-479
Nicotiamine	-5.1	ARG-518 GLU-406 SER-409 GLN-522 GLN-442
Glycyrrhizin	-9	ARG-559 GLN-388 ARG-393 ASP-30

the knowledge graph generated by the company BenevolentAI, six were found to inhibit AAK1 with high affinity. These included anti-cancer drugs such as sunitinib and erlotinib, which can cause serious side effects and therefore were not considered further. The janus kinase inhibitor baricitinib, on the other hand, was shown to inhibit AAK1 in doses as low as 2 or 4 mg daily suggesting its possible use in trials (Richardson *et al.*, 2020).

Current efforts are being geared towards drug repurposing of already FDA approved drugs as well as the virtual screening for molecules available from chemical libraries. *Insilco* Medicine designed and started the generation of novel drug-like inhibitors of 2019-nCoV using three of its validated generative chemistry approaches (Zhavoronkov *et al.*, 2020). The selected target was the C30 endopeptidase (3CLP) which is a homodimeric cysteine protease that cleaves polyproteins into individual polypeptides and plays a vital role in replication and transcription of the virus. Various virtual structures with high 3D complexity were generated which can then be used in computer modelling simulations or to synthesize and test the compounds *in vitro*.

Potential for development of point of care (POC) diagnostics

Early diagnosis of COVID-19 is critical to timely management of patients and control of spread of the disease. The key to this fight is to track, test and contain infection clusters. Indeed, this step helped to reduce the number of mortalities associated with COVID-19 in Germany whereby only 0.4% of people who have been tested positive for the virus have succumbed to the latter in contrast to 4.3 % in France (MarketWatch (2020)). It was recently pointed out that people showing mild or no symptoms of COVID-19 can actually be harboring high viral loads in the throat and may spread the virus through 'viral shedding' (Woelfel *et al.*, 2020).

However, the current tools; RT-PCR and radiological imaging, are not adequate to address point of care diagnosis especially in low resource settings that characterize sub-Saharan Africa. Indeed, as the pandemic situation evolves with control goals focusing both containment and mitigation (Parodi & Liu, 2020; WHO, 2020), capacity for wide scale diagnosis at most if not all levels of health care systems will be vital for long-term control. Again, as treatment solutions for the disease become available, prompt diagnosis will be essential in enabling prompt treatment of cases and determining isolation/quarantine decisions.

RT-PCR diagnostic capacity is limited in most African countries, with 1-3 labs in 40 countries as on 25th Feb, 2020 with WHO- Afro and AFTCOR keen to increase this number to cover all the 55 African countries (Nkengasong & Mankoula, 2020). However, the changing epidemiology of the disease calls for changes in strategies in diagnosis and several countries have tried several strategies. For instance, South Korea and USA are implementing drive-through testing, that allows for in-car oro-pharyngeal sampling and on site RT-PCR (Cohen, 2020). The whole process takes approximately 2 hours from sampling to result. However, this leaves out the vast non-driving population, and adds to queuing time. After the decision is shared with client, clinical follow up may be challenging due to the fact that the client leaves the site and does not return to the site for follow up.

Radiological testing using chest computed tomography (CT)-scans, has been shown to be highly sensitive at 97% but poorly specific at 48% in a Chinese study (Ai *et al.*, 2020). CT-Scans unlike RT-PCR enables shorter result times especially with the possibility of Artificial Intelligence (AI) enabled image analysis and interpretation. But this technology is highly limited to level 5 and 6 hospitals in most African countries, with very low numbers of radiologists and poor adoption of AI. This technology may not be optimal in addressing the covid-19 diagnostics challenges in Africa.

What is the way forward? As the focus is on point of care testing, it will be critical to ensure that the ASSURED characteristics of an ideal diagnostic test, i.e. Affordable, Sensitive, Specific, User-friendly, Rapid, Equipment-free, and Easy Delivery to those in need are met (Mabey *et al.*, 2004; Urdea *et al.*, 2006). These criteria are practical driving forces that are useful in the design, development and utilization of a point of care test for COVID-19. Potential strategies will include serological point of care testing, molecular-isothermal amplification such as RT-LAMP, CRISPR based SHERLOCK (Specific High Sensitivity Enzymatic Reporter UnLOCKing) and Helicase dependent amplification with paper or calorimetric visualization (Zhang *et al.*, 2020). LAMP is already in use with the Genie III device already adapted for POC for TB and several other infectious diseases but has largely been limited to research studies. Indeed, the Xpert® Xpress SARS-CoV-2 test by Cepheid, which uses the GeneXpert platform has received emergency use approval by the FDA (Cepheid®, 2020). Widespread use of this technology in Africa will make testing more accessible in the near future. This is a good time for countries, university research centers, biotechnology companies, and startups to take up the challenge and develop similar technologies in order to bring these devices to the peripheral healthcare system as soon as possible. However, innovative funding mechanisms need to be developed to enable development of point of care diagnostics research, prototyping, and implementation research as associated business and regulatory ecosystems in Africa, to reduce turn-around-time and reliance on solutions from out of Africa in such situations as presented by COVID-19.

While there are efforts towards preparedness in some countries, nothing is known about the readiness of some African countries towards curtailing COVID-19. According to the WHO Regional Director for Africa, there remain critical gaps as countries prepare for the readiness of an outbreak. The WHO Africa head identified it would be very challenging if the virus spread rapidly to African cities with no facilities to contain and treat people (Shaban, 2020a). Since the beginning of the pandemic, the African region is witnessing a rapid rise in the confirmed COVID-19 cases. This begs the question of how prepared are we in dealing with pandemics and epidemics on the African continent?

Considering the dramatic evolution of the COVID-19 pandemic, the WHO in the African Region has called on countries to implement critical actions in the next two weeks while there is still time to prevent the outbreak in the region from overwhelming health services (WHO, 2020f). While there are many interventions currently underway, as indicated in Table 3, there remains many gaps.

Table 3. Examples of national preparedness interventions of countries in each African region on 30 March 2020. (DFID: UK Department of International Development; WHO: World Health Organization; NICD: National Institute For Communicable Diseases).

Country	Region	Total cases	Health surveillence	Sensitization	Coordination platforms	Financing	Health infrastructure and capabilities	Ports of entry	Social protection	Water and hygiene provision	Social distancing	References
South Africa	Southern	1280	National Institute for Communicable Diseases (NICD) supports the core capacity for surveillance in response to outbreaks. 10,000 workers going into informal settlements to test people.	Social distancing, self-isolation, alcohol-based hand sanitizers, wearing face masks, avoidance of crowd gathering, raising awareness, social media awareness and dialogues	Ministry of Health, NICD, WHO Africa, Africa CDC	Solidarity Fund, money received from SA richest families- Ruperts and Opperheimers, and religious organizations such as the Muslim Judicial Council, Awqaf SA, Sanzaf and Islamic Relief South Africa	Netcare, SA's largest hospital group, refocused its communicable diseases hotline. Transport and mobile isolation units expanded into temporary isolation treatment facilities. Doctors and nurses of the Netcare group received training in managing such cases.	Enhanced surveillance at ports of all travellers from Asia- especially China. International. airports remain as the only ports of entry with direct flights from Asia	Gender-Based Violence Command Centre provides support for women and children at risk for abuse during the 21-day national lockdown.	Interventions on water services infrastructure, with an intention of improving water supply, access to sanitation and sanitizing of public spaces (e.g., government provision to 2000 communities of water tanks).	21 day lockdown that started at midnight 26 March 2020	Thebus, 2020; DeKlerk, 2020; NICD, 2020; NDoH, 2020; Thebus, 2020; Business Insider SA; Maphanga, 2020; SA Government, 2020; SocialProtectionOrg, 2020
Cameroon	Central	139	Surveillance system set up by the Ministry of Health, supported by WHO and US CDC. Jack Ma Foundation and Alibab Foundation founder Jack Ma donates 20,000 test kits, 100,000 masks and 1,000 medical-use protective suits	Full closure of educational institutions. Mass gatherings banned. public spaces closed. Measures are being put in place for vulnerable groups- elderly, prisoners. Sensitization and detection campaigns to be held in April 2020	Ministry of Health, WHO Africa	Coronavirus Relief Fund- set up by Social Development International	Hospital isolation and treatment centres have been set up for people who meet the case definition for Covid-19 at Yaoundé Central Hospital, Laquintinie Hospital in Douala, Garoua Regional Hospital, and Kribi District.	Full sea, land and air border closures indefinitely; only cargo planes allowed into country	Measure are being put in place for vulnerable groups-elderly	International Committee of the Red Cross delivering soaps and other household necessities to 650 families. Plans are to also deliver 22 tons of soap and 44 000 jerry cans to communities and prisons.	Schools closed and all prayers to be conducted at home.	ANA Reporter, 2020; Tih, 2020; APO, 2020a; SDI, 2020; Kindzeka, 2020; ICRC, 2020
Nigeria	Western	111	Only suspected cases are tested as there are shortages of testing materials.	Mass media campaign on the need for physical and social distancing, self-isolation, alcohol-based hand sanitizers, wearing face masks, maximum of 50 people in crowd gatherings.	Nigeria Centre for Control of Diseases. Federal Ministry of Health.	The Federal Government released 1.5 billion Naira ($42 Million) to fight the scourge, Private organizations as well as individuals have made generous contributions towards purchase of materials and conversion of some buildings to isolation centres.	100-bed Infectious Disease Hospital in Lagos is fully equipped to handle COVID-19 cases. Training new recruits and existing personnel to handle treatment of cases, contact tracing, etc.	The Federal Government shut all ports of entry to Nigeria effective March 21st	None	The provision of hand sanitizer is only available at some public buildings. The prices of the hygiene materials such as nose masks and sanitizers are now costly	The federal government has introduced a total lockdown for 14 days at the first instance in Lagos and Abuja, where 90% of the cases are. Other states have shut down interstate travel.	Nigeria Centre for Disease Control, 2020; CNBC Africa, 2020.
Kenya	Eastern	70	Conducting random temperature screenings in spaces frequented by the general public. China donates 12,000 testing kits. 1005 people have been tested.	Aga Khan national hospital, University of Nairobi and others have implemented a public awareness campaign. Ministry of Health, County Governments, Kenya Red Cross, and others sensitizing communities on how to maintain basic hand hygiene, and safe food practices, training volunteers to raise awareness in informal settlements.	National emergency response committee; Kenyan Centre for Disease Control.	Reduced Income Tax Rate (Pay-As-You-Earn) from 30% to 25%, Resident Income Tax (Corporation Tax) from 30% to 25%, and turnover tax rate from 3% to 1% for all Micro, Small and Medium Enterprises. Kenya's largest teleco, Safaricom fee-waiver on M-Pesa, to reduce the physical exchange of currency.	Identified available and efficient isolation, referral hospitals and treatment facilities and made ready to receive patients. Transport and mobile isolation units expanded into temporary isolation treatment facilities. Hospitals have set up 120 beds in Mbagathi Hospital preparation for possible cases. Capacity building of health workers and staff.	Banned international flights. Kenya-Uganda land border closed to all pedestrians and vehicles, except cargo trucks. Banning international meetings.	Government appropriated Ksh. 10 Billion to the elderly, orphans and other vulnerable people through cash-transfers by the Ministry of Labour and Social Protection. The Ministry of Agriculture will distribute cereals to the poor. Religious organisations and businesses calling for food donations.	Government set up water washing stations in informal settlements. UK DFID and Unilever donated funds for providing hygiene products and raise awareness.	Nationwide curfew (7pm to 5am). 2000 people in mandatory quarantine.	Government of Kenya, 2020; Bright 2020; Degun, 2020; Ssebwami 2020; Harper, 2020
Egypt	Northern	609	Activation of different acute respiratory infection (ARI) surveillance systems . 17 laboratories across the country and, with an additional four and university laboratories also wanting to engage. With WHO support, Egypt can now conduct 200 000 tests.	Sensitization campaigns responses to the pandemic, quarantine processes, development of risk communication strategy. Orientation workshops for healthcare workers.	Department of Epidemiology and Surveillance (DES) for the Ministry of Health, WHO, Egypt Field Epidemiology Training Program (FETP)	Egyptian government gives the Health Ministry 6.4 billion dollars to fight coronavirus	Egypt has ½ beds for every 1000 individuals., fragile hospitals and public health systems, only 4% of GDP spent on health infrastructure. Training of healthcare workers at the national and peripheral levels on the COVID-19 pandemic	all air traffic at airports suspended from March 19 until March 31; closure of some land borders	The Ministry of Manpower gave one-time $31 each to all registered irregular workers in Egypt to ease the burden of Covid-19	Mass distribution of sanitizers. In Dakahliya governorate, 600 tons of sanitizers were distributed in its cities and neighborhoods	14-day nation curfew from 7pm to 6am (24 March 2020); possible lockdown	APO, 2020b; Rezvani, 2020; Mourad & Lewis, 2020; Mezran *et al.*, 2020; Khalifa, 2020; APO, 2020a; SocialProtectionOrg, 2020; TEPHINET, 2020; EgyptToday, 2020

Future directions for research and practice

As SARS-CoV-2 virus is an efficient contagion, calculated measures are required to control the COVID-19 pandemic. The peculiarities of African populations should be considered as scientists race towards clinical investigation of chloroquine, hydroxychloroquine, remdesivir and other therapeutic options. For instance, following widespread resistance, many African countries halted the use of chloroquine as an antimalarial. It is however not clear if existing chloroquine pressure has any impact on the antiviral benefit of the drug in malaria-endemic regions. In addition, the safety, reactogenicity and immunogenicity of vaccine candidates should be tested within an African context. Comparative analysis of the breadth of immune response in asymptomatic carriers and symptomatic survivors of COVID-19 will provide information on specific anti-disease antibodies and the possibility of a re-infection with the virus after full recovery. As efforts to combat this current wave of COVID-19 begin to yield expected outcomes, health experts should be interested in exploring ways to prevent or minimize the impact of a potential rebound. There is a need to understand the genetic and evolutionary dynamics of the virus, protect vulnerable populations, conduct aggressive contact tracing and physical distancing to salvage Africa's health systems. Rapid, affordable and field-adaptable diagnostics will be required at borders and ports for real-time on-the-spot detection of asymptomatic and symptomatic cases. African governments should prepare a financial warchest and infrastructural capacity to support frontline healthcare workers. Indeed, the partnership of African economists, investors, scientists, tech-experts, health practitioners and political stakeholders will be required to slow down the COVID-19 trajectory on the continent.

Conclusion

Based on our synthesis of the current evidence, while there are plans for preparedness in several African countries, there are limitations. There is a need to address the identified gaps, more specifically the challenges and concerns must be a priority. There have to be multi-sectoral efforts from the science, education, medical, technology, communication, business, and industry sectors, as well as local communities, that can collaboratively work to assist countries as this pandemic continues to challenge the continent and the world further. The actions taken or failed to be taken by African countries in the coming weeks and months will determine how well African countries will fare in containing the spread of COVID-19.

In the concerted effort to develop potential COVID-19 treatment regimens, effective drugs and vaccines, a range of small molecules and biologics targeting the complex molecular interactions involved in the virus infection and replication processes are being considered. Since the development of new drugs/vaccines is a lengthy process, the current strategy being adopted for immediate treatment of COVID-19 infected individuals is drug repurposing whereby previously FDA approved drugs are being used to target COVID-19 receptor proteins, proteases etc (Liu *et al.*, 2020). Policy makers should facilitate the participation of their respective countries in ongoing international COVID-19 clinical trials such as the Solidarity trial so that more participants may be recruited thereby giving a more reliable and representative outcome.

There currently exist PCR platforms that are quick and field amenable such as LAMP and GeneXpert, which have already been approved by WHO for the diagnosis of tuberculosis. Countries can use their molecular biology departments to adapt these tests to test for COVID-19. This will be a sure way to improve accurate diagnosis turnover rate and also bring it to the community level.

As the understanding of the virus of the scientific community grows, along with government interventions of preparedness, we recognize this is a rapidly evolving area of study as new information becomes available on a daily basis, and there are therefore limitations, warranting deeper investigation. Results should be seen as complementary, and informing current and future strategies in the light of new evidence. We hope that actors in various sectors of society will consider these recommendations, among a suite of many, as well as their potential trade-offs, so that Africa is better prepared to combat the COVID-19 pandemic.

Data availability

Underlying data

All data underlying the results are available as part of the article and no additional source data are required.

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