Preparedness and vulnerability of African countries against importations of COVID-19: a modelling study

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Summary

Background The novel coronavirus disease 2019 (COVID-19) epidemic has spread from China to 25 countries. Local cycles of transmission have already occurred in 12 countries after case importation. In Africa, Egypt has so far confirmed one case. The management and control of COVID-19 importations heavily rely on a country's health capacity. Here we evaluate the preparedness and vulnerability of African countries against their risk of importation of COVID-19.

Methods We used data on the volume of air travel departing from airports in the infected provinces in China and directed to Africa to estimate the risk of importation per country. We determined the country's capacity to detect and respond to cases with two indicators: preparedness, using the WHO International Health Regulations Monitoring and Evaluation Framework; and vulnerability, using the Infectious Disease Vulnerability Index. Countries were clustered according to the Chinese regions contributing most to their risk.

Findings Countries with the highest importation risk (ie, Egypt, Algeria, and South Africa) have moderate to high capacity to respond to outbreaks. Countries at moderate risk (ie, Nigeria, Ethiopia, Sudan, Angola, Tanzania, Ghana, and Kenya) have variable capacity and high vulnerability. We identified three clusters of countries that share the same exposure to the risk originating from the provinces of Guangdong, Fujian, and the city of Beijing, respectively.

Interpretation Many countries in Africa are stepping up their preparedness to detect and cope with COVID-19 importations. Resources, intensified surveillance, and capacity building should be urgently prioritised in countries with moderate risk that might be ill-prepared to detect imported cases and to limit onward transmission.

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Introduction

On Jan 30, 2020, WHO declared the current novel coronavirus disease 2019 (COVID-19) epidemic a Public Health Emergency of International Concern.[1] As of Feb 11, 2020, the epidemic registered 42 708 cases in China and spread to 25 countries that reported a total of 395 cases.[2] Limited local transmission outside China was reported in Germany, France, Japan, Malaysia, Singapore, South Korea, Spain, Thailand, Vietnam, the United Arab Emirates, the UK, and the USA.

All continents reported confirmed cases of COVID-19. Africa confirmed its first case in Egypt on Feb 14, 2020. China is Africa's leading commercial partner; thus, there are large travel volumes through which severe acute respiratory syndrome coronavirus 2 could reach the continent. Several measures have already been implemented to prevent and control possible case importations from China;[3,4] however, the ability to limit and control local transmission after importation depends on the application and execution of strict measures of detection, prevention, and control. These measures include heightened surveillance and rapid identification of suspected cases, followed by patient transfer and isolation, rapid diagnosis, tracing, and follow-up of potential contacts.[1] The application of such a vast technical and operational set of interventions depends on each country's public health and laboratory infrastructures and resources.

We assessed the risk of importation of cases of COVID-19 to Africa from affected provinces in China, and contextualised this risk with each country's vulnerability to epidemic emergencies and capacity to respond. Importation risk was determined by the volume of air traffic connections[5–9] from areas where the virus currently circulates in China. Each country's functional capacity to manage health security issues is based on WHO International Health Regulations (IHR) Monitoring and Evaluation Framework (MEF),[10] and on an indicator of vulnerability to emerging epidemics.

Methods

The risk of importation of cases of COVID-19 to Africa from China was estimated based on origin–destination air travel flows from January, 2019;[8,11,12] number of cases in Chinese provinces; and the population in each of the Chinese provinces that reported transmission. Air travel flows counts the number of origin–destination tickets and account for any connection at intermediate airports.[11] Case data included all confirmed cases recorded until Feb 11, 2020.[13] Human population data per province[14]

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Research in context

Evidence before this study

The current outbreak of novel coronavirus disease 2019 (COVID-19) has spread rapidly within China and across many countries. Very few data are available that describe and estimate the risk of international spread beyond Asia and Europe. We searched PubMed for articles in English published on and before Feb 1, 2020, that included "coronavirus", "CoV", "2019-nCoV", and "international spread". Few studies have investigated the risk of spread based on local incidence of COVID-19 in China at the province level, international air travel to countries in Africa, local capacity to detect the outbreak, and capacity to contain the outbreak successfully.

Added value of this study

Given the scarcity of evidence of potential importations of COVID-19 to Africa, we used multiple data streams to assess the risk of spread to countries in Africa. By doing so, we have highlighted the risk of importation based on both local incidence data from provinces in China and air travel from airports most affected by the current outbreak. We further assessed, using multiple indicators, how the capacity to respond varies across the countries identified at risk. To better assess the changing epidemiology of risk, we also predicted how changes in local incidence in China might change the geographical distribution of importation risk in Africa.

Implications of all the available evidence

Based on measures of incidence in China, health capacity in Africa, and air travel volumes, the results presented in this study have implications for the prioritisation of deployment of resources across Africa.

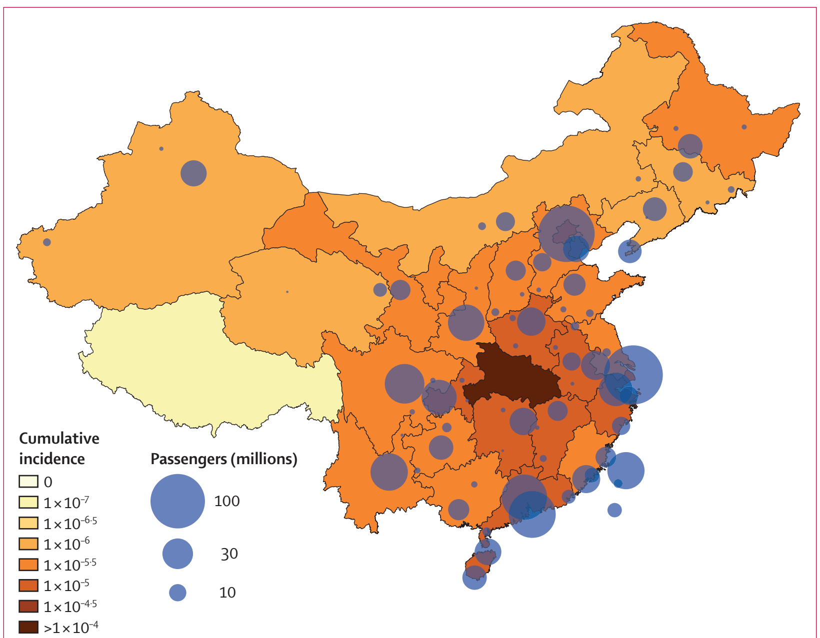

Figure 1: **COVID-19 incidence in China as of Feb 11, 2020,[13] and annual volume of outflow passenger per airport[12]**
Cumulative incidence was calculated as total number of confirmed cases per province divided by population of the province.

were used to estimate incidence in China. Province-level incidence data were linked to the three airports with the largest volumes in each province (figure 1).[12] The province of Hubei was not included among the possible locations able to export the virus, given the travel ban introduced by Chinese authorities on Jan 23 and 24, 2020.[5]

The importation risk per country in Africa was measured as the probability of importing a case from the infected provinces in China, accounting for the origin–destination travel flows originated from such provinces and for their different epidemic levels (appendix p 2).

See Online for appendix

For sensitivity, we considered a larger area as the basin of attraction of the airports of Beijing and Shanghai, which included their neighbouring provinces (appendix p 2).

For each African country, the most likely origins of potential case importation were identified by computing a country's exposure to each Chinese province, measuring the probability of a city in China being the origin of a travelling case to the country. Similarity between exposure profiles of different countries was quantified with entropy-based metrics,[15] and used to group countries with similar importation patterns via agglomerative clustering (appendix p 2).

The WHO IHR MEF is a set of four components developed by WHO to support the evaluation of a country's functional ability to detect and respond to a health emergency. The IHR MEF is composed of a mandatory self-reporting of capacity (the State Party Self-Assessment Annual Reporting [SPAR][10]), and three voluntary components, namely the Joint External Evaluation,[16] the after-action reviews, and simulation exercises, which are all collected and disseminated by WHO. SPAR generates data and has indicators for all African countries for 2018.[17] Joint External Evaluation is consolidated through joint internal and external evaluation processes. In Africa, Joint External Evaluation data were only available for 43 countries from 2016 to 2019.[16]

The 2018 SPAR database[17] contains 24 indicator scores, organised and grouped according to the following capacities (bracketed number shows indicators per capacity[10]): legislation (three), IHR Coordination (two), zoonoses (one), food safety (one), laboratory (three), surveillance (two), human resource (one), national health emergency framework (three), health service provision (three), communication (one), points of entry (two), chemical events (one), and radiation emergency (one). The SPAR index was derived to quantify each country's capacity to deal with the importation and spread of COVID-19 by averaging indicators from all capacities, except those of the capacities zoonoses, food safety, chemical events, and radiation emergency.

Both SPAR and Joint External Evaluation metrics were designed to quantify each country's functional capacity, without accounting for other indirect factors that might compromise the control of emerging epidemics, such as demographic, environmental, socioeconomic, and political conditions. The Infectious Disease Vulnerability Index (IDVI) was introduced as a synthetic metric of vulnerability to account for these factors.[18] Another indicator, the INFORM Epidemic Risk Index, was developed by the EU Joint Research Centre in collaboration with WHO, to account for different combined effects of each country's epidemic transmission risk, infrastructure, vulnerability, and coping capacity.[19]

For African countries where data were available, a multivariate analysis of these indicators showed a high correlation between SPAR and Joint External Evaluation indicators, and between IDVI and INFORM Epidemic Risk Index (appendix p 3). Given their coverage and complementarity, we selected SPAR and IDVI for our analysis. Both SPAR and IDVI indicators range from zero to 100, with increasing levels of capacity and decreasing vulnerability, respectively.

Role of the funding source

The funders had no role in study design, data collection, data analysis, data interpretation, writing of the manuscript, and decision to submit. The first author and the corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Egypt, Algeria, and South Africa were the countries at highest importation risk from China, with moderate to high SPAR capacity scores (87, 76, and 62, respectively) and IDVI (53, 49, and 69, respectively; figures 2, 3). Countries with the second highest importation risk ranking included Nigeria and Ethiopia, with moderate capacity (51 and 67, respectively), but high vulnerability (27 and 38, respectively), and substantially larger populations potentially exposed (figure 1). Morocco, Sudan, Angola, Tanzania, Ghana, and Kenya had similar moderate importation risk and population sizes; however, these countries presented variable levels of capacity (ranging from 34 to 75) and an

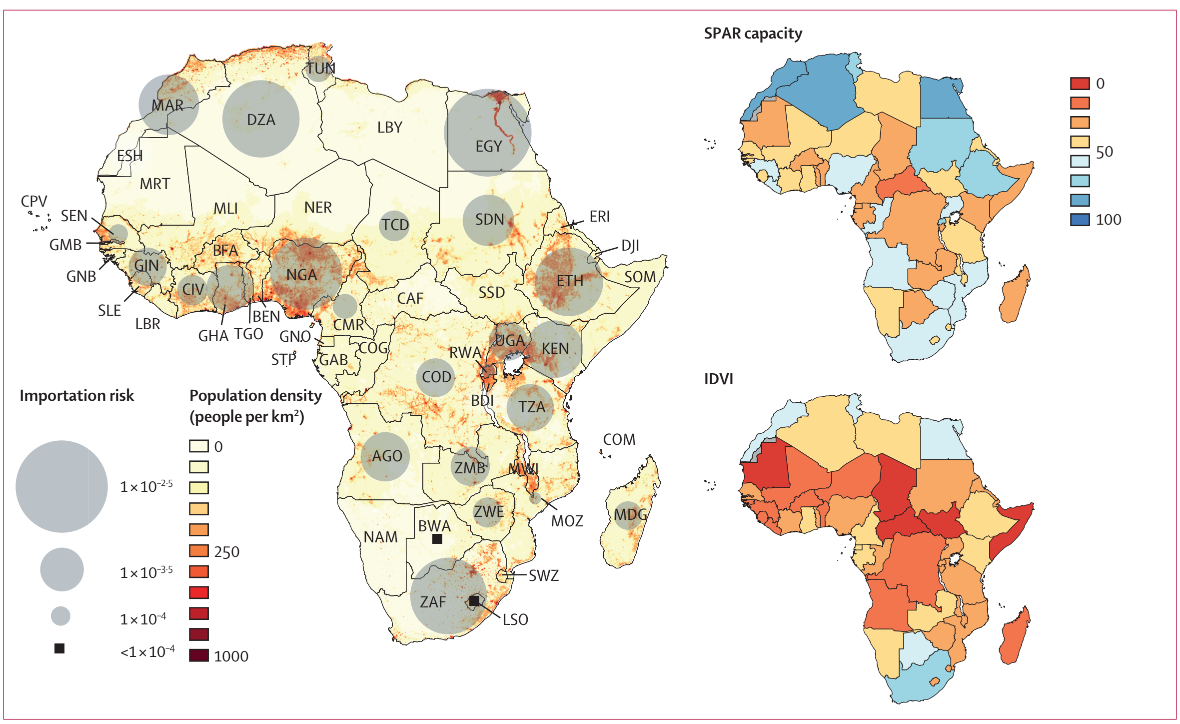

Figure 2: **Global distribution of importation risk over human population density, distribution of the SPAR capacity, and IDVI**
Countries with no estimates of importation risk correspond to situations where the risk of entry was found to be negligible at the time of analysis. The values of MUS (not visible on the maps) are importation risk $4·5 \times 10^{-4}$, SPAR 65, and IDVI 64. AGO=Angola. BDI=Burundi. BEN=Benin. BFA=Burkina Faso. BWA=Botswana. CAF=Central African Republic. CIV=Côte d'Ivoire. CMR=Cameroon. COD=Democratic Republic of the Congo. COG=Republic of the Congo. COM=Comoros. CPV=Cape Verde. DJI=Djibouti. DZA=Algeria. EGY=Egypt. ERI=Eritrea. ESH=Western Sahara. ETH=Ethiopia. GAB=Gabon. GHA=Ghana. GIN=Guinea. GMB=Gambia. GNB=Guinea-Bissau. GNQ=Equatorial Guinea. IDVI=Infectious Disease Vulnerability Index. KEN=Kenya. LBR=Liberia. LBY=Libya. LSO=Lesotho. MAR=Morocco. MDG=Madagascar. MLI=Mali. MOZ=Mozambique. MRT=Mauritania. MUS=Mauritius. MWI=Malawi. NAM=Namibia. NER=Niger. NGA=Nigeria. RWA=Rwanda. SDN=Sudan. SEN=Senegal. SLE=Sierra Leone. SOM=Somalia. SPAR=State Party Self-Assessment Annual Reporting. SSD=South Sudan. STP=São Tomé and Príncipe. SWZ=eSwatini. TCD=Chad. TGO=Togo. TUN=Tunisia. TZA=Tanzania. UGA=Uganda. ZAF=South Africa. ZMB=Zambia. ZWE=Zimbabwe.

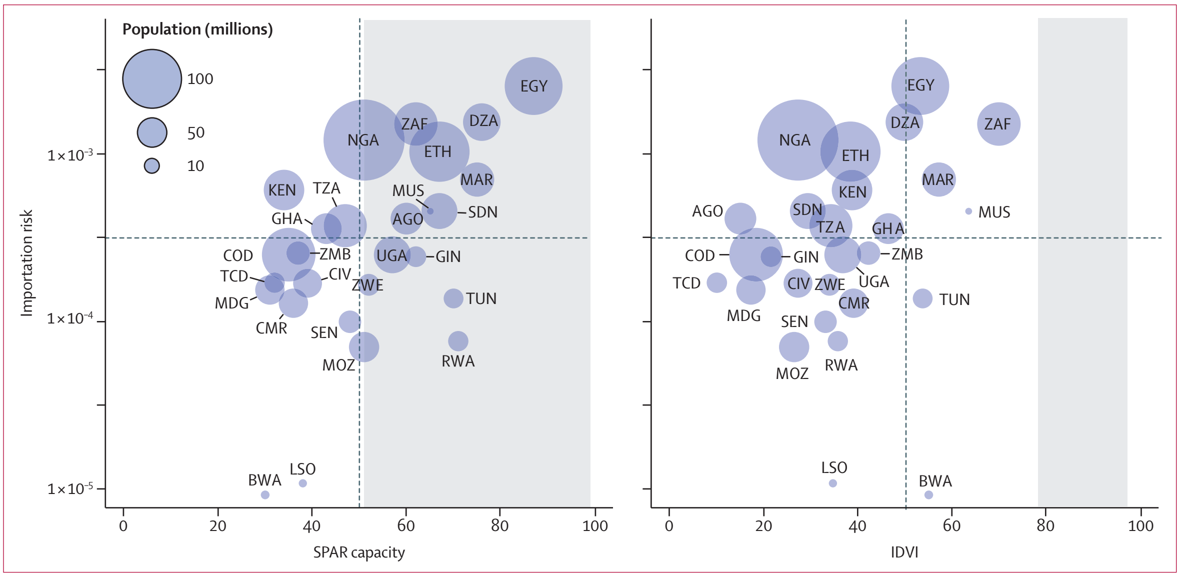

Figure 3: **Importation risk as a function of the SPAR capacity and IDVI in Africa**
Area of circles is proportional to country population. The grey area represents the intervals of SPAR and IDVI values for the Organisation for Economic Co-operation and Development countries. AGO=Angola. BWA=Botswana. CIV=Côte d'Ivoire. CMR=Cameroon. COD=Democratic Republic of the Congo. DZA=Algeria. EGY=Egypt. ETH=Ethiopia. GHA=Ghana. GIN=Guinea. IDVI=Infectious Disease Vulnerability Index. KEN=Kenya. LSO=Lesotho. MAR=Morocco. MDG=Madagascar. MOZ=Mozambique. MUS=Mauritius. NGA=Nigeria. RWA=Rwanda. SDN=Sudan. SEN=Senegal. SPAR=State Party Self-Assessment Annual Reporting. TCD=Chad. TUN=Tunisia. TZA=Tanzania. UGA=Uganda. ZAF=South Africa. ZMB=Zambia. ZWE=Zimbabwe.

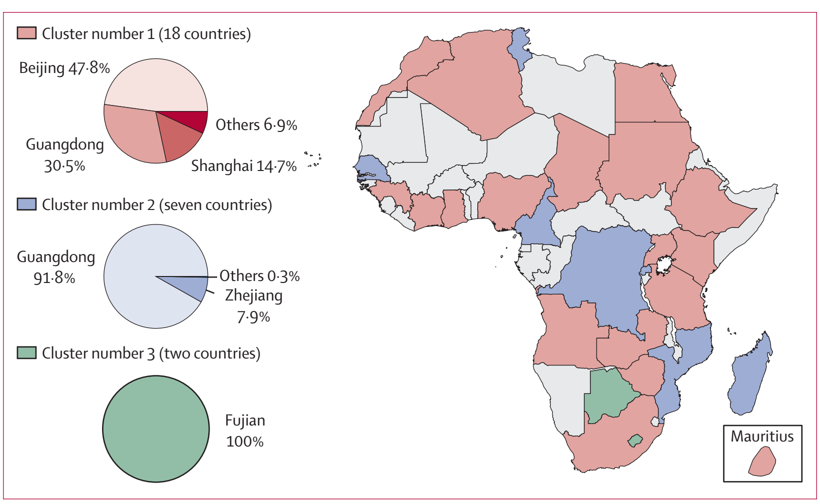

Figure 4: **Cluster of countries sharing similar risk of importation from specific Chinese provinces**
Cluster number 1: Algeria, Angola, Chad, Egypt, Ethiopia, Ghana, Guinea, Côte d'Ivoire, Kenya, Mauritius, Morocco, Nigeria, South Africa, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe. Cluster number 2: Cameroon, Democratic Republic of the Congo, Madagascar, Mozambique, Rwanda, Senegal, and Tunisia. Cluster number 3: Botswana and Lesotho. Countries in grey were estimated to have a negligible risk of entry at the time of analysis.

overall low IDVI (<46), reflecting a high vulnerability (except Morocco, with an IDVI of 56). All other countries had low to moderate importation risk and low to moderate IDVI, with most having a low SPAR capacity score, with the exception of Tunisia and Rwanda. No substantial change was observed when the larger basins of attraction for the airports of Beijing and Shanghai were considered (appendix p 3). For comparison, Organisation for Economic Co-operation and Development countries had a SPAR ranging from 51 to 99, with a mean of 84·2 (SD 12·36), and an IDVI ranging from 78 to 97, with a mean of 88·3 (SD 6·33; figure 3).

Three clusters were identified among the countries with non-negligible risk (figure 4). Each of the clusters corresponded to different Chinese airports as the main source of entry risk. Cluster number 1 was highly exposed to Beijing, and moderately exposed to Guangdong province and Shanghai; cluster number 3 (including Botswana and Lesotho only) was exposed exclusively to the potential risk from airports in the Fujian province; and cluster number 2 was heavily exposed to risk from Guangdong province and weakly to Zhejiang province (figure 4).

Discussion

Early detection of COVID-19 importation and prevention of onward transmission are crucial challenges to all countries at risk of importation from areas with active transmission in China. 12 countries in Asia, Europe, and North America have already reported secondary spread following importation. Onward transmission potentially occurring in countries with weaker health systems is a major public health concern.

We show that the risk of importation to African countries is highly heterogeneous, with Egypt, Algeria, South Africa, Ethiopia, and Nigeria estimated to be at highest risk. We also identified that part of this heterogeneity in Africa depended on the distribution of cases within Chinese provinces. Although certain provinces in China are currently the largest contributors to the risk of specific clusters of countries, enhanced surveillance at airports should consider that importation might still occur from provinces that appear to have a lower probability in our estimations. Moreover, shifts in local and widespread transmission in Beijing, Guangdong, and Fujian could have profound implications for risk in Africa. For example, a significantly higher incidence in Guangdong than in other provinces would have a greater effect on the importation risk of countries in the second cluster than in countries in the other clusters. Flight bans implemented by some African airline companies serving China[20] might alter future risk through a different repartition of the flow of travel; however, these bans are not expected to prevent importations. Not all connections between Africa and China have been cut—the main transporters continue to fly between the two (eg, Ethiopian Airlines, the largest carrier in Africa, operating almost half of the flights from Africa to China,[21] together with all Chinese airline companies, and others). Previous and current evidence indicates that realistic travel restrictions would have a limited effect in containing the epidemic and would delay the risk that the outbreak extends to new countries by only a few weeks.[8,22,23] Travel or trade restrictions are not currently recommended by WHO.[1]

Algeria, Ethiopia, South Africa, and Nigeria were part of the 13 top priority countries identified by WHO on the basis of their direct links and volume of travel to China.[4] Egypt, which we estimated to be at highest risk, was not part of that list, although Cairo was identified as the African airport with the highest passenger volume from the affected areas.[9] Few other discrepancies were observed (Morocco and Angola were estimated to be at moderate risk, but did not appear in WHO's 13 top priority list) that might be explained by different risk estimation approaches. In our assessment, we accounted for the distribution of incidence within China and the volume of travel from China with the passenger network. This assessment strongly affects the spatial pattern in the risk of importation. In addition, we considered full origin–destination itineraries as opposed to direct flights only. Yet our data do not allow us to distinguish between travel for tourism or business, or across nationalities of passengers. Contrary to Europe, where most cases among initial importations were Chinese tourists travelling for holiday, cases in Africa might be more likely to be business than travel related, given the strong commercial links between African countries and China.

An insufficiency of passenger data (eg, reason for travel [tourism *vs* business], nationality, age, sex, and socioeconomic status) also prevent us from accounting for different risk exposure of travellers to China. Travel flow data to estimate risk have already been validated against confirmed imported cases,[8] indicating that homogeneous assumptions on travellers' profiles and risk of exposure in China are enough to explain the exportations reported so far.

Countries at the highest risk of importation, based on the current epidemic situation in China, had moderate to high capacity scores; however, these scores might correspond to different contributions to the mean SPAR indicators, reflecting different aspects of a country's functional capacity. For example, South Africa had the maximum score for laboratory capacity (100), but a low score in risk communication (20). Conversely, Nigeria had a low score in the laboratory capacity (27) and the maximum score in the IHR Coordination capacity (100). Conversely, countries with the lowest SPAR capacity score (ie, Kenya, Tanzania, and Ghana) had moderate to low importation risk. The evaluation of additional factors (ie, demographic, socioeconomic, and political factors) included in the IDVI that might influence the overall potential effect of an unfolding epidemic identified several countries that had a significant importation risk with a low to medium IDVI, such as Nigeria, Ethiopia, Egypt, and Algeria. The risk of importation from other points of entry, such as seaports, was not evaluated.

Our results should be interpreted carefully. The overall risk of importation to Africa is lower than that to Europe (1% *vs* 11%, respectively, according to our estimates on the current situation), but response and reaction capacity are also lower. The overall SPAR score and IDVI of African countries are linked to their overall wealth, and are generally significantly lower than many high-income countries with higher overall resources for detection, prevention, and control. Comparatively, China has a SPAR score of 93 and an IDVI of 63.

African countries have recently strengthened their preparedness against COVID-19 importations.[3,4,24] Many countries have improved airport surveillance and implemented temperature screening at ports of entry,[4] thanks to equipment that was readily available following the 2013–16 Ebola epidemic, including high-risk countries according to our analysis—South Africa, Ethiopia, and Nigeria, with the latter also interviewing passengers arriving from China. Overall recommendations to avoid travel to China have been issued (eg, by the Ministry of Health of Nigeria). Communication campaigns have been intensified after the publication of WHO guidelines encouraging the provision of information to health professionals and the general public, often with 24 h dedicated hotlines, as in the case of Senegal.[3]

Some countries remain ill-equipped. Some are without the diagnostic capacity for rapid testing for the virus; thus, if cases are imported, tests will need to be done abroad, which might critically increase the delay from identification of suspected cases to their confirmation and isolation, affecting possible disease transmission. WHO is currently supporting countries to improve their diagnostic capacity. In the African region, this capacity has now expanded from just two referral laboratories[4] to a larger set of countries, and is expected to continue to increase in the upcoming weeks.[25] The capacity of these laboratories is still limited by the shortage of personnel trained to run the tests, and inadequate stock of materials needed to do these tests. It is essential to train, equip, and strengthen the diagnostic capacities of hospital laboratories close to infectious disease and emergency departments to reduce the time to deliver results, manage confirmed cases and contacts more rapidly, and preserve strict infection control measures.

In the African region, resources to set up quarantine rooms for suspected cases at airports and hospitals, or to trace contacts of confirmed cases, as recommended by WHO, might be scarce. 74% of countries in Africa have an influenza pandemic preparedness plan; however, most are outdated (prior to the 2009 influenza A H1N1 pandemic) and considered inadequate to deal with a global pandemic.[26] Countries might not have the same capacity to manage repatriations of nationals (eg, African students) from the province of Hubei in China, as done by high-income countries, because of a scarcity of resources, including personnel, centres, and equipment for quarantine and isolation. The epidemic in China highlights the rapid saturation of the hospital capacity if the outbreak is not contained. Increasing the number of available beds and supplies in resource-limited countries is crucial in preparation for possible local transmission following importation.

The aftermath of recent epidemics and pandemics (eg, severe acute respiratory syndrome, H1N1 pandemic, Middle East respiratory syndrome, and Ebola) have highlighted the need to reinforce national public health capabilities and infrastructures, including disease-surveillance systems and laboratory networks, as well as human capacity (eg, training in surveillance, epidemic response, and diagnostic testing).[27,28] National public health capabilities and infrastructures remain at the core of global health security, because they are the first line of defence in infectious disease emergencies.[27] Crisis management plans should be ready in each African country; involvement of the international community should catalyse such preparedness. Our findings should help to inform urgent prioritisation for intensified support for preparedness and response in specific African countries found to be at moderate to high risk of importation of COVID-19 and with relatively low capacity to manage the health emergency.

Contributors

MG, MUGK, EV, and VC conceived of and designed the study. MG, GP, MUGK, FP, EV, and BG collected and analysed the data, and did the analysis. MG, CP, P-YB, ED'O, YY, SPE, MA, MUGK, and VC interpreted the results. MG and VC drafted the Article. All authors contributed to the writing of the final version of the Article.

Declaration of interests

We declare no competing interests.

Data sharing

All data used are publicly available, and sources are cited throughout.

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