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COVID-19 and socioeconomic development in Africa: The first 6 months (February 2020-August 2020)

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Abstract: The study covers the first 6 months of the coronavirus disease 2019 (COVID-19) epidemics in 56 African countries (February 2020-August 2020). It links epidemiological parameters (incidence, case fatality) with demographic parameters (population density, urbanization, population concentration, fertility, mortality, and age structure), with economic parameters (gross domestic product [GDP] per capita, air transport), and with public health parameters (medical density). Epidemiological data are cases and deaths reported to the World Health Organization, and other variables come from databases of the United Nations agencies. Results show that COVID-19 spread fairly rapidly in Africa, although slower than in the rest of the world: In 3 months, all countries were affected, and in 6 months, approximately 1.1 million people (0.1% of the population) were diagnosed positive for COVID-19. The dynamics of the epidemic were fairly regular between April and July, with a net reproduction rate $R_0 = 1.35$, but tended to slow down afterward, when R_0 fell below 1.0 at the end of July. Differences in incidence were very large between countries and were correlated primarily with population density and urbanization, and to a lesser extent, with GDP per capita and population age structure. Differences in case fatality were smaller and correlated primarily with mortality level. Overall, Africa appeared very heterogeneous, with some countries severely affected while others very little.

Keywords: COVID-19; Demographic transition; Health transition; Economic development; Africa

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1. Introduction

For most infectious diseases, the relationships between disease prevalence, incidence or mortality, and the level of economic and social development are negative. The more advanced a country is in economic development and in the demographic transition, the more effective it is in controlling infectious diseases, and the less frequent and the less fatal are infectious diseases (Preston, 1976). However, this is not always the case for emerging diseases. The case of HIV/AIDS struck people's minds in the early years of the epidemic: The more advanced countries were often more affected, such as the United States on the American continent or South Africa on the African continent (WHO database, 2020). In addition, at the micro-level (at the individual level), in the first phase of the epidemic, HIV/AIDS was more prevalent among wealthier, more educated, more urban people than among others, whether in Europe, America, or Africa (Fortson, 2008; Mishra, Assche, Greener, *et al*., 2007). The situation changed with the maturation of the epidemic, and in Africa in particular, a reversal of this relationship was often observed, that is to say, that the underprivileged social strata became more affected because the privileged strata became more aware of danger, practiced prevention more effectively, and benefited earlier from medical treatment (Hajizadeh, Sia, Heymann, *et al*., 2014; Wojcicki, 2005).

The relationship between the coronavirus epidemics and socioeconomic development in Africa has not yet been investigated. This virus, officially called severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), emerged in China at the end of 2019, was quickly identified, and notified to the World Health Organization (2020) (WHO) on January 14, 2020. Since then, it spread across the world, affecting virtually every country in a matter of months. The virus belongs to the β-Coronavirus group; it is new to humans and therefore considered as an emerging disease. The virus is very contagious, it is transmitted in several ways: From person to person by aerosol, especially following the cough it causes in the infected person, and it can be maintained for several hours in a confined atmosphere, as well as by direct or indirect contact (hands, hugs, polluted surfaces, etc.). The disease has various clinical manifestations, ranging from asymptomatic infection, to mild illness, to severe illness requiring hospitalization and may cause death, especially in the elderly or in people with peculiar risk factors (diabetes, obesity, hypertension, etc.) (Velavan and Meyer, 2020). The fact that it often causes asymptomatic infections, especially among young people, makes it difficult to detect the virus in the general population. The diagnosis is usually made by detecting the virus by reverse transcriptase-polymerase chain reaction in a nasal sample, taken among subjects with clinical forms, among contacts traced in contagion studies, or among people wishing to know their infectious status. The more serious the clinical form, the greater the chances of detecting the virus, and in fact, many diagnoses, which are the source of statistics on the epidemic, are done in hospitals and other health structures, as well as in special case/contact surveys or in systematic screening (retirement homes, schools, health centers, travelers, etc.). The statistics available in the general population, therefore, depend on medical diagnostic capacities and, in particular, on hospital infrastructures, health personnel, and their training, as well as on the availability of screening kits. Statistical data are usually collected by specialized institutions (ministry of health, health agency, etc.) and must be transmitted to WHO daily as a notifiable disease.

Scientific output on this emerging disease is outstanding, with thousands of articles published in just 6 months, in one form or another, often in electronic pre-publication form. Most of these publications deal with the Far-East, Europe, America, but few with Africa. A search on Medline database on “coronavirus disease 2019 (COVID-19) epidemiology” on November 07, 2020, gave 687 references for Africa out of 20,373 in the world (3.4%) (Medline, 2020). There are several reasons for this difference: Africa was affected somewhat later than other continents, the medical infrastructure and research are less developed there, and it seems that, at least so far, the virus is less prevalent and less lethal than elsewhere (WHO database 2020).

The purpose of this study is to review the COVID-19 epidemics in Africa 6 months after onset (from mid-February to mid-August 2020) by documenting cases and deaths at country level first, and then linking the observed dynamics to economic development, demographic transition, population patterns, and health infrastructure, all important determinants of the dynamics of infectious diseases in the general population, as well as of the quality of statistics. Africa is indeed a particularly heterogeneous continent, with high-income and low-income countries, more densely and less densely populated countries, countries ahead (as South Africa) or backward (as Niger) in the demographic transition, countries with well-developed health infrastructure, and others with weak infrastructure.

Several determinants of COVID-19 epidemiology were analyzed: demographic characteristics (population density, urbanization, geographic distribution, progress in the demographic transition, and age structure of the population); economic characteristics (gross domestic product [GDP] and air traffic intensity) because the more developed is a country, the more frequent exchanges are, and the greater the risk of contamination; and public health characteristics (screening, intervention, prevention capacities for incidence, and health system performance for case fatality). The study does not deal with the important question of the effectiveness of prevention policies because, on the one hand, necessary data are lacking (the population coverage of preventive measures taken in each country is not available); and, on the other hand, because of reverse causality: The more infected is a country, the more it will tend to implement aggressive policies to fight the disease (as case for example in South Africa). A study of the impact of prevention would require a different methodology than the one proposed here, which is based on the empirical correlations between parameters of the epidemic and parameters of economic and social development.

2. Data and Methods

2.1. Country Databases

Data on the epidemics (reported cases and deaths) are those transmitted to WHO, published in the daily reports (WHO, 2020). The cumulative numbers of cases and deaths were used each week from February 16, 2020, to August 15, 2020, thus covering the first 6 months of the outbreak. This database covered the 54 African countries (classified in the AFRO zone or in the EMRO zone), as well as two territories located in the Indian Ocean (Reunion and Mayotte). Only one territory did not declare any case by August 2020: The island of Saint Helena, located in the middle of the Atlantic Ocean, one of the rare territories to have escaped the Spanish flu pandemic of 1918-1919 because of its geographic isolation (McSweeny, Colman, Fancourt, *et al*., 2007).

Demographic data for these countries were taken from the United Nations Population Division database: Population in 2020, age structure, mortality, fertility, and urbanization (United Nations, 2014; United Nations, 2019). The data on country area, allowing the calculation of the population density, came from the FAO database (FAO-Stats, 2019). This was added a database on the geographical distribution of the population, but which does not cover the islands (Linard, Gilbert, Snow, *et al*., 2012). The economic data came from the World Bank database (World Bank, 2019), which were supplemented when necessary by the Index Mundi database (Index Mundi, 2020): GDP per capita in purchasing power parity and in constant dollars; air traffic (in passengers per million populations).

2.2. Methods

This study links epidemiological parameters to demographic, economic, and public health parameters. The following indicators were defined:

- Cumulative incidence = Number of cumulative notified cases by August 15, divided by mid-year population (July 01, 2020), expressed in million inhabitants.
- Weekly incidence = Number of cases occurring during the week, from Sunday to Sunday.
- Case fatality = Number of deaths declared/number of cases declared (per 1000 cases).
- The epidemic's net reproduction rate (R_0), also called the "basic reproductive rate" in epidemiology (Anderson and May, 1991), was calculated in two ways:
- Weekly R_0 = 2 × Number of cases of the week/Number of cases of the two previous weeks. This calculation is justified because the contamination mainly occurs during the 2 weeks following the primary infection.
- R_0 smoothed over the period: It is calculated as the growth rate of the number of weekly cases (r), obtained by logarithmic adjustment, and by the average duration between the index and secondary cases (d) = 9 days, according to the classic formula: $R_0 = \exp(r \times d)$. The average interval between index and secondary cases was chosen so that the two measurements were identical over the same period.

The country characteristics were divided into five groups, corresponding to specific thresholds, and classified from least developed to most advance. The categories of demographic transition were developed in the same way based on the criteria of fertility and mortality. These categories with the selected thresholds are displayed in Table 1. A multivariate analysis is presented at the end of the study, which is a linear regression on country characteristics, with an aim trying to explain differences in incidence and case fatality between countries. Main results are presented in graphic form to better show patterns. Charts showing incidence or case fatality are organized according to increasing economic development or demographic transition. A priori, one could have expected a function parallel to the second bisector (more development corresponding to fewer cases and fewer deaths), but in most cases, the diagram was reversed (more development associated with more cases), with a few exceptions. Univariate relationships were confirmed by multivariate analysis, except those that were canceled out by the correlations between variables and one variable which had an inverted relationship: The population age structure.

3. Results

3.1. Diffusion of the COVID-19

First cases of COVID-19 in Africa were notified to WHO in February 2020, by Egypt (February 15), Algeria (February 26), and Nigeria (February 28), practically at the same time as European countries, which were probably the main sources of infection (Mehtar, Preiser, Lakhe, *et al*., 2020). Within 3 months, COVID-19 affected all African countries, the last affected being Comoros (May 01) and Lesotho (May 13). Of the 56 African countries or territories reporting cases, 45 made their first report in March, and 6 in April. The spread of the virus was therefore very rapid, faster even than that of the Spanish flu of 1918-1919 (Martini, Gazzaniga, Bragazzi, *et al*., 2019), and out of all proportion compared with other emerging diseases such as HIV/AIDS which spread in the continent over several years (Buvé, Bishikwabo-Nsarhaza, and Mutangadura, 2002), or Ebola which remained confined in a few countries (Kramer, Pulliam, Alexander, *et al*., 2016). In fact, infectious diseases transmitted by the respiratory tract spread very quickly, and all the more quickly as the communication routes are dense and travels are fast (planes, automobiles, coaches, public transport, etc.).

Table 1. Correlations of COVID-19 parameters with demographic and economic indicators, 56 African countries and territories.

Variable/Category	Threshold value	Number of countries	Mean incidence	Mean case fatality
Population density	**Inhabitants/km²**			
Very low	<40	18	706	29
Low	40-79	15	1730	24
Medium	80-199	11	1074	20
High	200-399	7	1063	16
Very high	400+	5	2477	13
Urbanization	**Percent urban**			
Very low	<20%	6	142	23
Low	20-35%	13	482	27
Medium	35-49%	19	1213	27
High	50-64%	13	2168	15
Very high	>65%	5	2389	16
Income	**GDP per capita ($)**			
Very low	<2000	20	274	26
Low	2000-3999	15	1080	22
Medium	4000-7999	8	1582	25
High	8000-15999	7	3616	23
Very high	>16000	6	1774	13
Age structure	**Mean age**			
Very young	20-21	11	175	36
Young	22-23	22	735	21
Medium	24-25	10	2370	16
Aged	26-29	6	3807	21
More aged	30-39	7	809	19
Fertility	**Children per woman**			
Very high	>5.0	10	163	38
High	4.5-4.9	12	510	18
Medium	4.0-4.4	13	900	26
Low	3.0-3.9	11	2234	19
Very low	<3.0	10	2627	14
Under-five mortality	**Deaths/1000 births**			
Very high	>90	10	577	30
High	70-89	11	496	28
Medium	50-69	11	532	28
Low	30-49	14	2107	22
Very low	<30	10	2372	30
Medical density	**Inhabitants/physician**			
Very low	>10000	21	460	29
Low	>5000	13	580	18
Medium	>2000	8	1723	25
High	>1000	8	4346	16
Very high	<1000	6	758	19

(*Contd...*)

Table 1. (*Continued*).

Variable/Category	Threshold value	Number of countries	Mean incidence	Mean case fatality
Air traffic	**Passengers/million population**			
Very low	<10	10	179	35
Low	<20	12	504	25
Medium	<100	14	624	21
High	<1000	15	2277	19
Very high	>1000	5	3913	12
Population concentration	**Concentration index**			
Very low	<20	8	1944	29
Low	<40	15	676	29
Medium	<50	10	405	20
High	<60	8	967	21
Very high	60+	8	1095	21
Special	Islands	7	3438	13
Date of first cases	**Date**			
Early	<March 15	21	1304	22
Medium	March 15-31	27	1360	25
Late	>April 1	8	776	19
Total		56	1255	23

NB. Thresholds values were designed by the author for this study

3.2. Dynamics of the Epidemic in Africa

While it was very rapid, the spread of the virus within the continent was slower than in Europe or America. Its speed rather corresponds to the dynamics of COVID-19 in the Indian subcontinent (India, Pakistan, and Bangladesh), as shown in Table 2, summarizing the cumulative incidence by August 15. The incidence in Africa was even significantly lower than the world average (31% of the total) and much lower than that found in Europe or America. Likewise, the case fatality in Africa was close to that of the Indian subcontinent, well below the world average (−38%), and much lower than that of Europe or America (Table 2).

3.3. Estimates of the Epidemic's Net Reproduction Rate (R_0)

Two methods were used to estimate the weekly net reproduction rate: a direct method, by weekly incidence, and an indirect method, by the growth rate of the epidemic (see details of calculations in the methodological section). Both methods gave similar results with an average generation time of 9 days. The net reproduction rate was high at the very beginning of the epidemic, as in all countries of the world, then stabilized from mid-April and remained practically constant at an average level of R_0 = 1.35 until mid-July, which corresponds to a weekly growth rate of cases r = 0.213. After the week ending on July 12, R_0 started to decline steadily, signaling that the first peak of the epidemic was passed, and even crossed the 1.0 bar line, reaching 0.62 in the week of August 15 (Figure 1).

3.4. Regional Differences

The spread of the coronavirus was not homogeneous across the continent. Large differences could be seen already within the six major regions: North Africa, West Africa, Central Africa, East Africa, Southern Africa, and African Islands. The worst affected region was Southern Africa, with an incidence 6.37 times the average, while North Africa and the Islands were close to average, and the other regions much less affected. East Africa was the least affected by August 15, about 3 times less than the average. In contrast, the case fatality was more homogeneous, with relative variations from 0.54 (Africa Islands) to 1.81 (North Africa) compared with the average (Table 3).

The decline in the epidemic's net reproduction rate after July 12 was reflected in the 6 large regions. If the R_0 was high everywhere at the start of the epidemic, as elsewhere in Europe and America, it was quickly restricted to a band between 1

Table 2. Cumulative incidence and case fatality, by major area of the world (as of August 15, 2020).

Continent/World area	Population (millions)	Incidence (cases/million)	Case fatality (deaths/1000 cases)
Americas	1023	11167	36
Europe	561	3672	90
Indian sub-continent	1766	1786	19
Africa	1280	857	22
China	1439	62	52
Other areas	1661	2091	21
World	7731	2755	36

Sources: Population: United Nations Population Division; Cases and deaths: World Health Organization. Americas include both North and South America

Table 3. Incidence and case fatality of COVID-19 in major regions of Africa (as of August 15, 2020).

Region	Absolute value		Relative value	
	Incidence (per million)	Case fatality (per 1000)	Incidence	Case fatality
Northern Africa	803	41	0.97	1.81
Western Africa	362	16	0.44	0.70
Central Africa	289	19	0.35	0.81
Eastern Africa	251	19	0.30	0.83
Southern Africa	5293	20	6.37	0.87
African Islands	708	12	0.85	0.54
Total	830	23	1.00	1.00

Sources: Population: United Nations Population Division; Cases and deaths: World Health Organization. Total is the reference category for relative values

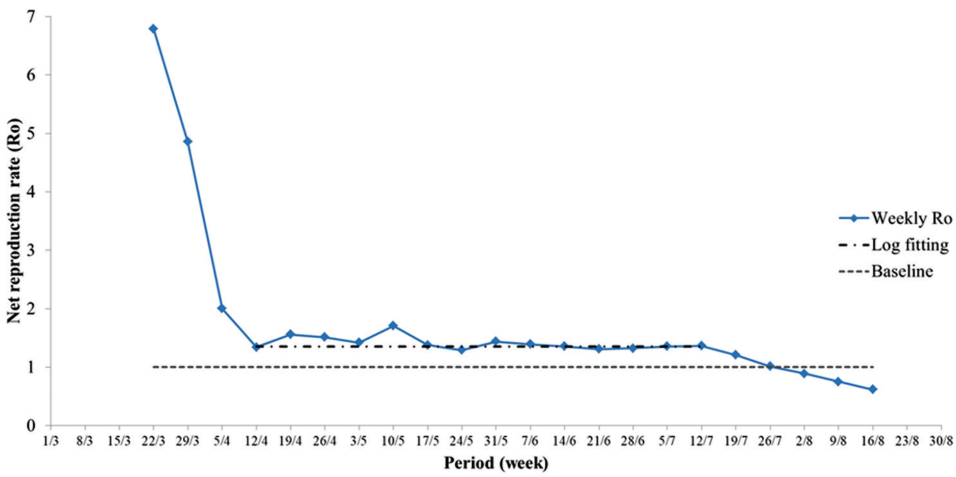

Figure 1. Weekly net reproduction rate (R_0) of COVID-19 in Africa.

and 2, with large local fluctuations. In five of the six large regions, it was decreasing since July and was close to- or <−1.0 by mid-August, with the exception of North Africa, where it seemed to increase again (Figure 2).

3.5. Country Differences

Country differences were considerable, especially with regard to incidence. Incidence expressed in cases per million population ranged from 9 (Tanzania) to 11,433 (Mayotte), which is also the area with the highest population density of all the countries and territories considered (728 inhabitants per km²). The distribution of incidences was fairly uniform, showing a great heterogeneity, without any concentration around the mean.

Countries or territories most affected were certain islands: Mayotte (11,433), Cape Verde (5689), Sao-Tome and Principe (4038), as well as Djibouti (5432) and South Africa (9841), and some oil-exporting countries: Gabon (3695) and Equatorial Guinea (3436). It should be noted that South Africa alone accounted for more than half of all reported cases in Africa (52.4%), while it accounted only for 4.4% of the inhabitants, and that the small islands or small countries that were badly affected accounted for an only small percentage of all cases. The least affected countries were: Some countries in East and Central Africa: Tanzania (9), Uganda (30), Burundi (35), Mozambique (89), Angola (57), and Congo-Kinshasa (108); certain Sahelian countries: Niger (48), Burkina-Faso (59), and Chad (58), as well as a country in the Horn of Africa: Eritrea (80). This list is, therefore, very heterogeneous, in which one could see certain geographical variations, as shown in the map (Figure 3).

Heterogeneity between countries was much less pronounced for case fatality. The case fatality rate varied from <1/1000 (Eritrea, Seychelles) to 80 per 1000 (Chad). The majority of countries and territories (33/56) were at a relatively low level of case fatality (<20/1000) when compared to international data, and the number of countries with higher case-fatality decreased rapidly with the level of case fatality (Figure 4).

Countries with the highest case-fatality rates were Sahelian countries: Chad (80), Sudan (64), Niger (61), Mali (49), Burkina-Faso (46), as well as Egypt (51), and Liberia (64). Countries with the lowest case-fatality rates were countries in East Africa: Eritrea (no deaths reported), Rwanda (2), Burundi (2), Uganda (3), and Mozambique (7); Southern African countries: Botswana (2) and Namibia (5); West African countries: Ghana (5), Guinea (6), and Ivory Coast (6); and Islands: Seychelles (no deaths), Reunion (6), as well as Gabon (7).

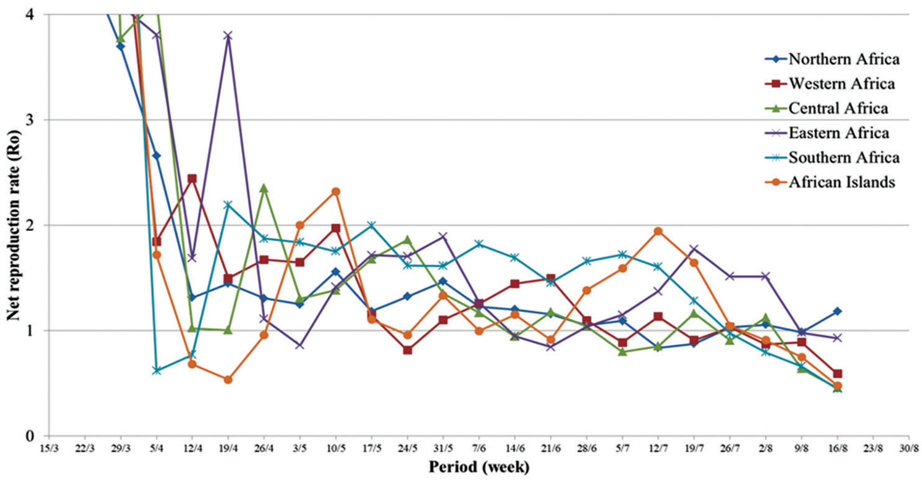

Figure 2. Weekly net reproduction rate (R_0) of COVID-19 in major regions of Africa.

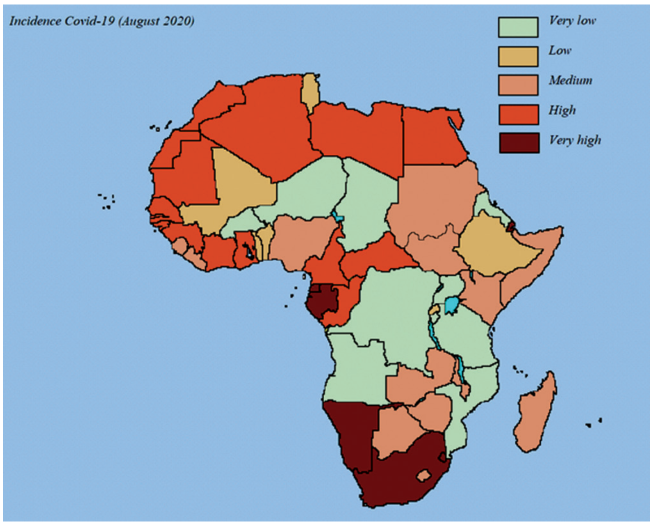

Figure 3. Geographical distribution of cumulative incidence of COVID-19 (as of August 15, 2020).

The geographical distribution of case-fatality levels revealed the particular situation of the Sahelian strip, except Senegal, as well as a strip ranging from Angola to Tanzania, and to a lesser extent, certain countries of North Africa (Algeria, Egypt, Tunisia). Therefore, there was little geographical correspondence between incidence and case fatality, and at the statistical level, the correlation between incidence and case fatality was weakly negative ($P = -0.22$), which implies that countries with high incidence had lower case fatality.

3.6. Correlations with Demographic Factors

This section explores the correlations between demographic parameters and the incidence of COVID-19. In a classic demographic transition framework, one would expect an inverse correlation: The further the country is in the transition, the more developed it is, and therefore the lower the incidence should be. The same goes for economic development. The figure in this section (Figure 5) is presented according to this framework, with the values corresponding to the most advanced situations in terms of development on the right side, that is to say, that one would expect relations parallel to the second bisector, but one finds in fact the opposite relation in most cases.

3.6.1. Population density

The relationship with population density was expected to be complex. On the one hand, economic development implies generally demographic growth, urbanization, densification, and concentration of the population, but a high population

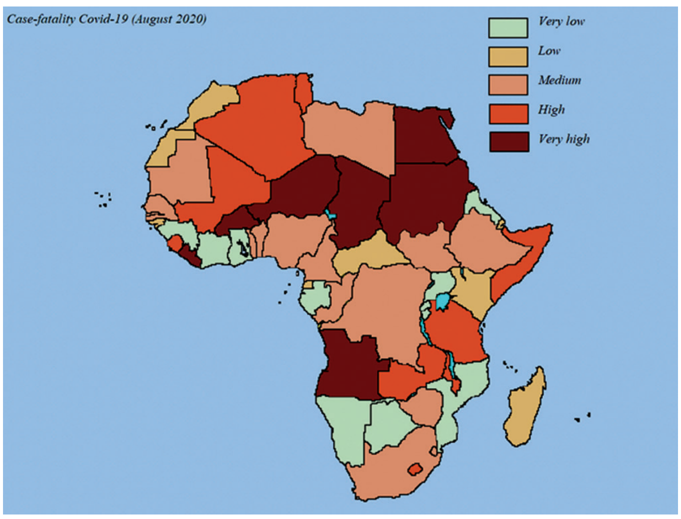

Figure 4. Geographical distribution of case-fatality rate of COVID-19 (as of August 15, 2020).

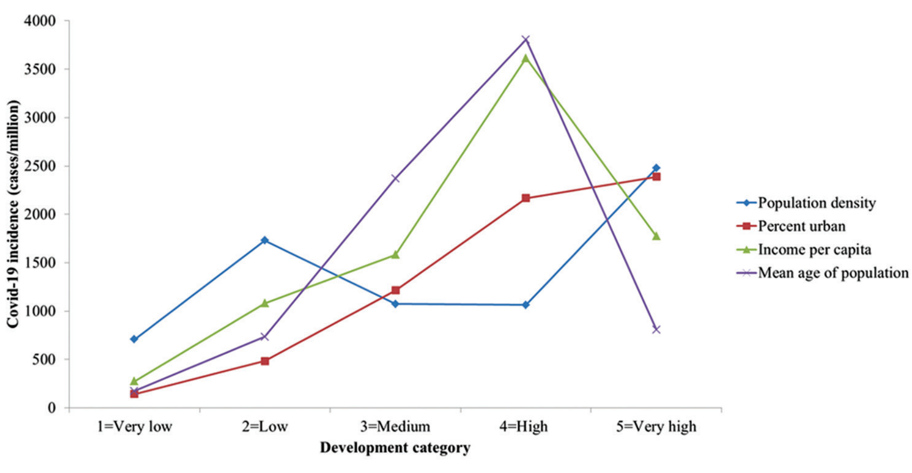

Figure 5. Relationship between COVID-19 incidence and selected demographic and economic development indicators, 56 African countries.

density also favors the spread of infectious diseases transmitted from person to person due to the greater proximity and the greater number of contacts between people. This is indeed what was observed empirically: A positive relationship between incidence and population density, although not totally monotonic. The apparent accident in the second category (density of 40-79 inhabitants per km²) was mainly due to the exceptional case of South Africa; otherwise, the relationship would be monotonously increasing (Table 1 and Figure 5).

3.6.2. Urbanization

The same pattern was found with urbanization, and for the same reasons as for density: The relationship was positive and strong, the most urbanized countries having more viruses, and here the relationship was monotonous with a wide gradient from 1 to 17 (Table 1 and Figure 5).

3.6.3. Population concentration

The relationship with the population concentration index, which measured the geographical distribution of the population in the territory, was U-shaped, which was difficult to explain by purely epidemiological criteria (Table 1).

3.6.4. Fertility level

The relationship between infectious disease and fertility level is often negative, with countries further behind in the fertility transition having more difficulty in controlling infectious diseases. But here the relationship was reversed, with a wide gradient between countries: When the total fertility rate (TFR) was >5 children per woman (10 countries), the incidence was low (108 on average), but much higher (2233) in the opposite case, when TFR was <3 children per woman (10 countries). Hence, the more countries are advanced in the fertility transition, the more COVID-19 they have, and gradients were wide, ranging from 1 to 16 (Table 1).

3.6.5. Mortality level

The same pattern was found for mortality level, here calculated as the under-five death rate per 1000 births. The more advanced in the health transition, the higher COVID-19 incidence. The gradients were weaker and less regular than for fertility, but they remained important, with variations from 577 to 2372 per million, that is, a gradient from 1 to 4 (Table 1).

3.6.6. Age structure of the population

The relationship with the age structure was also complex and not monotonic. The average age of the population and the proportion under age 20 were used, but the second parameter was somewhat less correlated with incidence. Large differences existed between countries, ranging from 175 in very young countries (average mean age 20-21 years, that is, 11 countries) to 3807 in older countries (average mean age 26-29 years, that is, 6 countries), but incidence fell to 809 in the oldest countries (average mean age of 30 years and over, or 7 countries). Here again, the relationship was rather reversed, although not confirmed in the most advanced countries. It should be remembered that the age structure is the result of past fertility and mortality levels, and therefore that one could expect an inverted and strong relationship with the mean age of the population (Table 1 and Figure 5).

3.6.7. Progress of the demographic transition

The five-category demographic transition indicator summarized the relationships with fertility, mortality, and age structure. The incidence gradient, according to this indicator, was close to that noted with the age structure: Monotonic and fairly regular for the first four categories, and different for the highest category (very advanced transition). This category grouped countries with demographic regimes different from others: Islands (Cape Verde, Mauritius, Reunion, and Seychelles) and Maghreb countries (Libya, Morocco, and Tunisia) (Table 1).

3.7. Relationship with Economic Factors

3.7.1. GDP per capita

The relationship with per capita income (GDP in purchasing power parity and in constant dollars) was also inverted and complex: The poorest countries (<$2000, that is, 20 countries) had less COVID-19 (average incidence = 274), middle-income countries ($8000-$15,999, or 7 countries) had more than 10 times as much (average incidence = 3616), but wealthier countries (>$16,000, or 6 countries) had 2 times less than the previous category (1774). This relationship resembles that of the demographic transition, but the countries in the top category were not the same (Table 1 and Figure 5).

3.7.2. Air transport

Air transport played a fundamental role in the rapid spread of the virus around the world: The first cases in Europe were often traced to contact with travelers from China, and the first cases in Africa to travelers returning from Europe, Italy, and France in particular (Mehtar, Preiser, Lakhe, *et al*., 2020). The relationship between incidence and air traffic was indeed strong and in line with what was expected: The greater the air traffic (in passengers per million population), the greater the incidence, with a gradient of incidence ranging from 179 to 3913, that is, a ratio of 1 to 22 (Table 1).

3.8. Relations with Public Health

3.8.1. Medical density

The relationship with medical density was multifaceted because the more developed the country, the larger the medical density, and the higher the capacity to diagnose cases of COVID-19. The relationship with medical density followed approximately that noted with economic development: Fewer cases (460) when medical density was low (more than 10,000 people per doctor, or 21 countries), more cases when it was high (4346 per 1000-1999 people per doctor, or 8 countries), and again fewer cases when the medical density was very high (<1000 people per doctor, or 6 countries, close to European levels). Therefore, it does not seem that the relationship with medical density could be explained by reporting bias; otherwise, one would have more cases in the last category (Table 1).

3.9. Multivariate Analysis of Incidence Factors

These demographic, economic, and health parameters were, of course, inter-correlated. A multivariate analysis at the level of the 56 countries and territories was therefore carried out. Results appear in Table 4. Two factors stood out clearly and were statistically significant: Population density ($P = 0.018$) and urbanization ($P = 0.030$). These are, in fact, direct epidemiological factors: The higher the density and the greater the proportion living in urban areas, the faster the virus is transmitted, and the higher the cumulative incidence. These two factors remained stable in all multivariate analyzes, regardless of the other variables added. To these, one must add two factors that also seem important but remained at the limit of statistical significance: GDP per capita ($P = 0.050$) and mean age of population ($P = 0.093$). Here, it should be noted that the effect of the mean age was reversed in the multivariate analysis: An older population corresponds to less COVID-19, while the relationship was the other way around in the univariate analysis. These four factors explained 28% of the variance between countries ($P = 0.002$).

These four factors appear to have an impact of the same order of magnitude, measured as the effect of one standard deviation of each variable: +700 for population density; +793 for proportion urban; +812 for Log(GDP); −701 for mean age of population, and all for an average incidence value of 1255 per million. Large variations in these variables could therefore account for the large gradients observed between countries. When added in a stepwise procedure, the other variables played a negligible and non-significant role when the first four factors were taken into account: Date of the first case ($P = 0.945$); medical density ($P = 0.959$); air traffic ($P = 0.887$); under-five mortality ($P = 0.296$); and only fertility remained at borderline statistical significance ($P = 0.068$).

Table 4. Results of multivariate analysis of COVID-19 incidence, 56 African countries and territories.

Variable X_i	Coefficient B_i	Standard error	*t*-test	*P*-value	Significance	Net effect
Constant	−3035.5	2244.0	−1.353	0.182		1255
Population density	+4.373	1.797	2.434	0.018	**	+700
Percent urban	+4249.7	1904.9	2.231	0.030	**	+793
Log(GDP/capita)	+763.3	380.4	2.006	0.050	*	+812
Mean age of population	−173.1	101.3	−1.710	0.093	*	−701

"***": $P<0.01$; "**": $P<0.05$; "*": $P<0.10$; "NS": Not significant. Coefficients are raw beta coefficients. The net effect was calculated for one standard deviation of each independent variable, for constant=mean value. Model: Incidence=Constant + $\sum_i B_i \times X_i$

3.10. Analysis of Case Fatality

The gradients in case fatality did not have a common measure with those of incidence: They were much more concentrated. In particular, there were few regular gradients, and few groups were different from the average. However, most of the extreme categories (the most advanced) had a lower than average case fatality, which corresponds to the relationship observed between incidence and development, or between incidence and demographic transition: Very high population density (13); very high urbanization (16); older age structure (19); very low fertility (14); heavy air traffic (12); population concentration in islands (13); and for an average of 23 deaths per 1000 cases. However, this effect was not verified for the two public health parameters: Very low under-five mortality (30) and very high medical density (19).

A multivariate analysis of case fatality was performed in the same way as that for incidence, using a simple linear regression model. Results revealed only one significant factor: Under-five mortality ($P = 0.003$) and a factor at borderline statistical significance: Geographic concentration of the population ($P = 0.084$) (Table 5). These two factors explained only 16% of the variance between countries. For the first factor, the relationship was straightforward: The higher the level of mortality, the higher case fatality could be expected because of failures or defects in the health system. The effect of the second factor indicates that the more concentrated the population, the lower the case fatality. This could be explained by better access to health care or by a correlation with another factor not taken into account. However, it should be noted that the relationship with the geographical concentration of the population was not linear and that the islands were treated separately. No other factor was significant when introducing under-five mortality into the linear regression equation for case fatality.

4. Discussion

For the continent as a whole, the dynamics of the COVID-19 epidemic appeared slower than in Europe or America and they rather resembled those in the Indian subcontinent. This observation can be related to the levels of economic development: The more developed countries have more transport, trade, and travelers, are more urbanized, and more densely populated, all factors contributing to the rapid spread of the virus. For instance, in Europe, Belgium is one of the most urbanized and densely populated countries and also one of the European countries most affected by COVID-19. Africa and South Asia have closer and lower levels of development, so one could expect similar and slower COVID-19 epidemics.

Variations in incidence by country were very large in Africa. The main factors seem to be demographic (density, urbanization) and economic (GDP, air traffic). The fact that these factors point to the transmission of the disease indicates that data are probably reliable, which indirectly validates the statistics, although they may be questioned in some countries. These variations between countries seem to be greater than in Europe. However, in Europe too, there were large variations in incidence, from 11,363 (Luxembourg) to 475 (Slovakia), that is, a ratio of 24 to 1 among the 48 European countries, excluding the former USSR (WHO database 2020). These large variations in Europe remain poorly explained, and the unexplained part could be due, in addition to population density and economic development, to random phenomena, chaotic dynamics, or quality of surveillance systems.

Variations in case fatality were much smaller, and Africa as a whole appeared fairly homogeneous. These results again point to good data quality, even if it seems surprising that some countries report so few deaths given the number of reported cases (Ghana, Guinea, Cote d'Ivoire in West Africa; Burundi, Rwanda, and Uganda in Central Africa; and Botswana and Namibia in Southern Africa). In Europe, there were also large variations in case fatality between countries, ranging from 16.3 (France) to 0.5 (Iceland) per 1000 reported cases, that is, a ratio of 32 to 1, variations which remain largely unexplained (WHO database 2020). Variations in case fatality in Africa could be explained in part by levels of mortality, by the effectiveness of treatments in the case of severe forms of the disease, by better inclusion of mild cases in the denominator, and perhaps by notification bias, or by other unidentified factors.

The question of the effect of the age structure of African populations remains open. In univariate analysis, more COVID-19 was found in countries with an older population, but in multivariate analysis, the reverse was found after

Table 5. Results of multivariate analysis of COVID-19 case fatality, 56 African countries and territories.

Variable X_i	Coefficient B_i	Standard error	*t*-test	*P*-value	Significance	Net effect
Constant	14.868	5.086	2.923	0.005		23.01
Under-five mortality	+0.261	0.084	3.123	0.003	***	+7.86
Population concentration index	−0.199	0.113	-1.764	0.084	*	−4.44

"***"=P<0.01; "**"=P<0.05; "*"=P<0.10; "NS"=Not significant. Coefficients are raw beta coefficients. The net effect was calculated for one standard deviation of each independent variable, for constant=mean value. Model: Case fatality=Constant+$\sum_i B_i \times X_i$

taking into account population density, urbanization, and GDP per capita. One possible explanation is that young people play an important role in transmission, and therefore in the cumulative incidence for all ages, all other things being equal. But since countries that are more developed are also more advanced in the demographic transition, they have both a higher mean age and more reported cases of COVID-19. The strong correlation with fertility levels could be due to a correlation with economic development, but could also be an indicator of relative isolation of the population: The more isolated is a group, the lower will be access to family planning, the higher the fertility, and the lower the incidence of COVID-19.

The negative correlation between incidence and case fatality could be due to the correlation with development: The most advanced countries having more cases and fewer deaths. However, it could also be due to reporting problems: Countries that work better detect and report more cases, and therefore, the case fatality (calculated as the ratio of deaths to cases) appears lower.

This study did not address the issue of climate and its impact on COVID-19 transmission. Other authors found correlations between climate, in particular temperature, and incidence of COVID-19 in Russia and in cities all over the world (Pramanik, Chowdhury, Rana, *et al*., 2020; Pramanik, Udmale, Bisht, *et al*., 2020). The same type of analysis could be repeated in Africa, contrasting arid with forest areas, high altitude versus low lands, cold versus warm weathers, etc. More could be done when the epidemic would have developed for at least 2 years to assess seasonality.

This study has serious limitations, and the main limitation is the quality of data on incidence and mortality. Even in Europe, COVID-19 cases were not fully reported in the 1st months of the epidemic, and the situation is likely to be worse in Africa because of deficient health systems and lack of tracking systems. If deaths are properly recorded in Europe, they are not in Africa because vital registration systems are deficient in many countries, with the exception of Islands such as Mauritius and continental countries such as South Africa (Joubert, Rao, Bradshaw, *et al*., 2012; Garenne, Collinson, Chodziwadziwa, *et al*., 2016).

The future of the epidemic is uncertain. The first few months of the epidemic were worrisome, as the R_0 remained stable above 1 for weeks and strong enough to eventually lead to a huge epidemic. The fact that it has started to decline since mid-July may lead to less pessimism. The momentum over the next 6 months is likely to be decisive, and it is, of course, too early to make any predictions, even at medium terms. Some authors liked to predict that the COVID-19 epidemic in Africa could be stopped by the end of April or the end of May, depending on the scenario considered, but their predictions have proved far from reality (Zhao, Li, Liu, *et al*., 2020). Recent data, updated in mid-October, are again worrisome, as R_0 increased again in September and over-passed the 1.0 threshold by October 12.

5. Conclusion

The preventive measures taken vary greatly from country to country and will need to be adapted to the local context. However, one could hope that the most advanced countries in economic, social, and health development, which are also the most affected, will find effective solutions to eventually control the epidemic.

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Author's Contributions

Sole author completed data analysis and wrote the paper.

Ethics

No human subject involved. Statistical analysis of available data.

Availability of Supporting Data

All data are in open access in United Nations Agencies.

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