CIRES Economic Policy
Analysis Unit

HERD IMMUNITY, VACCINE STRATEGY AND THE PREVENTION OF NEW WAVE : THE CASE OF CÔTE D'IVOIRE

ARE THE NEW WAVES OF COVID PREDICTABLE ?

UNDP Côte d'Ivoire
in collaboration with:
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MARS 2022

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List of Acronyms and Abbreviations

CAPEC	CIRES Economic Policy Analysis Unit *(Cellule d'analyse de politique économique du CIRES)*
CIRES	Ivorian Centre for Economic and Social Research *(Centre Ivoirien de Recherches Economiques et Sociales)*
COVID-19	Coronavirus Disease 2019
WHO	World Health Organization
UNDP	United Nations Development Programme
SIR	Susceptible-Infected-Removed

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Executive Summary

The objective of this study is to analyze **the predictability** of a possible new wave of COVID-19 in Côte d'Ivoire in light of the latest health statistics on the pandemic. These numbers show an increase in the number of positive cases in the last quarter of 2021. The methodology used was based on three main activities: (i) carrying-out a descriptive analysis of health data related to COVID-19 in order to have a clear overview of the health and vaccine situation as it relates to the disease (ii) using time series modelling to forecast health variables, taking into account historical data and (iii) building an SIR-type epidemiological model with calibrated compartments, assuming the exogenous and then endogenous rate of contamination, based on the data from Côte d'Ivoire.

Additionally, a behavior analysis was carried out to identify the underlying factors for vaccine hesitancy among individual persons.

The main findings of these analyses were as follows:

> ***The COVID-19 pandemic in Côte d'Ivoire is relatively under control***. As soon as the first positive case was detected, the Ivorian authorities put in place a series of measures that have proven to be effective in eliminating the effects of the coronavirus. Thus, it has a high average rate of recovery from COVID and a low mortality rate.

Nevertheless, **it should be noted that there has been in increase of active cases**, despite a decrease during the analysis period.

Also, **the vaccination situation is clearly improving**. Vaccination coverage has been increasing since the beginning of the campaign. More and more people are being vaccinated against COVID-19.

The forecast shows that **the variables of interest do not show an upward trend suggesting the imminent occurrence of a new wave of COVID-19**. Indeed, the number of positive COVID-19 cases, cured cases and active cases would show similar evolution patterns with trajectories that are more or less identical to the trajectories of the historical values.

Using the epidemiological model with the exogenous infection rate through three scenarios - *(i) we assume that the population susceptible to contracting the (S) disease is not vaccinated, (ii) we take into account the proportion of the population that is fully vaccinated, and (iii) we incorporate the concept of waning immunity to account for the fact that cured and vaccinated individuals can contract the disease* again - reveals that:

- without the vaccine, we can expect new and larger waves of covid-19

- Vaccination and respecting barrier measures are effective ways to ward off the occurrence of new waves.

By making the contamination rate endogenous in a second analysis using the SIR-type model, the results show that Côte d'Ivoire should expect a possible wave of COVID-19 contaminations around July 2022.

People's behavior towards vaccination has changed since the launch of the mass campaign. The likelihood of being vaccinated has decreased. The likelihood of being vaccinated depends on marital status, household size, compliance with certain barrier measures (wearing a protective mask, hand washing, social distancing).

Household size has a positive influence on the probability of being vaccinated.

Compliance with barrier measures such as wearing face masks and hand washing had a significant positive impact on the decision of individuals to get vaccinate. Individuals who observe these barrier measures have a higher propensity to be vaccinated compared to those who do not observe them.

Individuals with primary, lower secondary and tertiary levels of education in French are more reluctant to be vaccinated compared to individuals with no education in French.

In view of these results, the following recommendations are made:

To the State:

- Strengthen its mechanism put in place to vaccinate the population

- continue awareness-raising and information campaigns on COVID-19 and compliance with barrier measures

To the People

- get vaccinated to reduce the risk of a new wave of COVID-19 in Côte d'Ivoire
- respect barrier actions to reduce the transmission rate of COVID-19

1. Introduction

Since the end of the last quarter of 2019, the world has been facing an unprecedented health crisis. The health, social and economic impacts are affecting every country in the world to varying degrees. The evolution of cases of the disease were noted in countries by successive waves with peaks of contamination and hospitalization cases. In March 2020, Côte d'Ivoire recorded its first confirmed case of COVID-19. Since then, it has gone through several situations with varying levels of infection, death and hospitalization rates. Since the beginning of September 2021, Côte d'Ivoire has recorded an increase in cases of coronavirus contamination despite the deployment of a vaccination strategy and the strengthening of awareness and information campaigns.

This vaccination strategy, which has resulted in the reception of more than 729,000 doses of the AstraZeneca vaccine, 100,000 doses of the Sinopharm vaccine recently, followed by 100,620 doses of Pfizer vaccine, had as its main objective to better contain the disease through a reduction in mortality and severe forms of the disease. Despite the efforts made by the State through the Ministry in charge of public health, the health effects of the pandemic in Côte d'Ivoire have reached alarming proportions. Indeed, on Saturday 25 September 2021, the Ivorian Ministry of Health, Public Hygiene and Universal Health Coverage announced in its daily report, 122 positive cases of

Covid-19 out of 4,311 samples taken, i.e. 2.8% positive cases, 95 cured and 4 deaths. As of 25 September 2021, Côte d'Ivoire had 59,778 confirmed cases, of which 57,282 had been cured, 593 had died and 1,904 were active, noting that the total number of samples was estimated at 998,355.

Vaccination coverage is still relatively low compared to the efforts made by the State. Up to 24 September, 40,172 doses of vaccine had been administered, i.e. a total of 1,943,925 doses from 1 March to 24 September 2021, with more than 273,000 fully vaccinated (*1.1% of the population fully vaccinated*). The priority targets are 5.7 million people (20% of the total population) to be vaccinated through the COVAX mechanism, and eventually the Government hopes to vaccinate 19.6 million people (69% of the total population), enough to achieve herd immunity and thus halt the spread of the epidemic in the country.

From the above, it is easy to deduce that the main challenge for Côte d'Ivoire, like many other countries, is to achieve a collective immunity that will enable it to better control the pandemic. It is in this context that the present study aims to analyse the predictability of a possible new wave of COVID-19 in Côte d'Ivoire and to determine the explanatory factors of vaccine hesitancy among the population. This study will serve the government as an instrument to guide decision-making towards strengthening actions to better control the pandemic. The document also aims to inform of the actions that should be implemented to avoid or deal with a possible new wave of COVID-19 contamination.

The methodology used was based on three main activities: (i) carrying-out a descriptive analysis of health data related to COVID-19 in order to have a clear overview of the health and vaccine situation as it relates to the disease (ii) using time series modelling to forecast health variables, taking into account historical data and (iii) building an SIR-type epidemiological model with calibrated compartments, assuming the exogenous and then endogenous rate of contamination, based on the data from Côte d'Ivoire, and (iv) a behavior analysis was carried out to identify the underlying factors for vaccine hesitancy among individual persons.

The present document is the Final Report of the study. It is organized in four sections, not counting the introduction and conclusion. The first of section reviews the literature on the explanatory factors of the disease and the occurrence of possible new waves. The next section presents an overview of the health and vaccination situation in Côte d'Ivoire in the face of this pandemic. The third section analyses the predictability of a possible new wave of COVID-19 in Côte d'Ivoire. The fourth section analyses the behavior of the population in relation to vaccination. More specifically, this section focuses on determining the factors that explain hesitation of certain persons to be vaccinated, given that this hesitation to be vaccinated could increase the risk of a possible new wave of the disease. Finally, the conclusion summarizes the main results before proposing recommendations for dealing with the occurrence of a new wave of the disease in Côte d'Ivoire.

2. Explanatory factors for the occurrence of a possible new wave

This section provides a brief review of the literature on the factors that explain the occurrence of a new wave of infection in the evolution of a pandemic. Two lines of analysis are considered. The first focuses on individual factors related to each person, while the second looks at non-individual factors that could explain the reluctance to be vaccinated and influence the occurrence of a new wave in the evolution of a pandemic.

2.1. Individual Factors

Individual factors are those perceived exclusively by each individual in the population and which motivate their behavior towards a health crisis situation such as a pandemic. These behaviors guide their decision to adopt curative and/or preventive treatment.

Individuals have health, social and political experiences that influence their views about vaccination. Hesitancy also appears to be related to the use of social media and distrust of traditional and authoritative media sources (Murphy, J., Vallières, F., Bentall, R.P. et al., 2021).

To this end, social media provide opportunities for the spread of misinformation and rumors about the COVID-19 vaccine (Frenkel, S., Decker, B., & Alba, D., 2020). For example, rumors that allude that Africans would be used as guinea pigs in experiments or be poisoned by Western vaccines have fuelled social media exchanges (Africa Check , (2020, April 14).). This is happening in parallel on offline channels as well, particularly in contexts where access to the internet is limited. This is likely to lead to a decrease in the intention to be vaccinated against COVID-19. (Hrynick, T., Ripoll, S., & Schmidt-Sane, M. , 2020).

The attitude of medical personnel towards the vaccine is a key factor in whether or not an individual chooses to be vaccinated. Health care workers remain one of the most reliable sources of information in the eyes of the population. They help shape people's perceptions of vaccines and immunization programmes. The problem is that some health workers have doubts about the safety and efficacy of vaccines, especially in the case of vaccines developed quickly for emergency situations. Two main reasons for vaccine hesitancy among health professionals would be a fear of side effects and a distrust of vaccines and/or pharmaceutical companies and public authorities. (Hrynick, T., Ripoll, S., and Schmidt-Sane, M. , 2020).

Perceptions of the magnitude of the threat posed by COVID-19 and the risk of contracting the virus also influence behaviour. (Finney Rutten L. J., Zhu X., Leppin A. & et al., 2020). In situations of uncertainty, individuals are likely to make choices based on the perceived risk of a disease itself versus the risks associated with vaccination. The dynamics of a disease outbreak (actual and perceived rates of exposure and transmission) will vary from one context to another and will help shape people's risk assessments. (Hrynick, T., Ripoll, S., and Schmidt-Sane, M. , 2020).

2.2. Non-individual factors

Vaccine hesitancy is more likely to develop in contexts in which inequalities are high and citizens are not involved in government decisions and health systems, as populations are likely to perceive the State (and its partners) as having hidden (and harmful) agendas regarding vaccination. (Enria, L., Lees, S., Smout, E., Mooney, T., Tengbeh, A. F., Leigh, B., Greenwood, B., Watson-Jones, D., & Larson, H., 2016). In contexts of extreme poverty, high disease burden, or conversely, low epidemic disease burden, immunization may not be a priority for people. (Dubé, E., Gagnon, D., Nickels, E., Jeram, S., & Schuster, M. , 2014), (SAGE working group on vaccine hesitancy, 2014).

In addition, where political and social divides between populations persist, vaccination may be perceived as instruments to intentionally harm or control specific groups. (Hrynick, T., Ripoll, S., and Schmidt-Sane, M. , 2020).

Criticism of the political and financial issues surrounding vaccination can act as a barrier to vaccine uptake. Indeed, people may be under the perception that collusion exist between pharmaceutical companies and governments in order to maximise the profits generated by vaccination. (Hrynick, T., Ripoll, S., and Schmidt-Sane, M. , 2020).

Work-related constraints, lack of physical access to vaccination sites, inadequate logistics, limited resources, conflict or insecurity may impede the demand for vaccination. (Hrynick, T., Ripoll, S., and Schmidt-Sane, M. , 2020)

Uncertainties regarding COVID-19 and the duration of acquired immunity from the vaccine may be cause for concern. There are still many unknowns about

SARS-CoV-2 and COVID-19. This may undermine people's confidence that safe and effective vaccines can be successfully produced, while at the same time there is a continuing lack of understanding about the virus, its transmission, the disease and especially the occurrence of new variants of the virus. People are likely to

attribute other unrelated diseases or health problems that emerge during the vaccination period to the vaccine.

Uncertainty about the duration of vaccine-acquired immunity may create or exacerbate public distrust. Indeed, the duration of immunity offered by Covid-19 vaccines is still unknown.

Different vaccines show different degrees of efficiency in terms of percentage reduction in disease incidence among the vaccinated group compared to an unvaccinated group under optimal conditions. This may generate confusion as to why some people are infected even when they have been vaccinated. (Heyerdahl, L. W., Ngwira, B., Demolis, R., Nyirenda, G., Mwesawina, M., Rafael, F., Cavailler, P., Bernard Le Gargasson, J., Mengel, M. A., Gessner, B. D., & Guillermet, E., 2018).

Thus, confidence in a vaccine may also decrease if people perceive it to be not very effective. (Forster, P. , 2012).

Incentives to participate can help increase participation, but also have the opposite effect if they are distributed inequitably, feeding into pre-existing perceptions of unfairness. (Masquelier, A., 2012). Vaccination services have been more successful when local gender and cultural sensitivities have been incorporated. (Jalloh, M. F., Bennett, S. D., Alam, D., Kouta, P., Lourenço, D., Alamgir, M., Feldstein, L. R., Ehlman, D. C., Abad, N., Kapil, N., Vandenent, M., Conklin, L., & Wolff, B., 2019).

The coexistence of several vaccines within the same setting can lead to mistrust. Different requirements for vaccine transport and administration, number of doses and eligibility can generate confusion and anxiety. (Bardosh, 2019; Child, D. (2019).

The occurrence of another wave of infection in Côte d'Ivoire depends on several factors. Both individual and non-individual factors influence the behaviour of populations and generate reactions to policies implemented to limit the spread of the disease. The pandemic facing the world in general and Côte d'Ivoire specifically is testing health systems and populations. The following section provides an overview of the pandemic in Côte d'Ivoire.

3. Status of the COVID-19 pandemic and vaccination coverage in Côte d'Ivoire

This section describes the effects of COVID-19 and the vaccination situation in Côte d'Ivoire from the detection of the first positive case on 11 March 2020 to 31 January 2022. It is organized in three parts. The first part deals with the health situation. The second presents the vaccination situation. The third part forecasts the main variables describing the health situation in Côte d'Ivoire due to COVID-19.

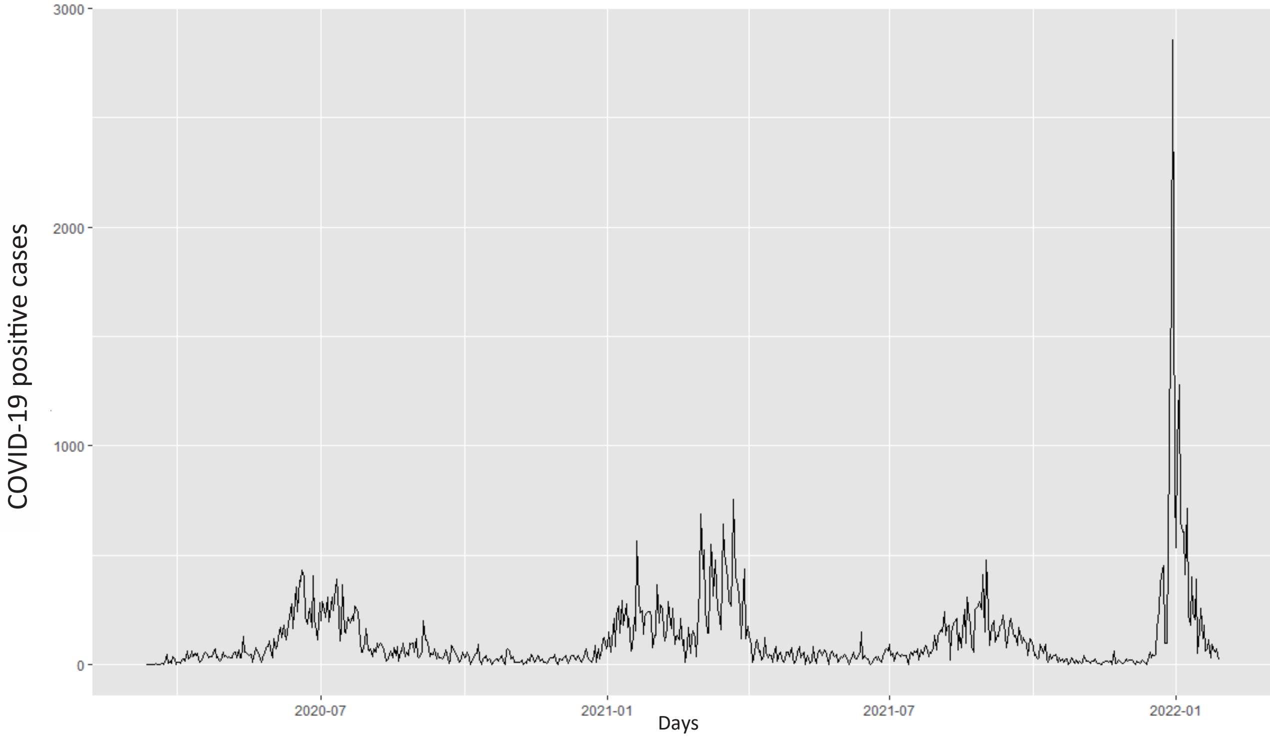
3.1. Recent health situation

This health situation focuses on the evolution of positive cases, the rate of cured persons, the rate of deaths due to COVID-19 and the rate of active cases.

3.1.1. Evolution of the rate of positive cases

The daily evolution of positive cases of COVID-19 in Côte d'Ivoire, over the period running from 11 March 2020 to 31 January 2022, is presented in graph 1 below. It shows trend of positive cases of COVID-19 characterised by an up and down evolution with increases followed by decreases in positive cases of COVID-19. Furthermore, it reveals that since the appearance of the first case of COVID-19, Côte d'Ivoire has experienced four main waves of contamination. It should be noted that the period running from 19 December 2021 to 31 January 2022 is a period during which Côte d'Ivoire experienced a resurgence of the COVID-19 pandemic with an average of 431 new cases of infection per day, with a peak of 2,858 cases observed on 31 December 2021.

Graph 1 Daily evolution of positive cases of COVID-19 in Côte d'Ivoire

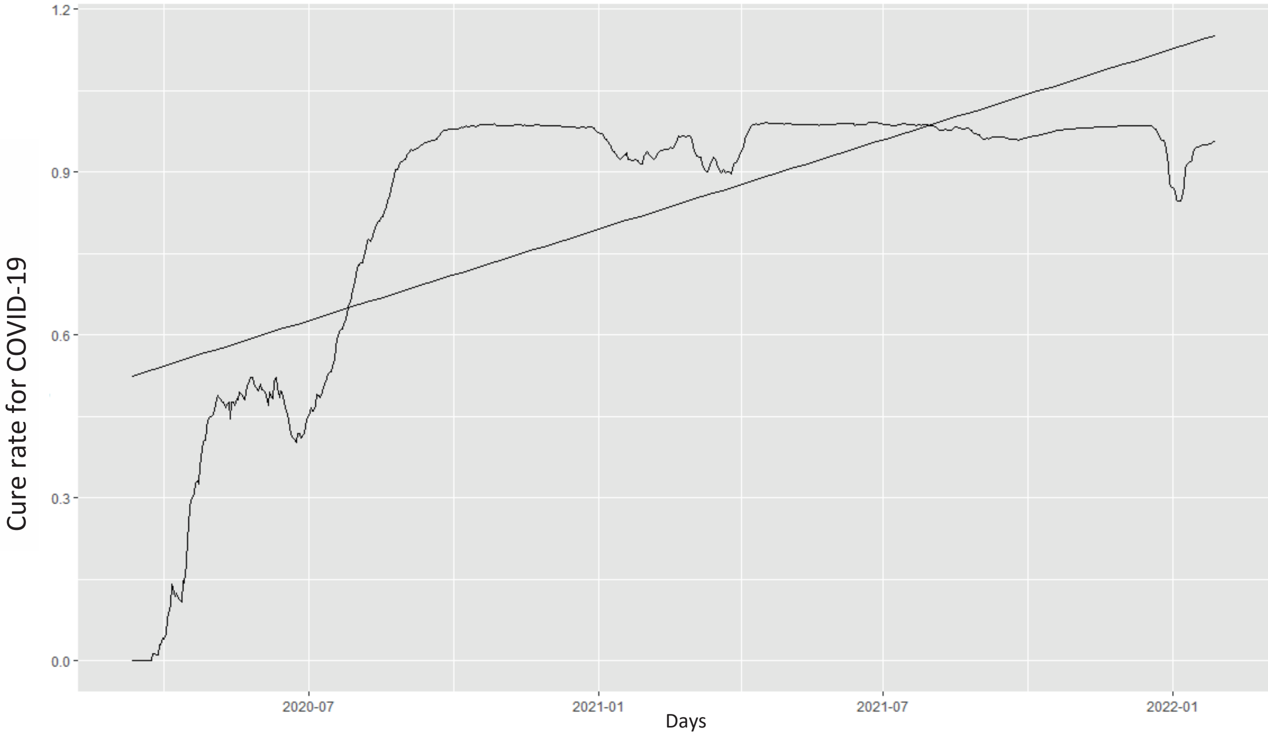


Source: CAPEC based on data from the Ministry of Health and Public Hygiene of Côte d'Ivoire

3.1.2. Evolution of the cure rate

The evolutionary trajectory of the COVID-19 cure rate in Côte d'Ivoire is presented in the below graph. It shows an overall upward trend. This trend indicates that more and more confirmed cases of COVID-19 are being cured.

Graph 2 Evolution of the cure rate of COVID-19



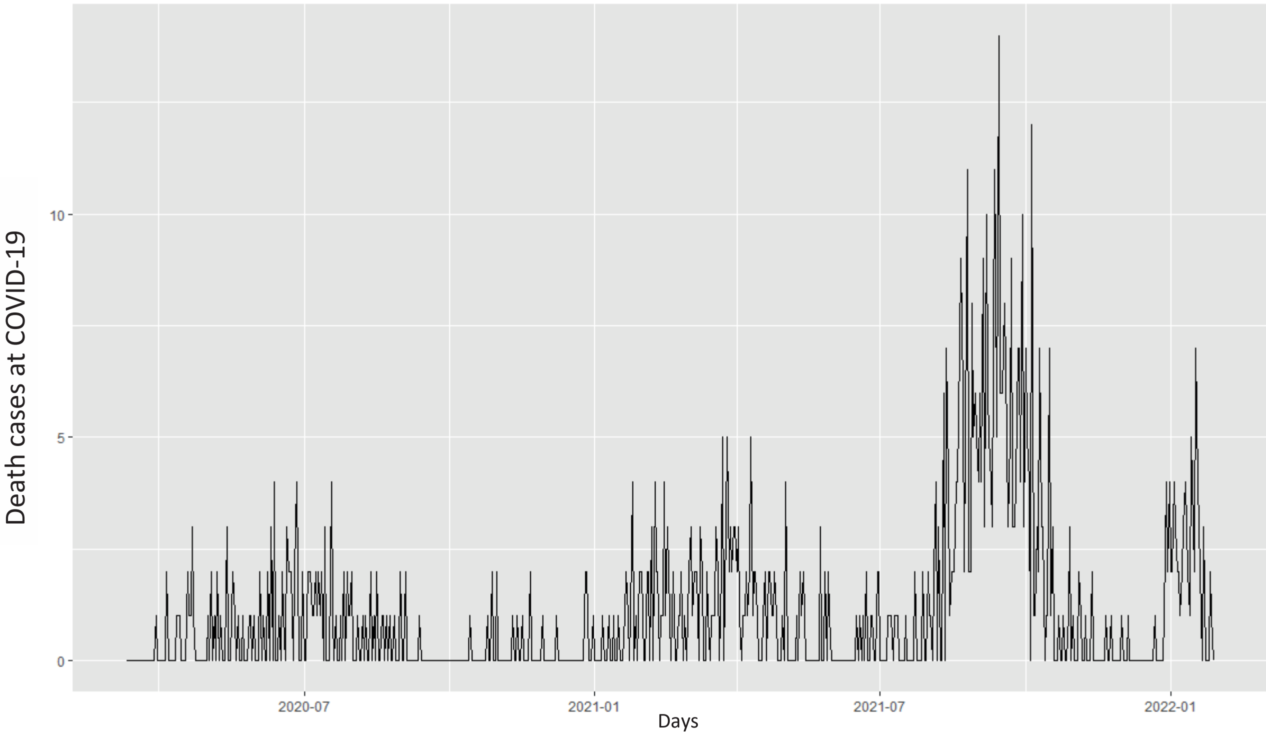
Source: CAPEC based on data from the Ministry of Health and Public Hygiene of Côte d'Ivoire

This situation shows that the Ivorian health system has been able to adapt to the global health situation. Thus, the pandemic response mechanism has certainly contributed to the achievement of this result.

3.1.3. Evolution of new cases of death

The daily evolution of new cases of death due to COVID-19 over the period from 11 March 2020 to 31 January 2022 is described by the graph below. Thus, examination of this graph reveals an overall upward trend in new cases of death due to COVID-19 with a peak of 14 deaths recorded on 14 September 2021.

Graph 3 Daily evolution of new cases of death due to COVID-19



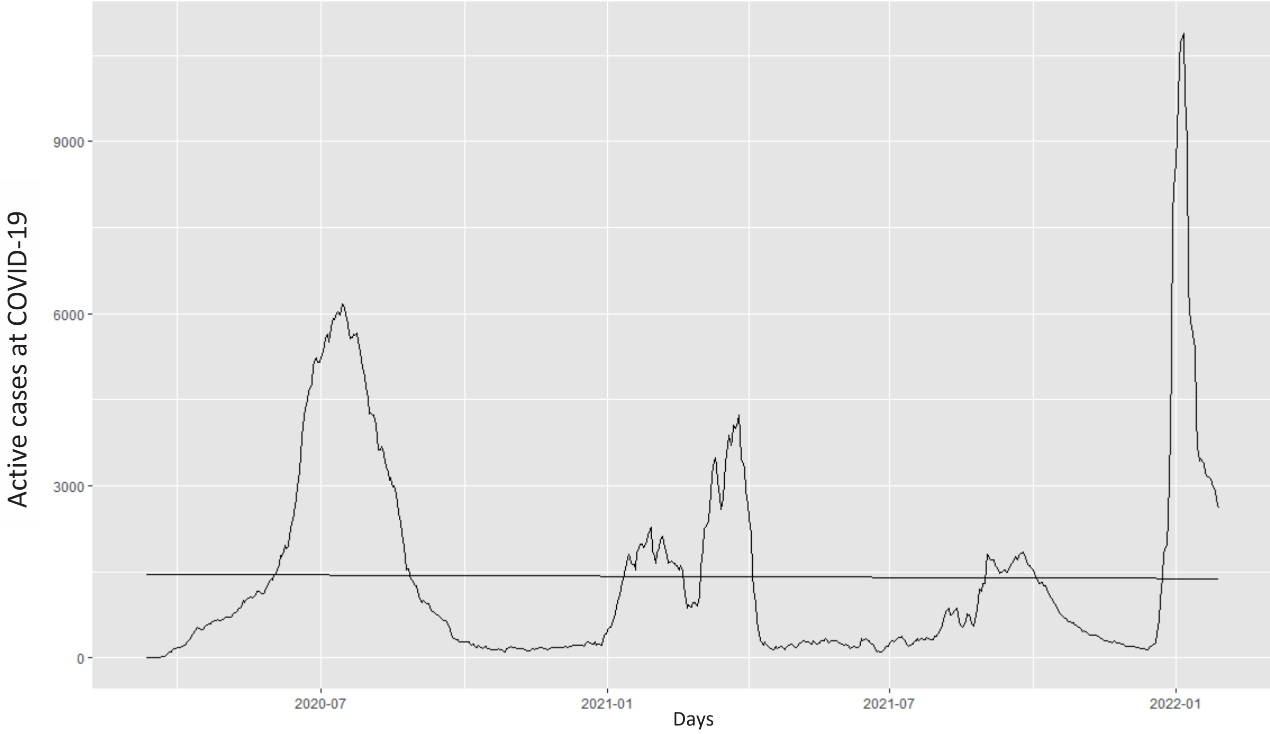
Source: CAPEC based on data from the Ministry of Health and Public Hygiene of Côte d'Ivoire

In addition, it highlights that the period from 22 July 2021 to 30 October 2021 is the period during which Côte d'Ivoire has experienced the most deaths due to the coronavirus, with an average of about 4 deaths per day during this period.

3.1.4. Evolution of active cases

The dynamics of the evolution of active cases of COVID-19 in Côte d'Ivoire over the period from 11 March 2020 to 31 January 2022 show an overall downward trend (see graph below). This downward trend in active coronavirus cases is probably a testimony to the speed and efficiency of the health management of positive COVID-19 cases in Côte d'Ivoire. Nevertheless, it should be noted that the disease persists in view of the number of active cases, albeit on the decline. Consequently, the population should be doubly vigilant in observing the barrier measures recommended by the health authorities.

Graph 4 Evolution of active cases of COVID-19 in Côte d'Ivoire



Source: CAPEC based on data from the Ministry of Health and Public Hygiene of Côte d'Ivoire

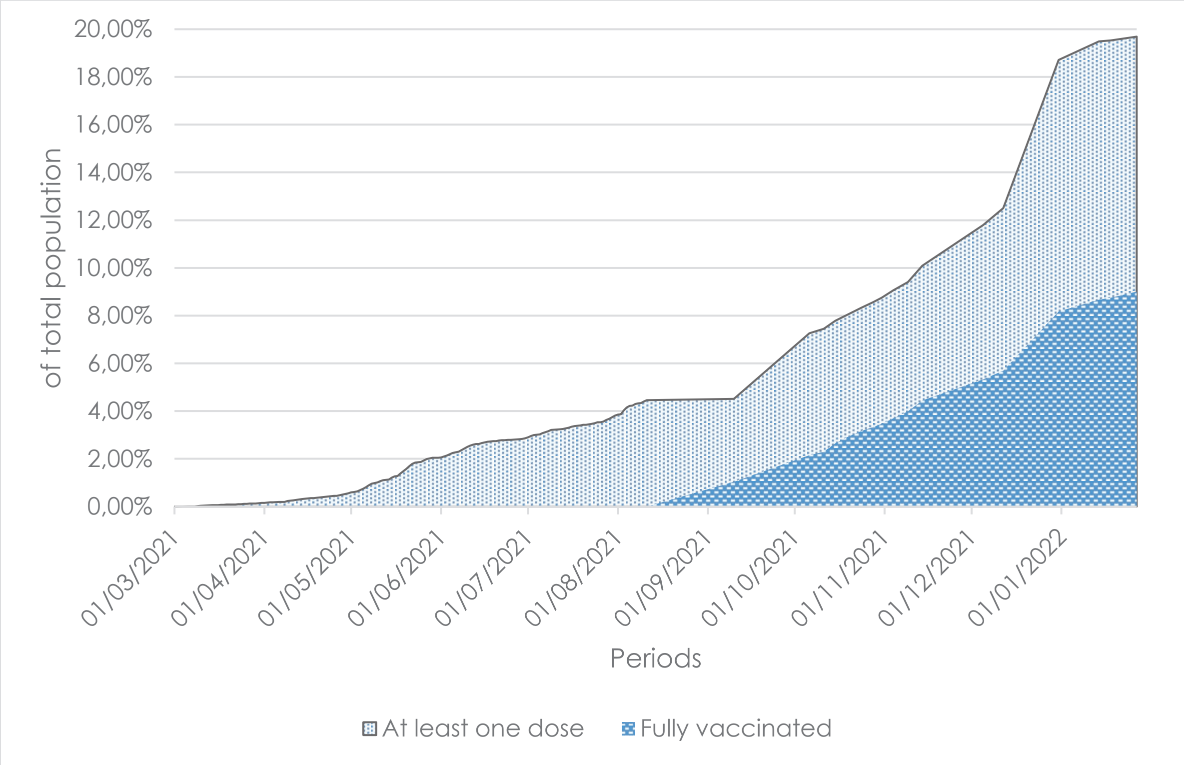
3.2. Recent vaccination status

This section successively presents the evolution of the proportion of the population vaccinated in Côte d'Ivoire and the quantities of vaccine doses according to the vaccine.

3.2.1. Evolution of the proportion of the population vaccinated in Côte d'Ivoire

Côte d'Ivoire began its vaccination campaign thanks to the COVAX mechanism on 01 March 2021. The below graph shows the evolution of the proportion of people vaccinated in Côte d'Ivoire between 01 March 2021 and 27 January 2022.

Graph 5   Evolution of the proportion of the population vaccinated in Côte d'Ivoire



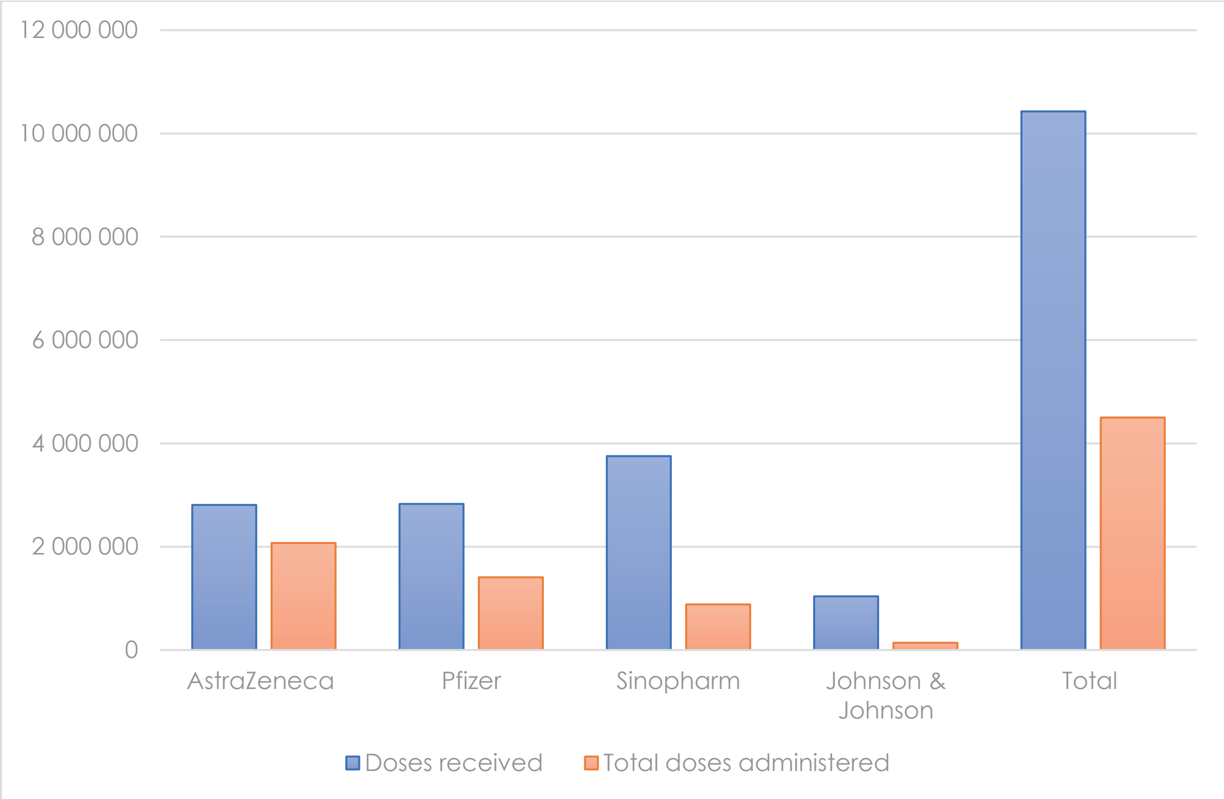
Source: CAPEC from Our World in Data COVID-19 database

The administration of the first doses of vaccine began on 6 March 2021 and the assessment as of 27 January 2022 reveals that 19.69% of the population has received at least one dose of vaccine and 9.01% of the population is fully vaccinated (i.e. 2,382,472). Through the COVAX mechanism, the government's priority targets are 5.7 million people (20% of the total population) to be vaccinated, and then eventually hopes to vaccinate 19.6 million people (69% of the total population), enough to achieve herd immunity and thus limit the progression of the pandemic in the country.

3.2.2. Evolution of the quantities of doses of vaccines according to the type

The graph below shows the quantities of doses received and administered by type of vaccine received by the Ivorian government.

Graph 6   Quantities of doses received and administered



Source: CAPEC from the DC-PEV database

This graph shows that the Ivorian government has received more doses of the Sinopharm vaccine. In addition, the AstraZeneca vaccine is the most administered vaccine by the Ivorian health authorities. In addition, it should be noted that almost half of the vaccine doses received have been administered.

What is the situation in other African countries? The following section provides a comparative analysis of the health situation in Côte d'Ivoire compared to other African countries.

3.3. Comparative analysis of the health situation with other countries in Africa

The new wave of infection caused mainly by the presence of the Omicron variant is causing concern in most countries on the continent. WHO data indicate an increase in the number of Covid-19 cases in Africa. More than 1,095,845 new cases have been reported in Africa, with an average of 35,000 cases recorded per day in early 2022.

Indeed, health systems on the African continent have provided a more effective and rapid response to this new upsurge in COVID-19 cases, thanks in part to lessons learned from previous outbreaks of COVID-19.

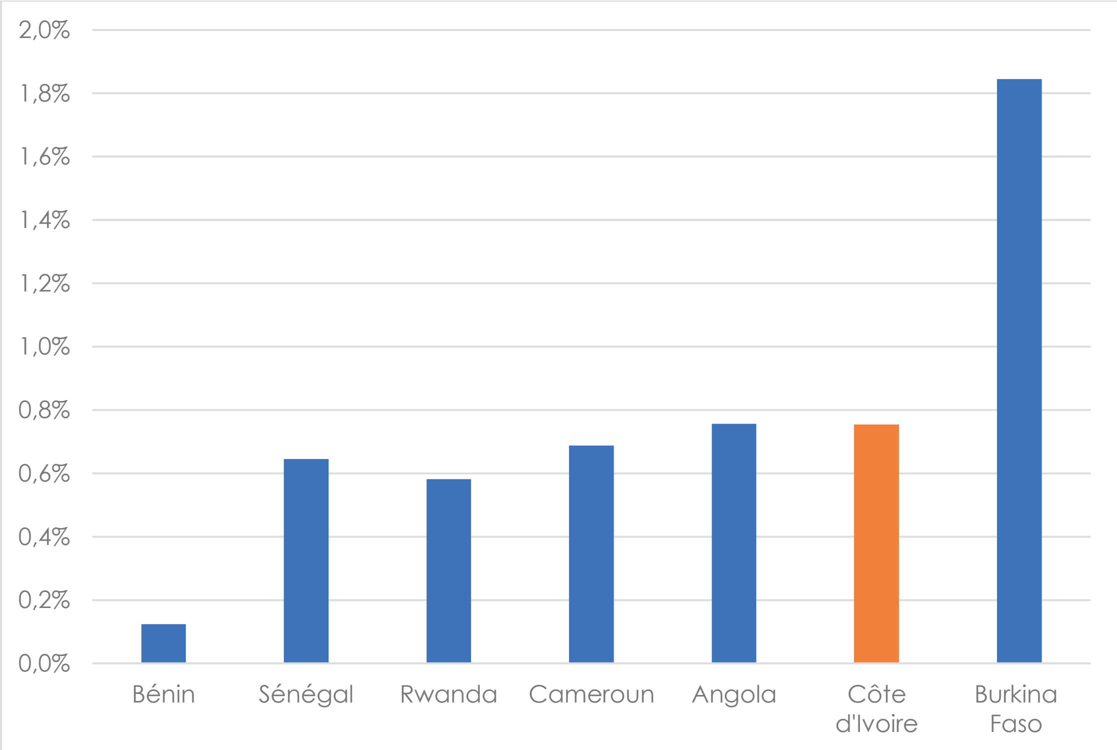
The continent's capacity to manage COVID-19 cases has gradually improved, with increased availability of trained health workers, oxygen and other medical supplies. The number of intensive care unit beds has increased across the continent, from eight beds per million people in 2020 to 20 beds per million people currently.

This section presents a comparative analysis of the health situation and the vaccination rate of Côte d'Ivoire with other African countries. The aim is to provide information on the health situation in Côte d'Ivoire in relation to the selected countries. These countries are: Angola, Benin, Burkina Faso, Cameroon, Senegal and Rwanda.

3.3.1. Evolution of the COVID-19 mortality rate

The below graph shows the average mortality rate due to COVID-19 in the selected countries and in Côte d'Ivoire, over the period from 01 January to 14 February 2022. The average mortality rate is 0.8%, i.e. than 1% on average per day in the comparative sample. Benin has the lowest average daily rate of 0.1% over the period. In contrast, Burkina Faso has the highest average rate among the selected countries.

Graph 7Mortality rate from 01 January to 14 February 2022



Source: CAPEC calculations based on data from [Our World in]Data

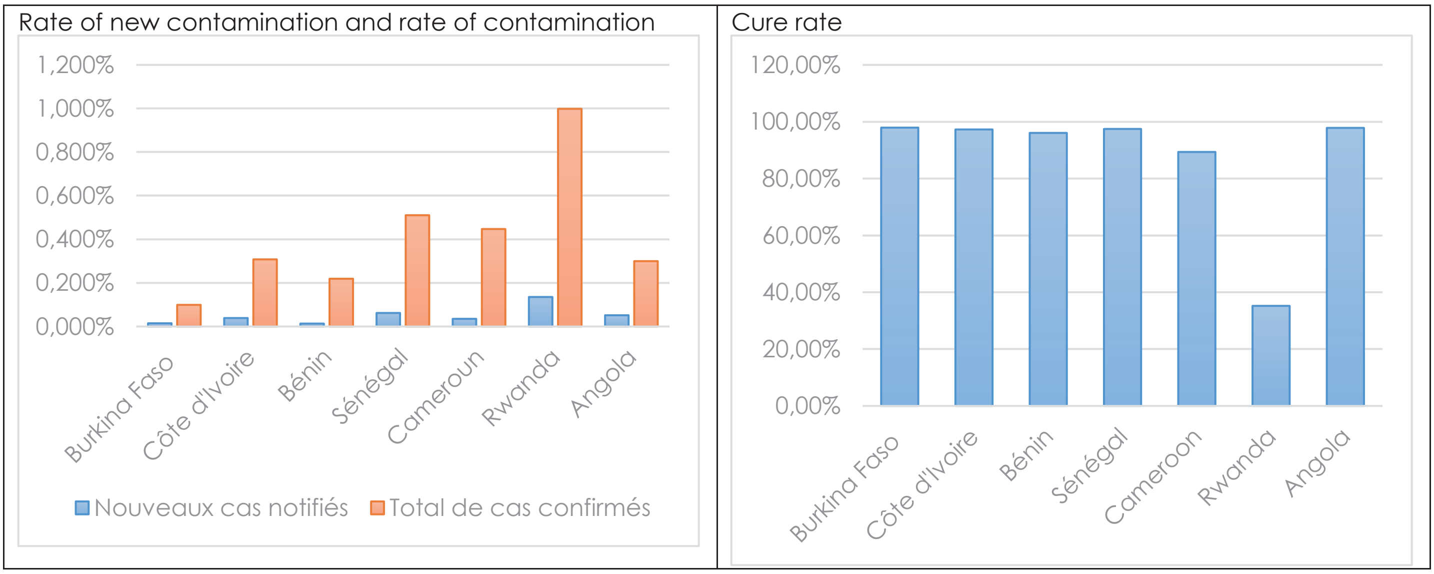
Côte d'Ivoire has a mortality rate of about 0.8%. These results show that although the pandemic has put pressure on the countries' health systems, the average mortality rate caused by the pandemic remains relatively low in these countries.

3.3.2. Number of confirmed cases, cured cases, new infections

Figure 8 below shows the proportions of confirmed cases, cured cases and new cases of COVID-19 infection as a percentage of the total population over the period 01 January to 14 February 2022.

It shows low rates of new infections in all the countries considered, the highest being in Rwanda with a rate of 0.135% of the total population. The low rates of new infections could be explained by the low sample size in the countries considered. Côte d'Ivoire has a lower rate of new infections (0.039%) than Rwanda (0.135%), Senegal (0.062%) and Angola (0.051%). However, it has a higher infection rate than Cameroon (0.035%), Burkina Faso (0.015%) and Benin (0.013%).

Graph 8 New infection rate, infection rate and cure rate



Source: CAPEC calculations based on [Our World in Data/WHO] and World Population Prospect 2019

Like the rate of new infections, the rate of total confirmed cases remains low, with the highest rate observed in Rwanda (less than 1% of the Rwandan population). Figure 8 shows that the infection rate observed in Côte d'Ivoire (0.308%) is one of the lowest in comparison with the rates observed in the comparator countries considered.

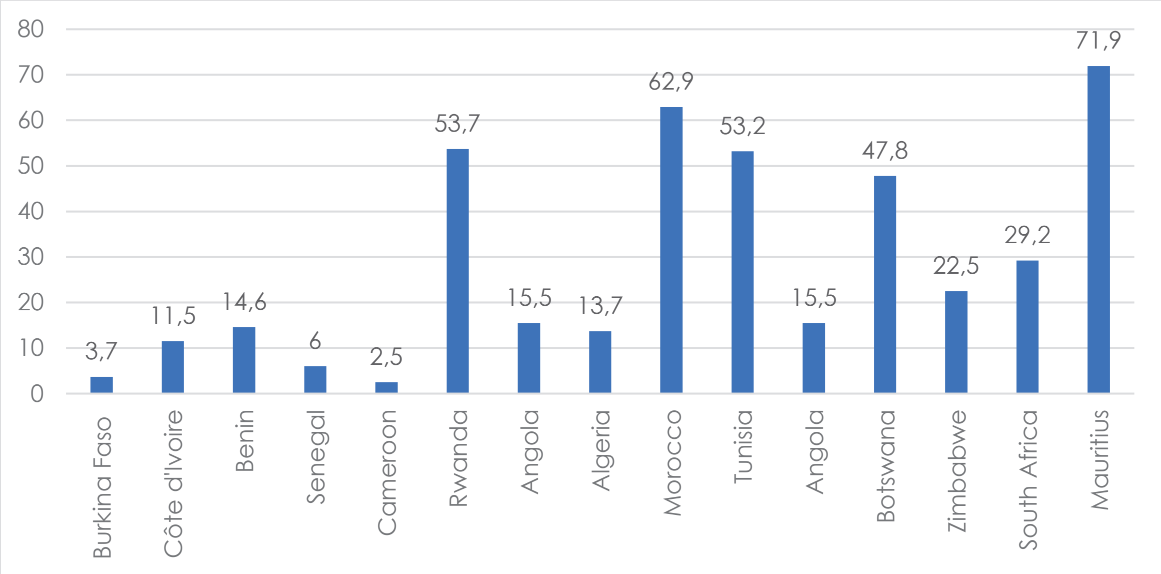
In contrast, the observed COVID-19 cure rates are high, with the highest rate recorded in Burkina Faso (97.92%) and the lowest rate observed in Rwanda (35.20%). The COVID-19 cure rate observed in Côte d'Ivoire (97.28%) is among the highest cure rates in all the countries considered.

3.3.3. Vaccination rate

The graph below shows the vaccination rate in several African countries as of 31 January 2022. The vaccination rate is clearly on the rise[1] at the beginning of 2022 (with an average of 6 million people vaccinated each week). However, it must be acknowledged that this rate is still below the 70% target set by the WHO despite the regular supply of doses of anti-Covid-19 vaccine[2] . Indeed, only 11% of the adult population is fully vaccinated against COVID-19 in Africa.

[2] About 672 million doses of COVID-19 vaccine have been received in Africa, 65% through the COVAX mechanism, 29% through bilateral agreements and 6% through the African Union Vaccine Fund.

Graph 9 Population fully vaccinated (%)



Source: CAPEC calculations based on [Our World in Data/WHO]

According to the data provided by Our World Data, only 5 countries in our panel have exceeded the 40% mark. These include Mauritius (71.9% vaccinated), Morocco (62.9% vaccinated), Rwanda (53.7% vaccinated), Tunisia (53.2% vaccinated) and Botswana (47.8%). In other countries, the vaccination rate remains relatively low. This is the case for countries such as Burkina Faso (3.7%), Senegal (6%) and Cameroon (2.5%), which have a vaccination rate of less than 10%. As for Côte d'Ivoire, it is struggling to succeed in its vaccination campaign. Only 3,028,763 Ivorians are fully vaccinated against COVID-19, i.e. 11.5% of the population.

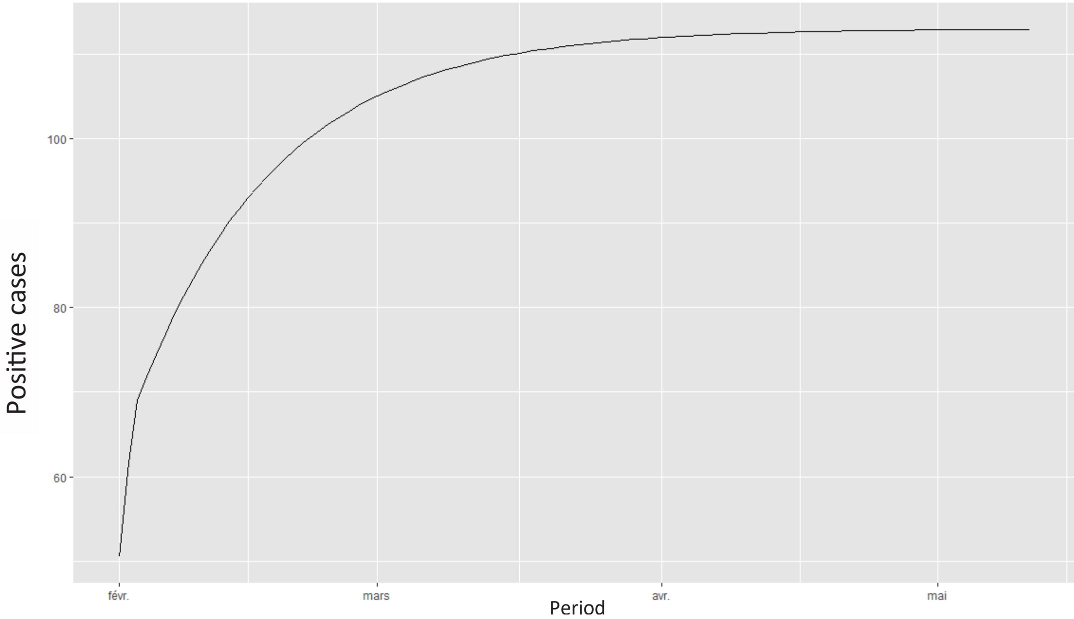
3.4. Forecast of the main indicators of the health situation in Côte d'Ivoire due to COVID-19.

This section forecasts the variables described above using the Box and Jenkins method, over a 100-day upcoming period (horizon) after 31 January 2022. This method makes it possible to forecast the future evolution of a variable from an explanatory model constructed by taking into account only the history of the variable.

3.4.1. Prediction of the number of positive cases

The dynamics of the evolution of the forecast of positive COVID-19 cases in Côte d'Ivoire over a forecast horizon of 100 days is highlighted in Graph 7. The analysis of Graph 7 shows an overall upward trend in positive COVID-19 cases. In addition, a small wave of contagion results. This increase in the number of positive cases is also correlated with the number of samples tested during the period.

Graph 10   Evolution of the forecast of positive COVID-19 cases



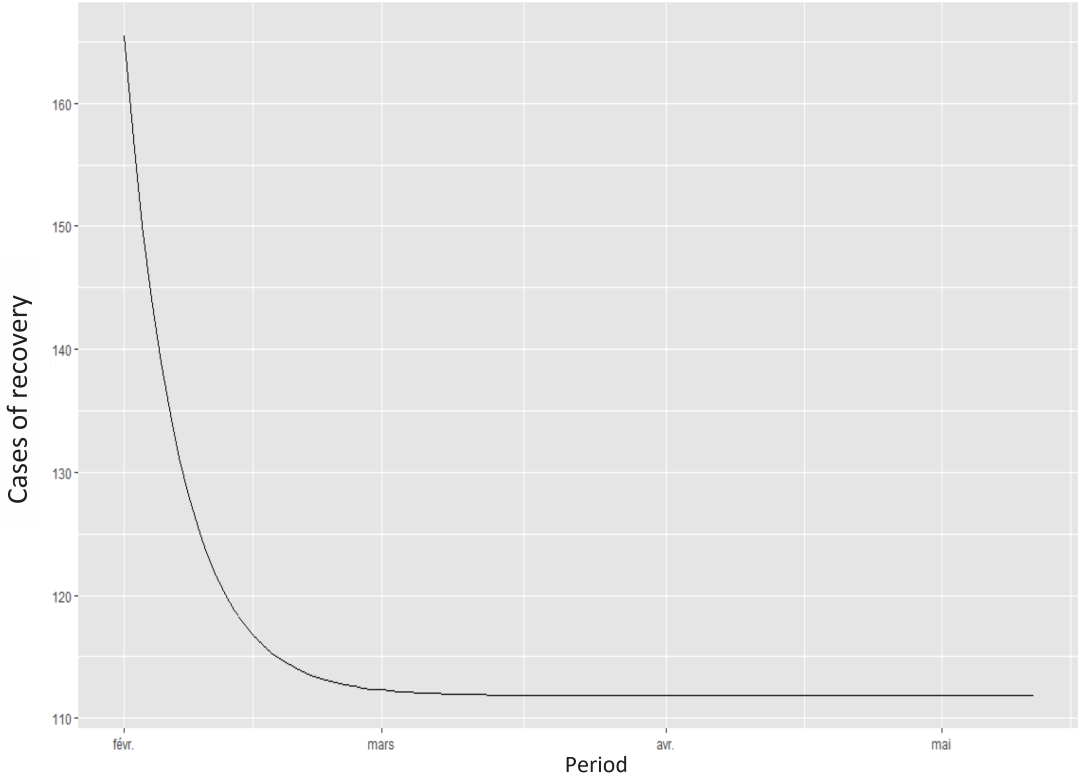
Source: CAPEC calculations based on data from the Ministry of Health and Public Hygiene of Côte d'Ivoire and the forecasting model

This development is also the result of the emergence of a sense of fear among the unvaccinated population, hence the increase in the number of tests carried out.

3.4.2. Prediction of the number of cured cases

The graph below looks at the projected number of cured cases of COVID-19 in Côte d'Ivoire. It shows an overall downward trend in the number of COVID-19 cured cases.

Graph 11 Evolution of the forecast of recovery cases at COVID-19



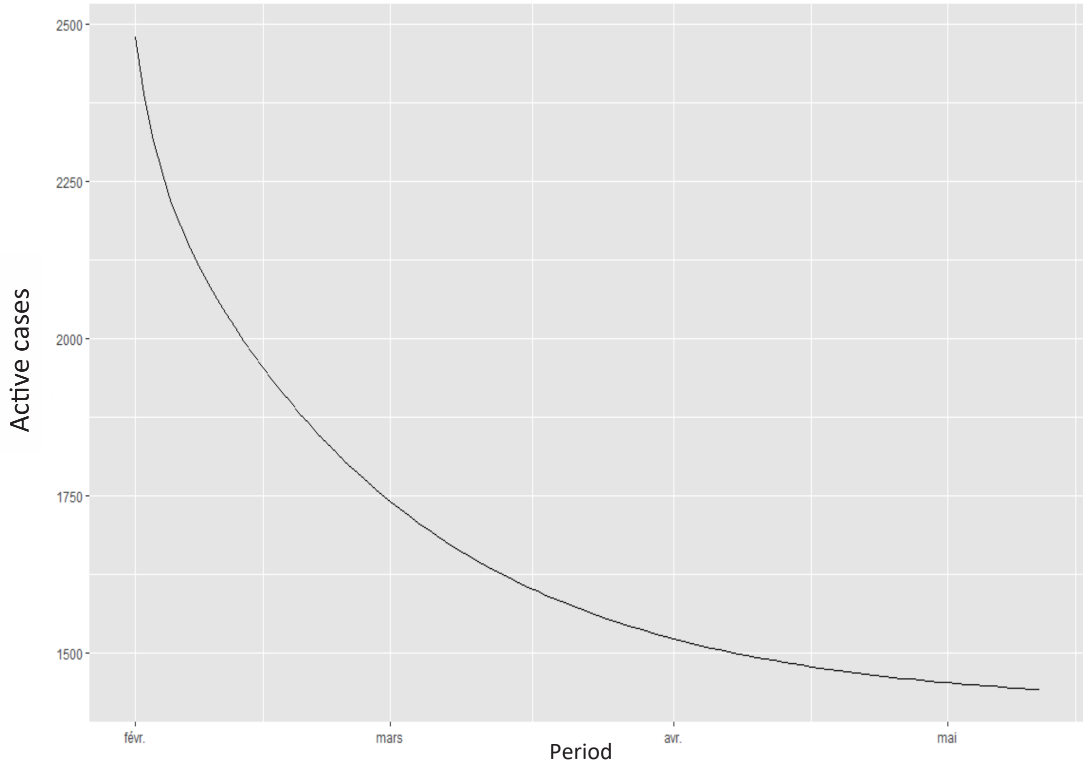
Source: CAPEC calculations based on data from the Ministry of Health and Public Hygiene of Côte d'Ivoire and the forecasting model

The analysis shows that the average daily number of cases of recovery stabilises at around 112 cases.

3.4.3. Forecasted number of active cases

The forecast of the number of active cases is presented in the graph below. It shows an overall downward trend in the number of active cases.

Graph 12 Evolution of the forecast of active cases in COVID-19



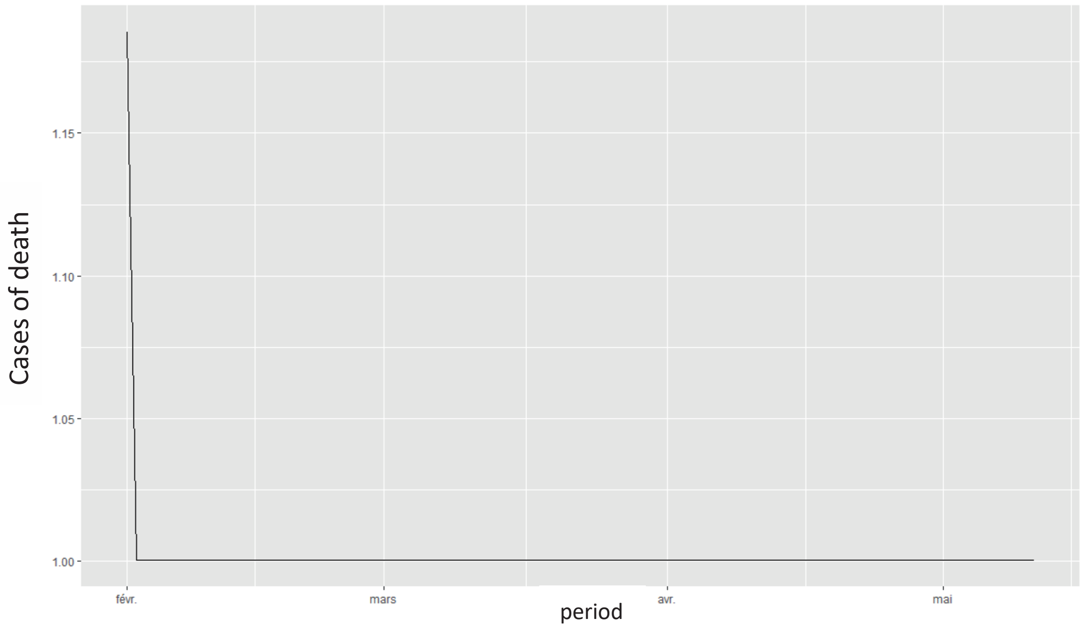
Source: CAPEC calculations based on data from the Ministry of Health and Public Hygiene of Côte d'Ivoire and the forecasting model

This downward trend could be explained by the success of the health authorities and development partners in implementing the health response plan. This mechanism has helped to slow down the progression of the pandemic in Côte d'Ivoire.

3.4.4. Projected number of deaths due to COVID-19

The below graph presents the forecasted number of deaths due to COVID-19 in Côte d'Ivoire. The analysis shows that the average number of deaths per day decreases and then stabilizes at an average of one (1) death per day due to the coronavirus.

Graph 13 Evolution of the forecast of deaths due to COVID-19



Source: CAPEC calculations based on data from the Ministry of Health and Public Hygiene of Côte d'Ivoire and the forecasting model

In short, based on the above analyses, it can be said that COVID-19 in Côte d'Ivoire is relatively well contained. As soon as the first positive case was detected, the Ivorian authorities, with the support of international partners, put in place a health system that made it possible to contain the spread of the disease. As a result, Côte d'Ivoire has a high average cure rate for COVID-19 and a low mortality rate. Nevertheless, it should be noted that the disease persists, given the number of active cases, although decreasing, and the number of positive cases.

In addition, the vaccination situation is clearly improving. More and more people are being vaccinated against COVID-19. Finally, the forecast of the number of positive cases, the number of deaths and the number of cured and active cases shows that the pandemic continues to exist. The number of positive cases could increase and the number of cured cases could decrease over time. It also shows that the number of active cases would decrease while the number of deaths would be reduced to an average of one (1) death per day. Finally, in view of the upward trend in positive cases and the downward trend in cured cases, it could be said that the possibility of another wave of COVID-19 infection in Côte d'Ivoire is not ruled out. This assertion will be discussed in more detail in the next section by estimating an epidemiological model to analyse the predictability of a new wave of COVID-19 in Côte d'Ivoire.

4. Analysis of the predictability of a new wave of COVID-19

In the literature, several approaches are used to model and predict the spread of epidemics or pandemics within a population. These include the Verhulst logistic growth model, the discrete logistic equation model and compartmental models[3] . The implementation of the first two types of models requires data collected on populations before and during the pandemic. Survey data with the detail required for analysis is not available for this assignment. This is why we have chosen the third type of model to analyse the predictability of a new wave of COVID-19 in Côte d'Ivoire.

Compartmental models divide the population into epidemiological classes. They are mathematical models used to analyse infectious diseases. They were originally purely theoretical models that came into practical use with the advent of AIDS in the 1980s. With the COVID-19 pandemic, this type of model is gaining momentum as an aid to public health policy decisions and good

3 Such as SIR, SEIR, SIRS, SAIR epidemiological models

epidemiological surveillance of the disease. Compartmental models are used to facilitate calculations of the probability of contagion. Therefore, in this study, this type of model was used to analyse the predictability of a new wave of COVID-19 in Côte d'Ivoire. Referring to the work of Atkeson, Kopecky, & Zha, (2020), Khan, Dabla-Norris, Lima, & Sollaci, (2021) and Atkeson A. (2021), we built a SIR-type model to forecast a possible new wave of COVID-19 in Côte d'Ivoire. Two approaches have been adopted depending on whether the contamination rate is exogenous or endogenous. Indeed, we assume that the occurrence of a new wave of contamination is closely linked to the evolution of the contamination rate within the population. If the contamination rate increases, then the occurrence of a new wave is inevitable, whereas if the contamination rate decreases, this means that a new wave is unlikely. In the first approach, the contamination rate is a parameter of the model and in the second approach the contamination rate is not a parameter. It is explained in the model by other variables. This section presents the results of each approach after a brief description of the model and how it works.

4.1. Analysis with an exogenous contamination rate

4.1.1. Presentation of the model

The SIR model presented is inspired by the work of d'Atkeson, Kopecky, & Zha (2020). It is a Markov model of the spread of a pandemic in a population (N) subdivided into four categories or states, at each period. The first category concerns the susceptible population (S); the second concerns the infected population (I); the third concerns the resistant population (R); and the fourth concerns all deaths (D) related to COVID-19. We therefore adopt the following total population distribution:

$$N_t \quad S_t \quad I_t \quad R_t \quad D_t \tag{1}$$

The susceptible population is at risk and can contract the disease. The infected population is contagious and can transmit the disease to susceptible people if they are in physical contact. The resistant population is not at risk of contracting the disease, either because they are immune from a vaccine or from previous experience with this or similar diseases. Similarly, people who have died of the disease are no longer at risk of contracting the disease.

In the proposed model, Atkeson, Kopecky, & Zha (2020) make the assumptions that immunity is permanent and the total population is normalized to 1. The initial distribution of the population across states at the time $t \quad 0$ is given by $S\ 0 \quad 0$, $I\ 0 \quad 0$, $R\ 0 \quad 0$, $D\ 0 \quad 0$. For a new disease such as COVID-19, Atkeson, Kopecky, & Zha (2020) assume that the entire population is at risk and can contract the disease, thus $R\ 0 \quad D\ 0 \quad 0$; $S\ 0$ is very close to 1 and $I\ 0$ is a small number corresponding to either the initial cases of the disease transmitted to humans from an animal source (as in Wuhan) or introduced into a country or other geographical location through travel. These fractions of the population formally evolve over time as follows:

$$\frac{dS\ t}{dt} \qquad t\ \frac{S\ t}{1 \quad D\ t} I\ t \tag{2}$$

$$\frac{dI\ t}{dt} \qquad t\ \frac{S\ t}{1 \quad D\ t} I\ t \qquad I\ t \tag{3}$$

$$\frac{dR\ t}{dt} \quad 1 \qquad I\ t \tag{4}$$

$$\frac{dD\ t}{dt} \qquad I\ t \tag{5}$$

All parameters of these equations are positive.

t is the rate at which infected populations transmit the virus to others they encounter at time t

y is the rate at which infected agents cease to be contagious and therefore cease to transmit the disease.

is the mortality rate due to the disease

The flow of populations follows a single direction, from susceptible to infected and then to resistant or dead.

4.1.2. Analysis of the results

Projections were made from 19 December 2021 to cover a horizon period of 600 days, following different scenarios. In the first scenario, we assume that the population likely to contract the (S) disease is not vaccinated, considering two distinct rates of disease transmission. In the second scenario we consider the number of fully vaccinated individuals (having received two doses of vaccine), keeping the transmission rates identical to the first scenario. The first two scenarios assume that individuals acquire immunity after recovery. However, evidence shows that recovered and vaccinated individuals can reacquire the virus. In the third scenario, we take into account the decreasing immunity of recovered and vaccinated individuals, considering the same transmission rates of the virus as in the previous scenarios.

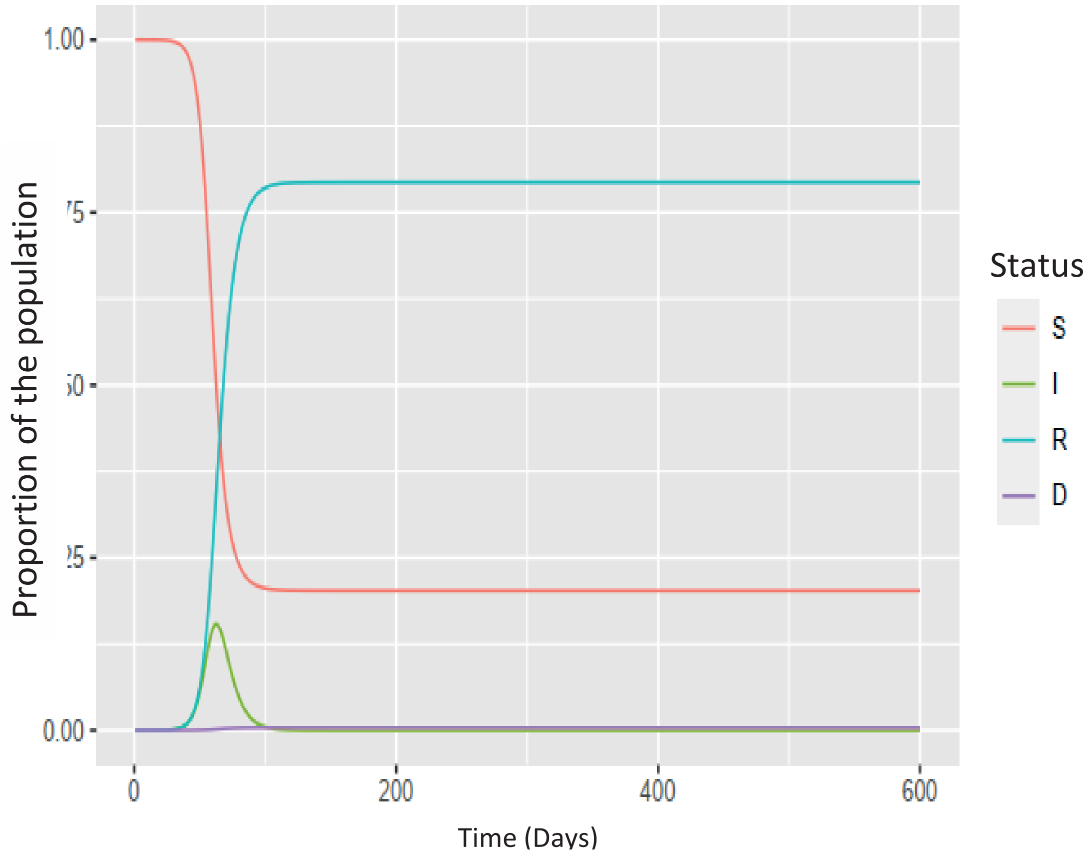
4.1.2.1. Scenario 1: Number of vaccinate = 0

In this scenario we assume that the population likely to contract the disease is not vaccinated, considering two transmission rates of the virus. The transmission rate is reduced from 2 to 1.3. It is assumed that the rate decreases as a result of the government's awareness campaigns on the respect of barrier measures.

Transmission rate: $\boldsymbol{\beta = 2}$

Figure 10 shows the evolution of those susceptible to the (S) disease, those infected (I), those recovered (R) and those who died (D). The results show that a potential wave of COVID-19 cases would occur within the first 100 days after the projection period. At the peak of this wave, the infection could infect approximately 15.35% of the susceptible population or 1,640,313 individuals.

Graph 14 Forecast of the COVID-19 epidemic

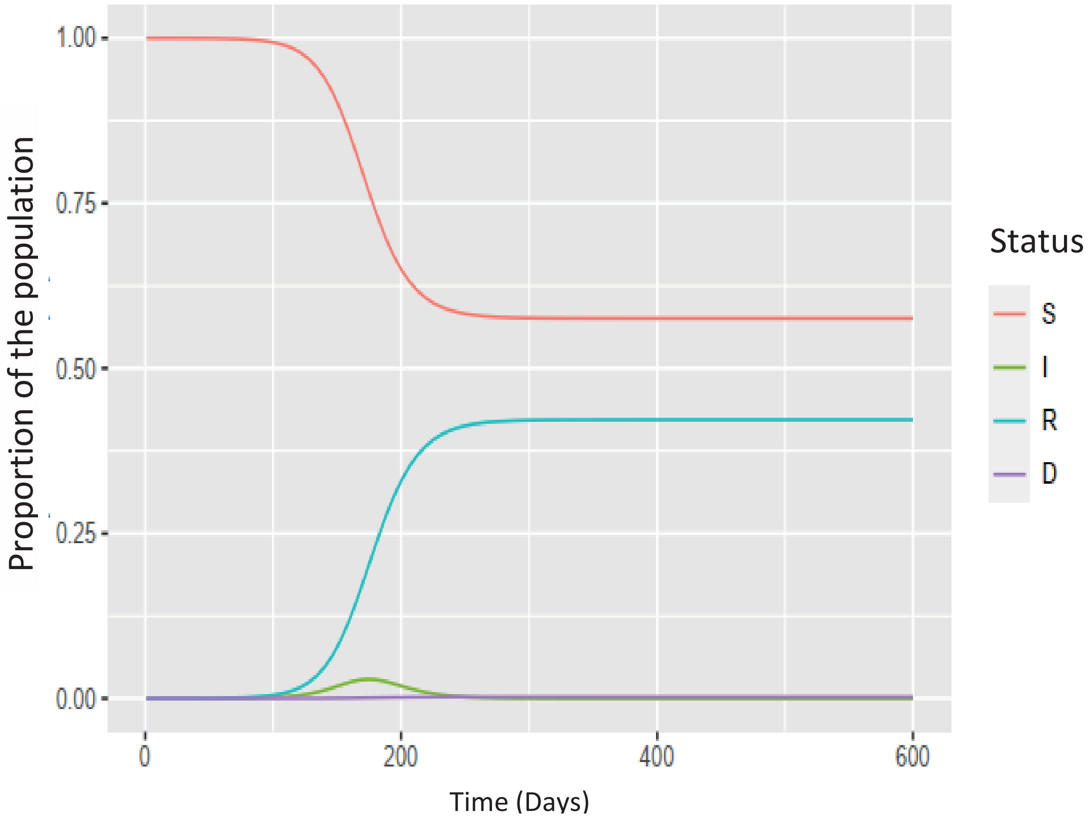


Source: SIR model forecasts

Transmission rate : $\beta = 1,3$

The above analysis was repeated using a smaller transmission rate value to account for the lower contact rates in the population. This reduction in the transmission rate implies better compliance with barrier actions than in the previous analysis. The result is presented in Figure 11. This graph shows that the potential wave of Covid-19 cases is expected to arrive between 100 and 250 days after the projection period. The peak of this wave would be reached 175 days after 19 December 2021, with 2.91% of the population infected, or 310,374 individuals. Furthermore, Figure 11 also shows that compliance with the barrier measures postpones the occurrence of the infection wave and the number of infections.

Graph 15 Forecast of the COVID-19 epidemic



Source: SIR model forecasts

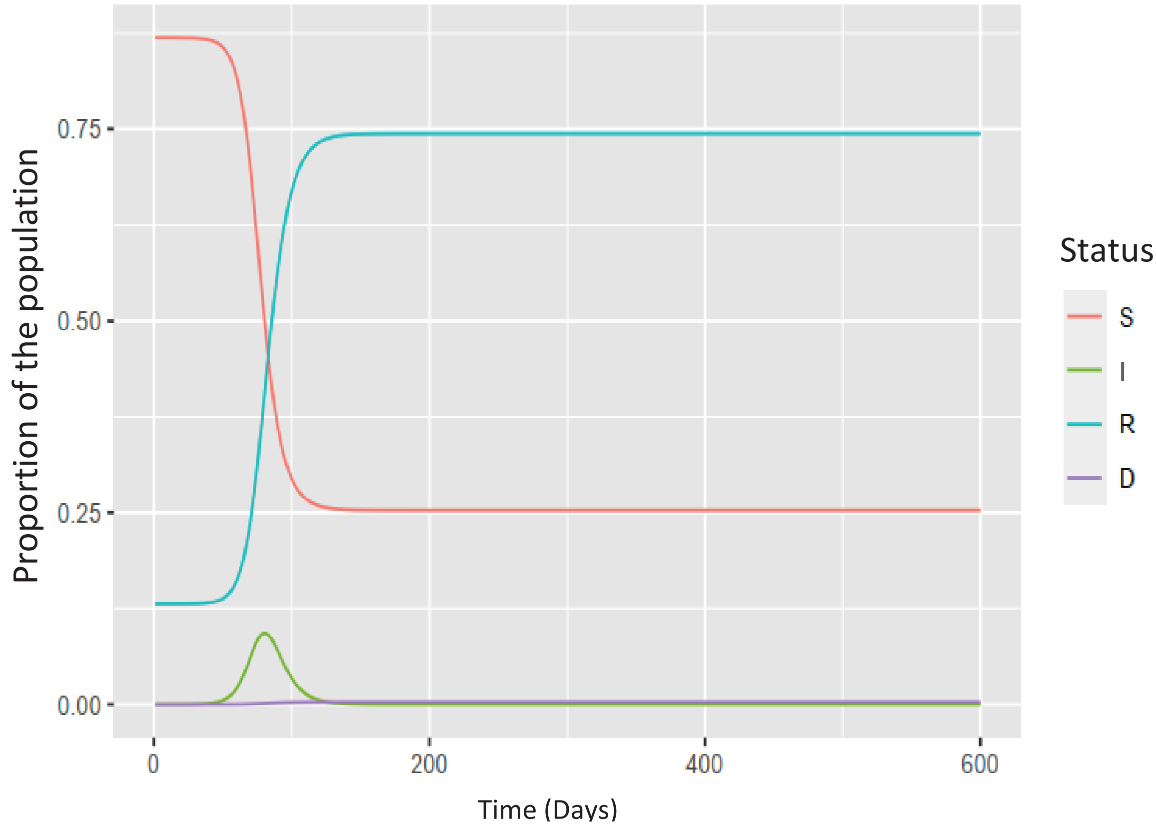
4.1.2.2. Scenario 2: number of people vaccinated= 1,396,492

In this second scenario we take into account the number of fully vaccinated individuals (having received two doses of vaccine) while keeping the transmission rates identical to the first scenario.

Transmission rate: $\beta = 2$

In this analysis, we consider the 1,396,492 fully vaccinated individuals with a disease transmission rate of 2. The results are shown in the **Erreur ! Source du renvoi introuvable.**. We observe on this graph that a wave of Covid-19 cases is likely to occur even with this proportion of the population fully vaccinated. Indeed, infection is expected to peak around day 80 of the projection period, with 9.29% of the population infected with Covid-19, or approximately 992,290 individuals.

Graph 16 Forecast of the COVID-19 epidemic

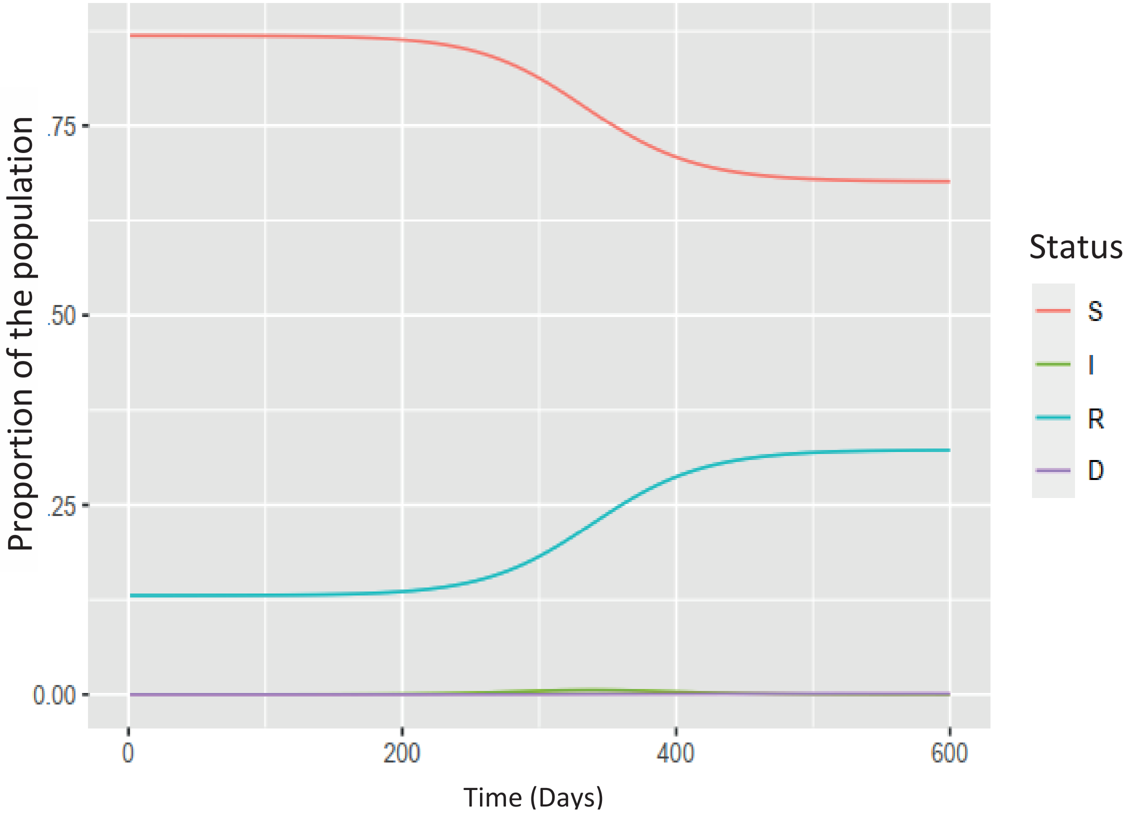


Source: SIR model forecasts

Transmission rate: $\boldsymbol{\beta = 1,3}$

In this analysis, we consider a lower rate of disease transmission than in the previous analysis. **Erreur ! Source du renvoi introuvable.** presents the results of the forecast. It can be seen that there are fewer COVID-19 infections compared to the previous scenarios.

Graph 17 Forecast of the COVID-19 epidemic



Source: SIR model forecasts

Vaccination combined with adherence to barrier practices will result in a decrease in the number of COVID-19 infections.

4.1.2.3. Scenario 3: Declining Immunity

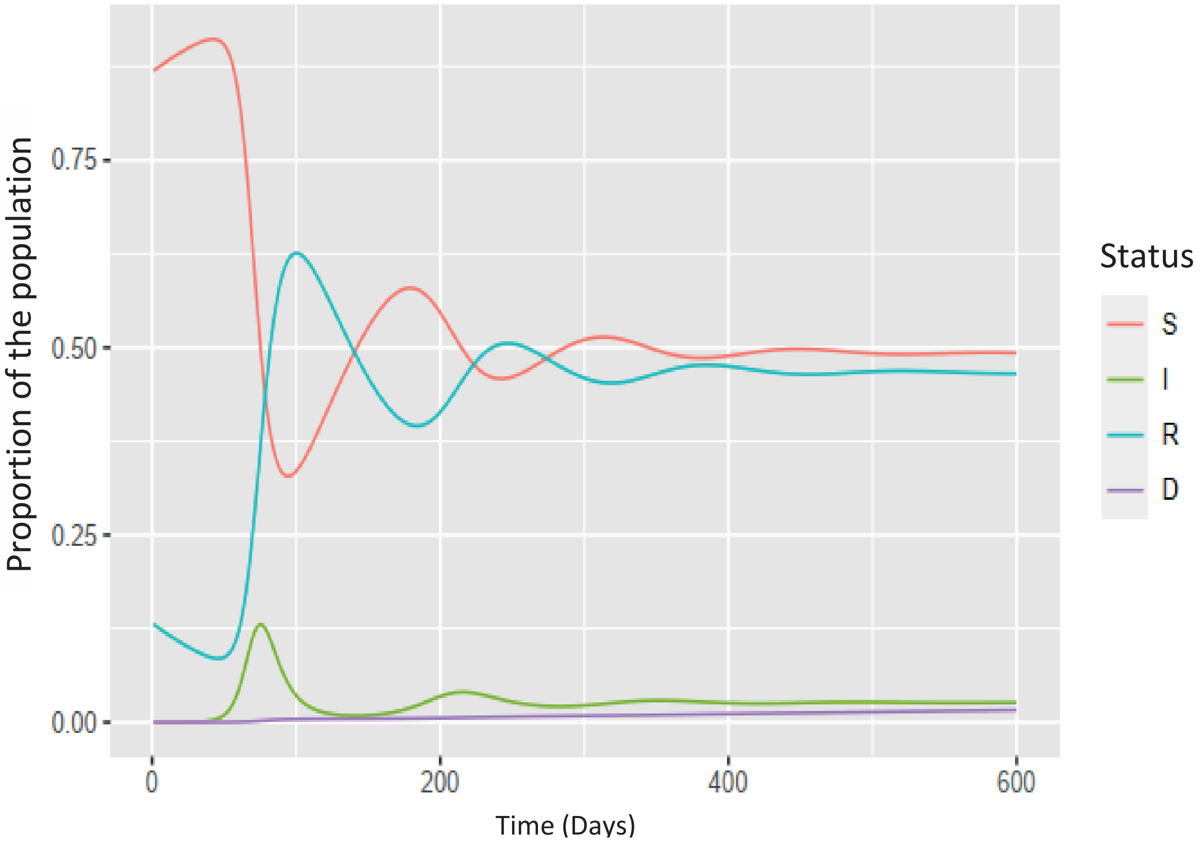
Immunity can be defined as the ability of living organisms to defend themselves against foreign agents (viruses, parasites, bacteria, etc.). We assume that the duration of this immunity varies over time. We consider two cases concerning the duration of immunity. First, we assume that cured and vaccinated individuals retain immunity for 3 months (90 days) and second, we assume that immunity lasts 6 months (180 days). In this simulation, we maintain the assumptions of the two previous scenarios: we consider the proportion of the population vaccinated

(1,396,492), the transmission rates identical and we assume that cured and vaccinated individuals are susceptible to the virus after a certain time.

Transmission rate: $\beta = 2$, immunity: $\sigma = 90$

In this scenario, we assume a virus transmission rate of 2 and an average immunity period of 90 days. Under these conditions, the projections reveal 2 waves of infection, the first of which is the most important. The first wave occurs less than 100 days after 19 December 2021 and the second around 200 days after 19 December 2021. At the peak of the first wave, approximately 13.02% of the population is infected, or 1,390,842 individuals.

Graph 18 Forecast of the COVID-19 epidemic

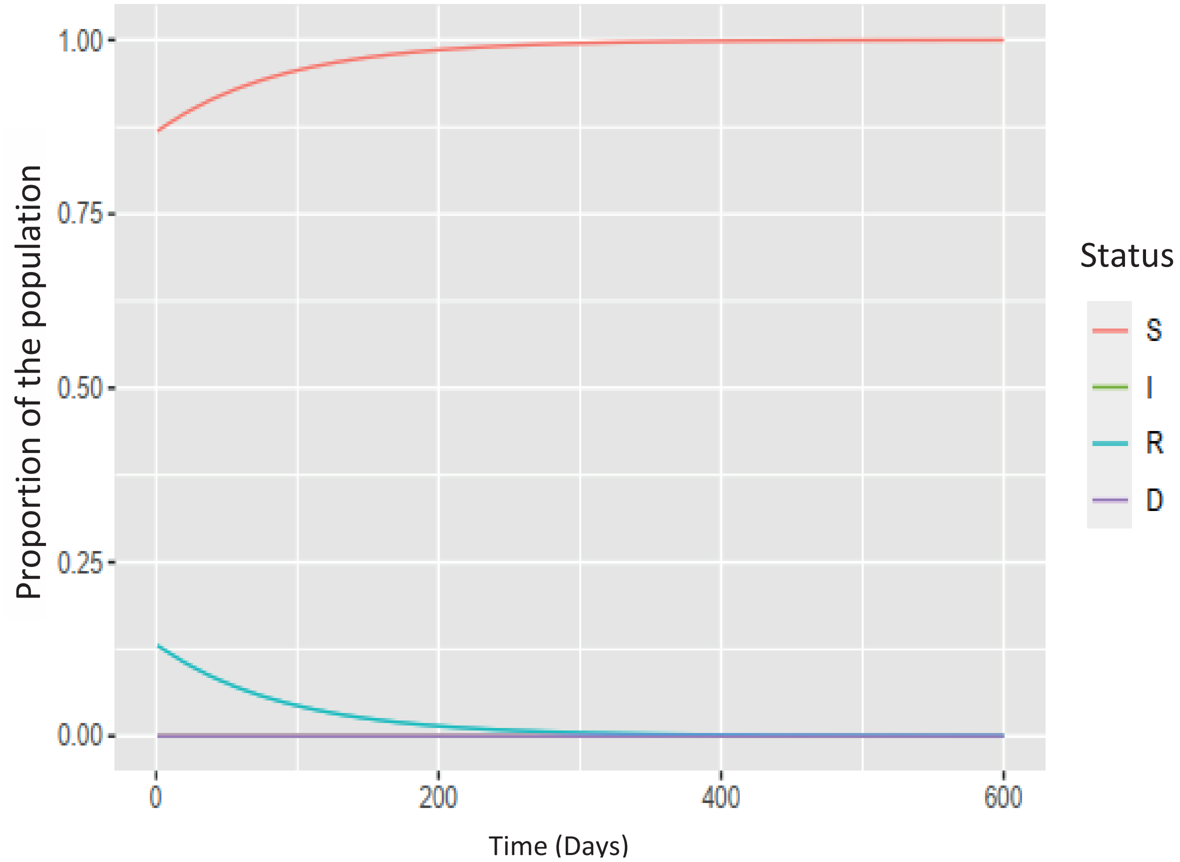


Source: SIR model forecasts

Transmission rate : $\beta = 1,3$, immunity : $\sigma = 90$

This scenario assumes a virus transmission rate of 1.3 and an average immunity period of 90 days. It can be seen that in this scenario new infections will be low. Indeed, this explains why the graph representing infections (I) is not visible on graph 19. Furthermore, it appears from the projections that the percentage of cured individuals is decreasing while the percentage of susceptible individuals is increasing. This reflects the decreasing immunity of cured and vaccinated individuals.

Graph 19 Forecast of the COVID-19 epidemic

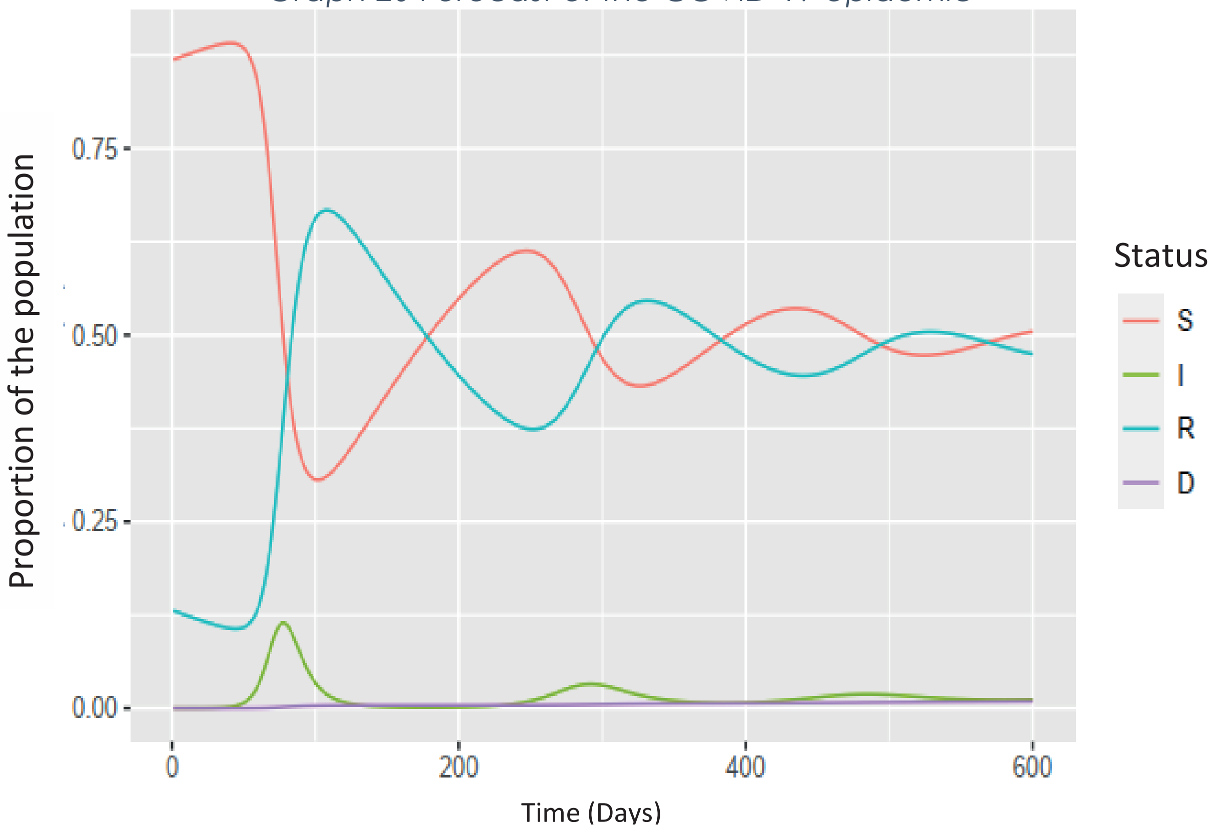


Source: SIR model forecasts

Transmission rate: $\beta = 2$, immunity: $\sigma = 180$

Here we assume a virus transmission rate of 2 and an average immunity period of 180 days. The projections show 3 decreasing waves of infection, the first of which is the most important. The first wave occurs less than 100 days after 19 December 2021, the second between 200 and 300 days after 19 December 2021 and the third between 400 and 600 days after 19 December 2021. The peak of the first wave occurs on the 77th day after 19 December 2021, with approximately 11.43% of the population infected or 1,220,614.

Graph 20 Forecast of the COVID-19 epidemic



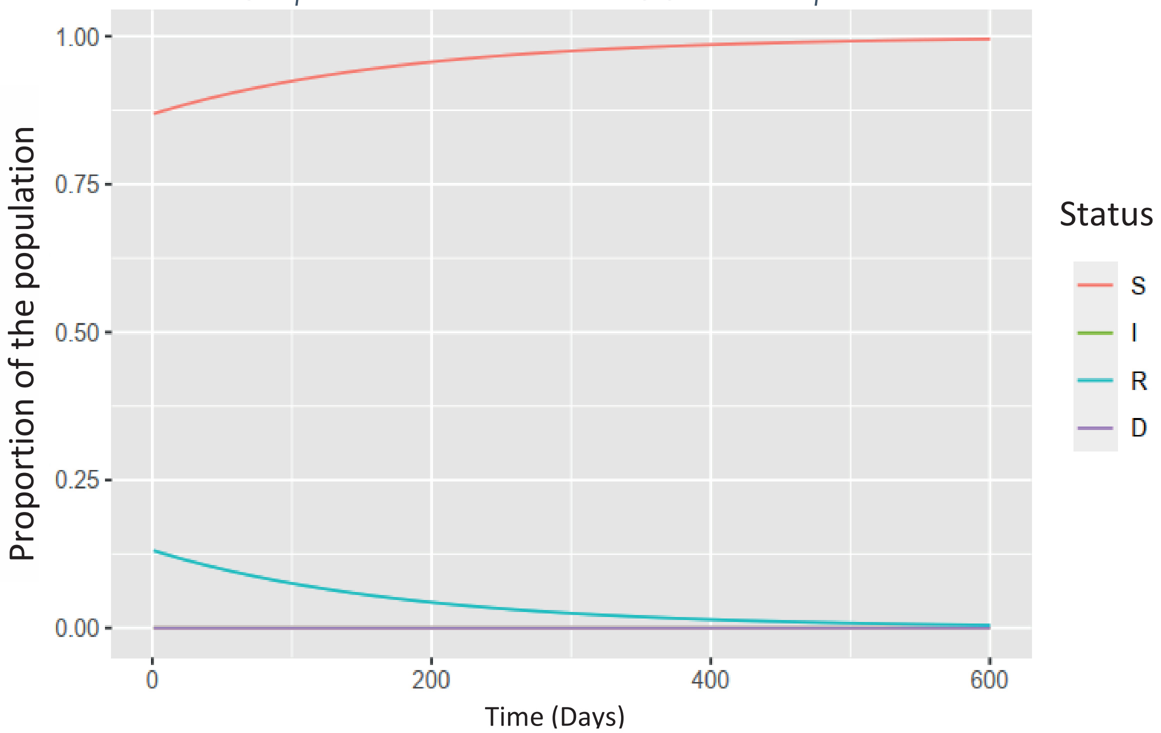
Source: SIR model forecasts

Transmission rate: $\beta = 1,3$, immunity: $\sigma = 180$

In this simulation, we assume a virus transmission rate of 1.3 and an average immunity period of 180 days. In Figure 21, the infection curve (I) is not visible, reflecting the low

proportion of new infections in the population. Graph 21 also shows that the percentage of cured individuals is decreasing while the percentage of susceptible individuals is increasing. This reflects the fact that cured and vaccinated individuals are becoming susceptible to the disease again.

Graph 21 Forecast of the COVID-19 epidemic



Source: SIR model forecasts

Partial conclusion

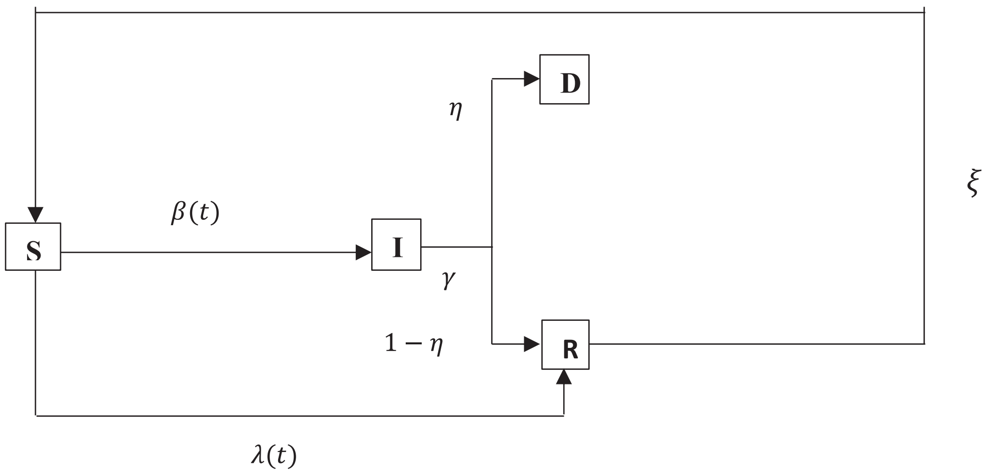
In this analysis, forecasts of possible waves of COVID-19 were made. The forecasts were implemented over a time horizon of 600 days starting on 19 December 2021. The forecasts made progressively move from less realistic scenarios to more realistic ones. Indeed, in the first scenario, we assume that the population likely to contract the (S) disease is not vaccinated, in the second, we take into account the proportion of the population that is fully vaccinated and in the third, we integrate the concept of decreasing immunity to account for the fact that cured and vaccinated individuals can contract the disease again. The predictions reveal that without the vaccine, we should expect larger waves of Covid-19 than in case where the vaccine is used. Therefore, the results indicate that vaccination and adherence to barrier measures are an effective way to reduce the extent of new infections.

4.2. Analysis with an endogenous contamination rate

4.2.1. Description of the model

This section briefly presents the compartmental model inspired by the work of Atkeson, Kopecky, & Zha (2020) and Atkeson (2021) with the endogenous contamination rate. In this version of the SIRD model, the total population N is given by the sum of susceptible agents S, infected I, recovered and/or vaccinated against infection in R and deceased in D. Susceptible individuals in the S state, i.e. those who have not contracted any COVID-19 variants, have not been vaccinated or have lost their previous immunity due to waning immunity, are inferred to have a transmission rate $\beta(t)$. The parameter $\beta(t)$ is the rate at which infected agents transmit the virus to others they encounter at date t. When agents leave compartment I, the fraction of them that die and a fraction of the people they meet die. η of them die and a fraction $1-\eta$ recover. The rate at which agents leave compartment I is noted as γ. Of those who leave the compartment Ia fraction η die and $1-\eta$ recover. The figure below describes how the SIRD model works.

Figure 1 Schematic diagram of the SIRD model



The impact of the vaccines is modelled by moving individuals from the S compartment to the recovered compartment(R) at the rate λ per day. This implies that the vaccine blocks both transmission by the vaccinated and disease in the vaccinated. Decreasing immunity is modelled as a movement of individuals from the recovered compartment (R) to the susceptible compartment (S) at a rate ξ per day. Population growth is not considered in the model.

4.2.2. Model Dynamics

The dynamics of the model are given by the following equations:

$$\frac{dS(t)}{dt} = -(\beta(t)I(t))S(t) - \lambda(t)S(t) + \xi R(t) \tag{6}$$

$$\frac{dI(t)}{dt} = \beta(t)S(t)I(t) - \gamma I(t) \tag{7}$$

$$\frac{dR(t)}{dt} = (1-\eta)\gamma I(t) + \lambda(t)S(t) - \xi R(t) \tag{8}$$

$$\frac{dD(t)}{dt} = \eta\gamma(I(t)) \tag{9}$$

In the model, the transmission rate of the virus is endogenous and is a function of the level of deaths and seasonality. The reduced form of the behavioural response of the transmission rate to the level of daily deaths is given by :

$$\beta(t) = \bar{\beta}\exp(-\kappa(t)\frac{dD(t)}{dt} + \psi(t)) \quad (10)$$

where the parameter $\bar{\beta}$ controls the basic transmissibility of the original strain and the COVID-19 variant, the parameter $\psi(t)$ is used to introduce seasonality into transmission, and $\kappa(t)$ is the semi-elasticity of transmission with respect to the level of daily deaths.

The seasonality of virus transmission is modelled as follows:

$$\psi(t) = seasonalsize * (\cos((t + seasonalposition) * \frac{2\pi}{365}) - 1)/2 \quad (11)$$

where $seasonalsize$ controls the magnitude of seasonal fluctuations in transmissibility by keeping the behaviour fixed and $seasonalposition$ controls the location of the seasonal transmission peak.

To model pandemic fatigue[4] :

$$\kappa(t) = \bar{\kappa} * (1 - normcdf(t, fatiguemean, fatiguesig)) +$$

$$fatiguesize * \bar{\kappa} * (1 - normcdf(t, fatiguemean, fatiguesig)) \quad (12)$$

where $\bar{\kappa}$ sets the initial semi-elasticity of transmission with respect to daily deaths, $fatiguesize$ sets the percentage reduction of this semi-elasticity in the long run, *normcdf* is the normal distribution function, $fatiguemean$ sets the date at which the transition of $\kappa(t)$ from its initial level to the new long-term level is half completed, and $fatiguesig$ defines the speed at which this transition occurs.

[4] A "new syndrome" which is characterised by a form of weariness and demotivation, due to the lack of social life and perspectives as well as the deprivation of freedoms, which can lead to more severe long-term consequences such as anxiety, depression and even the occurrence of suicidal thoughts.

The initial conditions of all simulations are I(0) >0 , R(0) = D(0) = 0, S(0) = 1 - I(0). We consider I(0) =6 on 18 March 2020 on a population of 26,453,542.

4.2.3. SIRD Model Estimates

4.2.3.1. *Choice of model parameters :*

In this section, we discuss the parameters of the model. In the simulations, we include the vaccine on 1 March 2021 at the rate of $\lambda(t) = 0{,}000329$. We assume that vaccinations are offered to the general population. For a population of 26,453,542 inhabitants, the daily number of vaccinations administered is close to 8,728. This implies that about 11.5% of the population is fully vaccinated by 11 February 2022. We assume that the loss of immunity occurs after one and a half years.

To model the seasonality of COVID-19 transmission, we rely on information on the seasonality of seasonal influenza. In the case of tropical countries, WHO indicates that the virus circulates throughout the year with peaks during the rainy season.

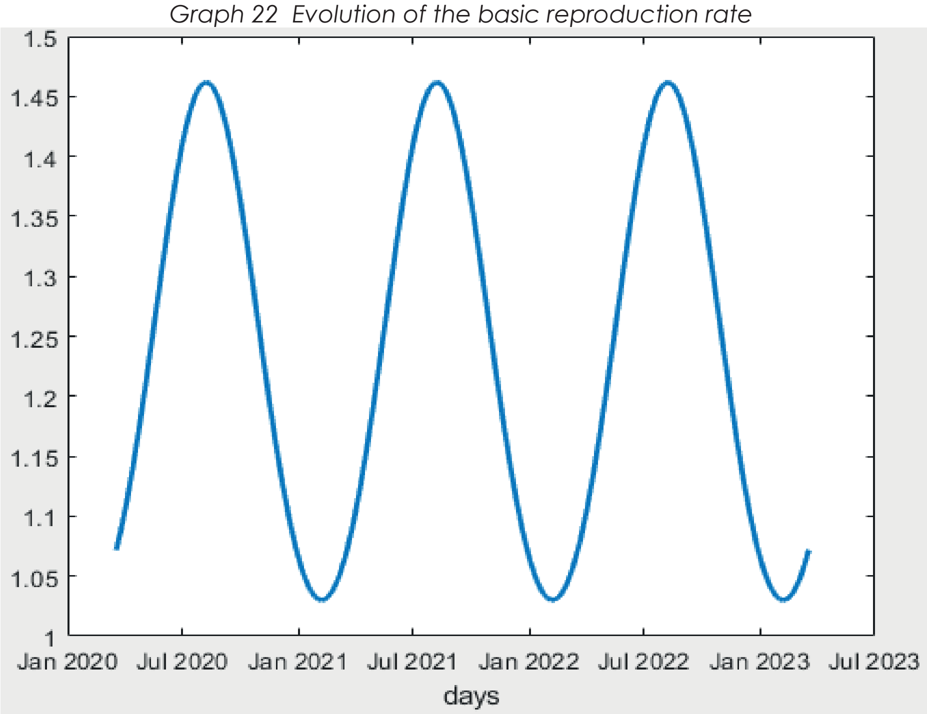
We define these two parameters in the model as :

$seasonalsize = -0.35$ and $seasonalposition = 40$.

The seasonal variation of the $\psi(t))$ parameter leads to a variation in the number of basic virus replicas over time. The graph below shows the basic reproduction number of the virus in the absence of a reduction in transmission due to a behavioral response.

We see that the assumed pattern of seasonality shows that the seasonal evolution of the number of basic breeding marked by increases around the rainy seasons and decreases over the rest of the period.

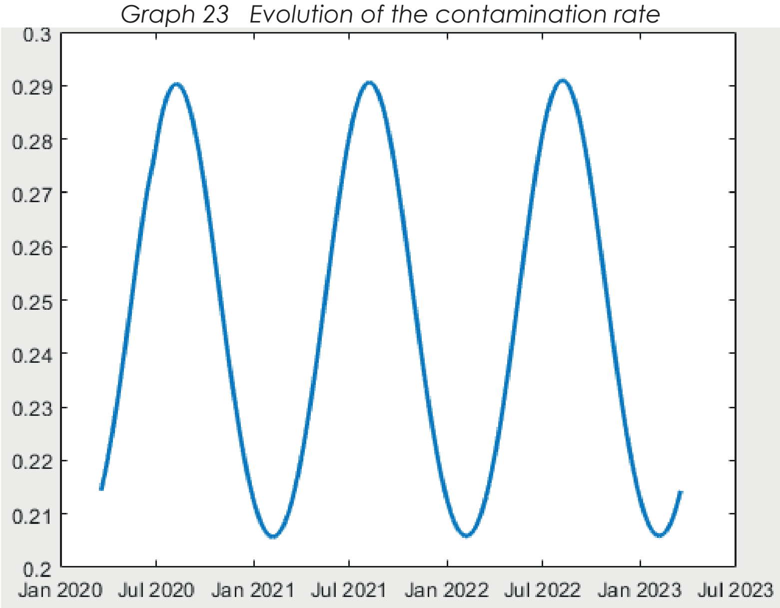
Graph 22 Evolution of the basic reproduction rate



Source: model projection

From this seasonal variation in the number of basic reproductions, the rate of infection of the virus evolves as illustrated by the graph below. There is an increase in the rate of contamination with a peak in the different months of July and lows around the months of December. This hypothesis is in line with the observations of peaks of contamination at COVID-19 in Côte d'Ivoire.

Graph 23 Evolution of the contamination rate



Source: model projection

The below table shows the main parameters and their values in the simulation model.

Table 1 Model parameters

Parameters	value
γ	1/5=0,2
$\bar{\beta}$	1.03*gamma
$\bar{\kappa}$	5000000
η	0,0007
$seasonalsize$	-0,35
$fatiguesize$	55
$fatiguemean$	100
$fatiguesig$	4
$seasonalposition$	40
λ	0.000329
ξ	1/(1.5*365)

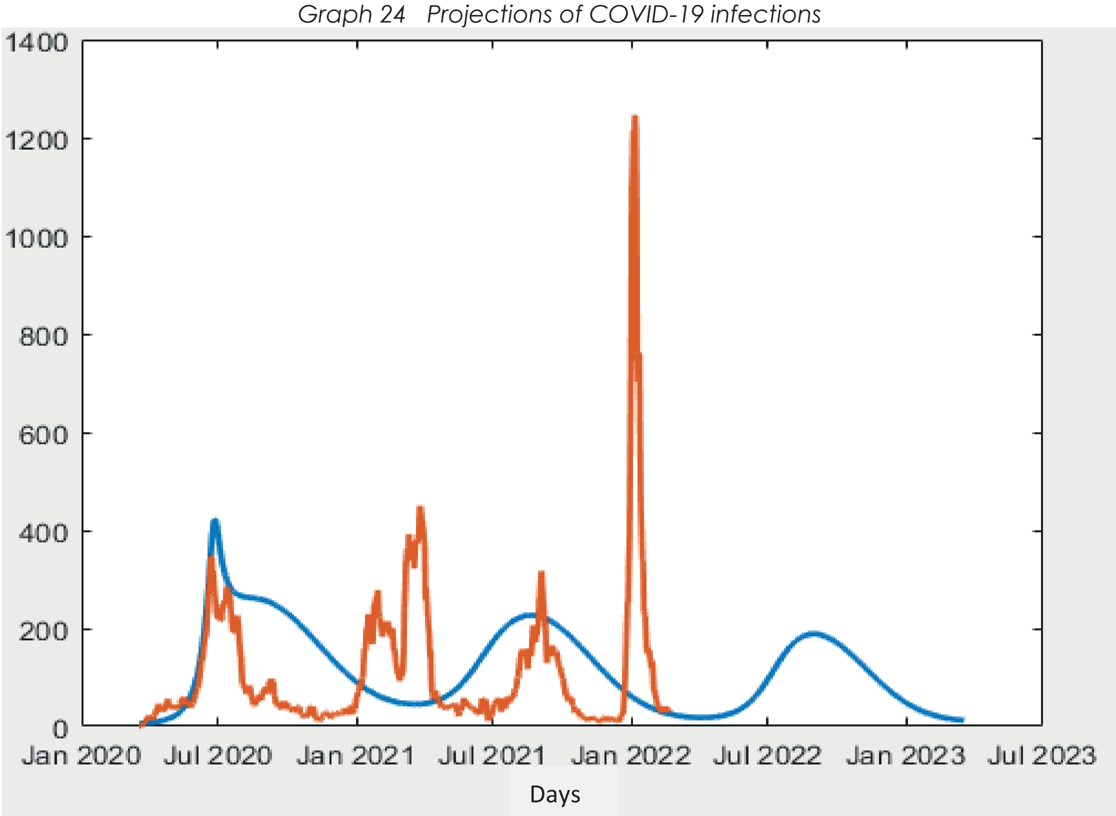
Source: CAPEC, UNDP study, 2022

4.2.3.2. Analysis of the results

The graph shows the evolution of the number of COVID-19 infections per day. The orange curve *is* the history of daily positive *cases of COVID-19* (7-day moving average) and the blue curve *represents the number of COVID-19 cases estimated and projected* by the model.

The theoretical model selected reproduces the reversals and the main trends in the number of positive COVID-19 cases observed in Côte d'Ivoire. Indeed, the model reproduces two waves of COVID-19 quite well, namely the first wave and the third wave, as shown in the graph below.

Graph 24 Projections of COVID-19 infections



Source: Model Projection

The wave of COVID-19 that occurred between December 2021 and January 2022 is partly explained by the omicron variant. The model as calibrated does not incorporate the different mutations of COVID-19. According to the model's projections, we should expect a possible wave of COVID-19 between May 2022 and January 2023 with a peak in August 2022. These new infections should not exceed an average of 200 cases per day, according to the model's estimates.

Partial conclusion

In the analysis of the predictability of a new wave of contamination, two modelling approaches were adopted. The first approach considers an exogenous transmission rate in which 3 scenarios were simulated. The second approach assumes a transmission rate that is endogenous to the model, i.e. explained by model variables. The forecasts were implemented over a time period (horizon) of 600 days starting from 19 December 2021. According to the first approach, the results indicate that vaccination and compliance with barrier measures are an effective means of delaying the occurrence of a possible new wave of infections.

In the second approach, which is complementary to the previous one, the projections reveal a possible wave of covid-19 during the rainy season, particularly around July 2022, with a peak in contamination in August 2022.

5. Analysis of explanatory factors for vaccine hesitancy

This section presents the analysis of population behavior in the study area considering two periods. The first period concerns the first quarter of 2021 and the second period is the last quarter of 2021. These two data collection operations were chosen in order to understand the behavior of the population before and after the launch of the vaccination campaign. As a reminder, the vaccination campaign was officially launched on 01 March 2021 by the Ivorian Prime Minister. The following sections present the sources of data in more detail, the surveys carried out, the analysis methodology used, and finally the results of the analysis of the factors explaining vaccine hesitancy.

5.1. Data Presentation

The data used come from two surveys carried out in Côte d'Ivoire, one before the launch of the mass vaccination campaign and the other after. The first survey was carried out by the National Institute of Statistics of Côte d'Ivoire and covered the entire national territory. The objective of this survey was, among other things, to evaluate the impact of COVID-19 on households in Côte d'Ivoire. The data were collected from 15 January to 28 January 2021.

The second survey was conducted by CAPEC as part of a research project on the evaluation of the impact of public policies related to COVID-19 on the informal sector, youth and women. Data collection took place from October 1 to 02 November 2021.

For the purposes of this mission, we have considered the greater Abidjan area as the field of study. There are two reasons for this choice. Firstly, just over 20% of the Ivorian population is concentrated in Greater Abidjan (INS, RGPH 2014). Secondly, this area is the focus of the COVID-19 pandemic in Côte d'Ivoire. Indeed, about 90% or even (slightly more) of confirmed cases are concentrated in this area.

Thus, from the INS database, information on Greater Abidjan was extracted in order to make a comparative analysis of household behavior with regard to the vaccine before and after the launch of the mass vaccination campaign. The aim is to examine which key factors influence vaccine hesitancy and how this has changed after the launch of the vaccination campaign. The distribution of households by location of analysis is presented in the Table 2.

Table 2 Localities covered by the surveys

Localities	1:NSI survey		Survey 2: CAPEC	
	Workforce	Proportion % of total	Workforce	Proportion % of total
Abobo	342	23,11	262	12,39
Adjamé	5	0,34	87	4,11
Anyama	47	3,18	87	4,11
Attenuated	149	10,07	122	5,77
Bonoua	6	0,41	136	6,43
Cocody	149	10,07	85	4,02
Dabou	13	0,88	224	10,59
Grand-Bassam	16	1,08	197	9,31
Jacqueville	6	0,41	62	2,93
Koumassi	127	8,58	95	4,49
Marcory	23	1,55	38	1,8
Port Bouet	177	11,96	269	12,72
Yopougon	420	28,38	451	21,32
Total	1480	100	2115	100

Source: Authors after calculation

This table shows that the two study samples take into account relatively similar distributions of the populations in the target cities. It is possible to make a comparison of the populations' behaviour towards vaccination.

5.2. Methodology

The aim of the analysis is to identify the explanatory factors of the vaccine hesitancy of individuals. The behaviour of individuals with regard to the COVID-19 vaccine is studied before and after the launch of the mass vaccination campaign initiated by the State. Logistic modelling was chosen because a binary variable was available. The intuition is to analyze the explanatory factors of vaccine hesitation through the estimation of the behavior of individuals before and after the launch of this vaccination campaign. How the identified factors influence the decision to vaccinate or not among individuals. The variable of interest has two modalities. Let Y_i be this variable of interest. It is defined as follows:

$$Y_i = \begin{cases} 1 \quad si\ l'individu\ accepte\ de\ se\ faire\ vacciner \\ 0 \quad si\ non \end{cases} \tag{13}$$

The quantity is called Logit :

$$Logit = ln\left(\frac{Prob(Y_i=1|X_i)}{1-Prob(Y_i=1|X_i)}\right) \tag{14}$$

The logit model can be written as follows:

$$ln\left(\frac{Prob(Y_i=1|X_i)}{1-Prob(Y_i=1|X_i)}\right) = \beta_0 + \sum_j \beta_j X_{ij} \tag{15}$$

In these equations X_{ij} denotes a set of explanatory variables. In the analysis, based on the literature review, the explanatory variables retained in the analysis are presented in the table below.

Table 3 Description of the explanatory variables of the study

Variables	Modalities
Gender	1. Female 2. Male
Marital status	1. Single 2. Married 3. Separated 4. Divorced 5. Widow(er) 6. Cohabitation
Level of education in French	1. No 2. Primary 3. 1st secondary cycle 4. Upper secondary 5. Higher education
Source of information	1. Traditional channel (radio and television) 2. Newspapers (paper) 3. Internet (social networks, online press, blog, etc.) 4. SMS (Government, NGOs, International Institutions, etc.) 5. Other
Barrier measures	1. Wearing the mask 2. Hand washing 3. Social distance of at least one metre 4. Avoiding greeting gestures based on physical contact 5. Avoid gatherings of large numbers of people

Source: INS data, CAPEC

According to the literature, two approaches are generally considered in this type of modelling. The first approach is based on the Odds Ratio analysis and the second is the latent variable method. In this study, the first approach was chosen because the objective is to analyze the explanatory factors of vaccine hesitancy given the characteristics of the individuals and we did not identify a latent variable linked to vaccine hesitancy behavior. However, we assume that vaccine hesitancy could explain the low rate of vaccination coverage against COVID-19. This rate, if high, would significantly reduce the probability of another wave of infection.

Given any two probabilities p_1 (the individual agrees to be vaccinated) and p_0 (the individual does not accept to be vaccinated), we call Odds Ratio, noted OR the quantity

$$OR = {}^{\frac{p_1}{1-p_1}} / {}_{\frac{p_0}{1-p_0}} \tag{16}$$

This quantity will capture the propensity of individuals to be reluctant to get vaccinated according to their observable characteristics. In addition to the *Odds Ratio*, other elements of interpretation of the binary model are: predicted probabilities, marginal changes or discrete changes in predicted probabilities; probability profiles for some relevant explanatory variables. These tools are used after checking the quality of the estimation.

5.3. Analysis of Population Behaviour

The Table 4 presents the results of the estimation of the effect of sources of information on COVID-19, compliance with barrier measures and socio-demographic variables on the vaccine hesitancy of individuals before the launch of the mass vaccination campaign against COVID-19.

The estimates reveal that all three groups of variables influence the decision of individuals to be vaccinated or not. When the size of the household increases, the probability of individuals being vaccinated increases. Indeed, an additional person in the household increases the probability of being vaccinated by more than 7.8% (100 * (1.078-1)) compared to the probability of not being vaccinated.

When analyzing behavior according to the barrier gestures, it was found that: from an individual who does not avoid shaking hands to an individual who avoids shaking hands, the probability of being vaccinated against COVID-19 increases. In other words, people who respect the handshake barrier measure have a higher probability of being vaccinated. The same is true for those who comply with the hand washing measure. For the latter, the probability of being vaccinated increases by 5.8% from a person who does not wash his hands regularly to a person who washes his hands regularly.

On the measure of social distancing, individuals who apply this barrier action are more likely to be vaccinated. Overall, individuals who follow the barrier measures (handwashing, social distancing) have a higher probability of being vaccinated.

However, the probability of being vaccinated drops when it comes to the barrier measure of avoiding crowds and gatherings. This probability drops by 6.9% when moving from individuals who do not avoid gatherings and crowds to individuals who do. The measure relating to compliance with this barrier measure is still far from being complied with by the population.

Analyzing the effect of the source of information on the probability of individuals accepting to be vaccinated, the estimates on the data collected before the mass vaccination campaign show that the source of information is an important factor in vaccine hesitation. Indeed, from individuals who get information from traditional channels such as radio and television to those who get information from newspapers, the internet and SMS from government, NGOs, international institutions, etc., the probability of being vaccinated drops by 27.1%. This result suggests that the use of radio and television as a means of communicating about the evolution of COVID-19 should be privileged and reinforced.

Table 4 Explanatory factors for vaccine hesitancy in the year 2021 quarter

	(1)	(1)	(1)	(2)	(2)	(2)
VARIABLES	logit1	Logistic1	Mfx1	logit2	logistic2	Mfx2
	coef	GOLD	coef	coef	GOLD	coef
Marital status	0.03	1.032	0,006	0.04	1,039	0,008
	(0.70)	(0.698)	(0.698)	(0.64)	(0,642)	(0,641)
Gender	-0.12	0,886	-0,024	-0.13	0,875	-0,026
	(0.33)	(0,327)	(0,0328)	(0.28)	(0,283)	(0,284)
level of French instruction	-0.05	0,948	-0,01	-0.04	0,961	-0,008
	(0.24)	(0,241)	(0,241)	(0.38)	(0.38)	(0.38)
Source of information (reference modality=traditional channel)						
Source of information	-1.03***	.358	-0,202			
	(0.00)	(0.00)	(0.00)			
Source of information : Newspapers, internet and sms				-1.21***	0,298	-0,271
				(0.00)	(0.00)	(0.000)
Source of information : Other sources of information				0.17	1,185	0,032
				(0.83)	(0.835)	(0.828)

Wearing a face mask	0.26	1.889	0,053	0.31	1,367	0,065
	(0.35)	(.001)	(0,375)	(0.25)	(0.254)	(0.280)
Avoid shaking hands (baseline=no)						
Avoid shaking hands	0.64***	1.889	0,113			
	(0.00)	(0,001)	(0,000)			
Avoid shaking hands: yes				0.65***	1,916	0,115
				(0.00)	(0.00)	(0.00)
Avoiding gatherings of people (baseline=no)						
Avoid gatherings of people	-0.34**	.714	-0,069			
	(0.04)	(0,042)	(0,050)			
Avoiding gatherings of people: Yes				-0.32*	0,726	-0,065
				(0.05)	(0.055)	(0.064)
Hand washing (reference modality=no)						
Hand washing	0.29**	1.335	0,058			
	(0.03)	(0,033)	(0,039)			
Hand wash: yes				0.29**	1,33	0,058
				(0.04)	(0.036)	(0.042)
Physical distance (reference modality=no)						
Physical distance	0.31**	1.367	0,059			
	(0.03)	(0,029)	(0,024)			
Physical distance: Yes				0.33**	1,397	0,063
				(0.02)	(0.02)	(0.016)
Age	0.00	1.003	0,001	0.00	1,003	0,001
	(0.59)	(0,589)	(0,589)	(0.60)	(0.601)	(0.601)
Household size	0.08***	1.079	0,015	0.08***	1,078	0,015
	(0.00)	(0,001)	(0,001)	(0.00)	(0.001)	(0.001)
Constant	1.24***	3.463		0.13		
	(0.00)	(0,004)		(0.74)		
Comments	1480	1480	1480	1,480	1480	1480
Prob > chi2	0,000	0,000	0,000	0,000	0,000	0,000

Notes: The receiver operating characteristic (ROC) curve is presented in Annex 3

Source: estimates

In the end, before the launch of the mass vaccination campaign, the determining factors for vaccine hesitancy are sources of information, compliance with barrier measures and household size. The estimates show that compliance with barrier measures: hand washing,

respect of social distancing. Wearing a face mask is not a determining factor in the decision of individuals, neither is marital status or the level of education in French. The source of the information received on COVID-19 influences the decision taken by individuals, with traditional sources (radio, television) increasing the probability of being vaccinated. Indeed, the credibility of the information disseminated by these traditional channels of communication allow heads of households to have a clearer picture of the situation and therefore be more willing to get vaccinated than others who receive information from other sources. It is worth noting that, apart from traditional sources, information received via social media contributes to heads of household receiving false information.

Table 5, seen below, shows the results of the estimates of the explanatory model for the behaviour of individuals in the greater Abidjan area after the launch of the mass vaccination campaign. The analysis of the Table 5 shows that that marital status, level of education in French, wearing a face mask, hand washing and household size are the main factors influencing an individual's decision to be vaccinated or not. Thus, the fact that an individual is married, widowed or in a common-law relationship increases the probability of that individual being vaccinated, compared to an individual in a single situation. These heads of household with this status are more likely to be vaccinated because not only is it their responsibility to protect the people around them (spouse,

partner, collateral, etc.). This is why these heads of household are more willing to be vaccinated.

Individuals with primary, lower secondary and higher levels of French education are more reluctant to be vaccinated than those with no French education. Regarding the level of education in French, they have the ability to have the right information about the pandemic. Their level of education in French allows them to better analyse facts related to the vaccine, which in turn allows for a more informed decision making process, comparatively to heads of households with no education in French. Therefore, we can note that this group with higher levels of French education, depending on their level of perception of the vaccine, are more willing to be vaccinated than those with no and lower levels of French education.

Observing the barrier measures, such as wearing a face mask or washing hands, has a positive and significant influence on the decision of individuals to be vaccinated, in contrast to individuals who do not observe these barrier measures after the launch of the vaccination campaign. Consequently, individuals who observe these barrier measures have a higher propensity to be vaccinated compared to those who do not observe them. Household heads who observe the barrier measures have a perception of the severity of the disease that is different from those who do not observe the barrier measures. This perception makes them more likely to be vaccinated and they are not hesitant to be vaccinated. This is how we

could explain the result that shows that individuals who respect the barrier measures have a greater probability of being vaccinated.

Household size has a positive and significant influence on the decision to be vaccinated or not. Indeed, as household sizes increases the probability of an individual in that same household being vaccinated by more than 5% (100*(1,054-1)). As the number of people in the household increases, the number of people potentially exposed to the virus increases. Consequently, the head of a household with a more persons living in the household will be more willing to be vaccinated as a precautionary measure than a head of a household whose household size is relatively small.

Table 5 Explanatory factors for vaccine hesitancy in the fourth quarter of 2021

VARIABLES	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	logit1	logistic1	mfx1	logit2	logistic2	mfx2
	coef	GOLD	coef	coef	GOLD	coef
	Reference type: Single					
Marital status	0,09***	1,093	0,022***			
	(0,01)	(0.005)	(0,005)			
Married				0,58***	1,795***	0,144***
				(0,00)	(0)	(0,000)
Separate				1,31*	3,715	0,311
				(0,09)	(0,088)	(0,046)
Divorced				-1,01	0,365	-0,207
				(0,38)	(0,375)	(,258)
Widow(er)				1,29***	3,632	0,308
				(0,00)	(0)	(0,000)
Cohabitation				0,32*	1,371	0,077
				(0,06)	(0,065)	(0,068)
Other				-		
gender	0,05	1,047	0,011	0,06	1,063	0,015
	(0,67)	(0,666)	(0,666)	(0,57)	(0,574)	(0,575)
Reference modality: None						
Level of education in French	-0,12***	0,886***	-0,029***			
	(0,00)	(0,004)	(0,004)			
Primary				-0,55***	0,574	-0,128
				(0,00)	(0,001)	(0,001)
1st secondary cycle				-0,48***	0,617***	-0,113***
				(0,01)	(0,006)	(0,004)
Upper secondary				-0,25	0,777	-0,060
				(0.14)	(0.14)	(0.133)
Higher				-0,59***	0,556***	-0,134***
				(0,00)	(0,003)	(0,001)
Source of information	0,09	1,097	0,022	0,08	1,087	0,020
	(0,11)	(0,114)	(0,114)	(0,16)	(0,161)	(0,161)
Reference modality: No						
Wearing a face mask	0,71***	2,036***	0.160***			

	(0,00)	(0,001)	(0.000)			
Wearing a nose guard: Yes				0,68***	1,981***	0,154***
				(0,00)	(0,001)	(0,000)
Physical distance	0,11	1,118	0,027	0,13	1,138	0,031
	(0,42)	(0,424)	(0,423)	(0,36)	(0,364)	(0,362)
Avoiding reassurances	-0,20	0,82	-0,048	-0,15	0,865	-0,035
	(0,16)	(0,159)	(0,160)	(0,31)	(0,309)	(0,310)
Reference modality: No						
Hand washing	1,01***	2,735***	0,214***			
	(0,00)	(0)	(0,000)			
Hand wash: Yes				1,11***	3,035***	0,231***
				(0,00)	(0)	(0,000)
Avoid shaking hands	0,09	1,09	0,021	0,12	1,126	0,028
	(0,59)	(0,588)	(0.586)	(0,47)	(0,466)	(0,463)
Age	-0.00	0,998	-0,000	-0,00	0,997	-0,001
	(0,61)	(0,611)	(0,611)	(0,36)	(0,363)	(0,363)
Household size	0,05***	1,054***	0,013***	0,06***	1,057***	0,013***
	(0,00)	(0,002)	(0,002)	(0,00)	(0,001)	(0,001)
Constant	-2,28***	0,102***		-2,42***	0,089***	
	(0,00)	(0)		(0.00)	(0)	
Comments	1 531	1 531		1 531	1531	
Prob > chi2	0,000	0,000	0,000	0,000	0,000	0,000

Notes: The ROC curve is presented in Annex 4

Source: estimates

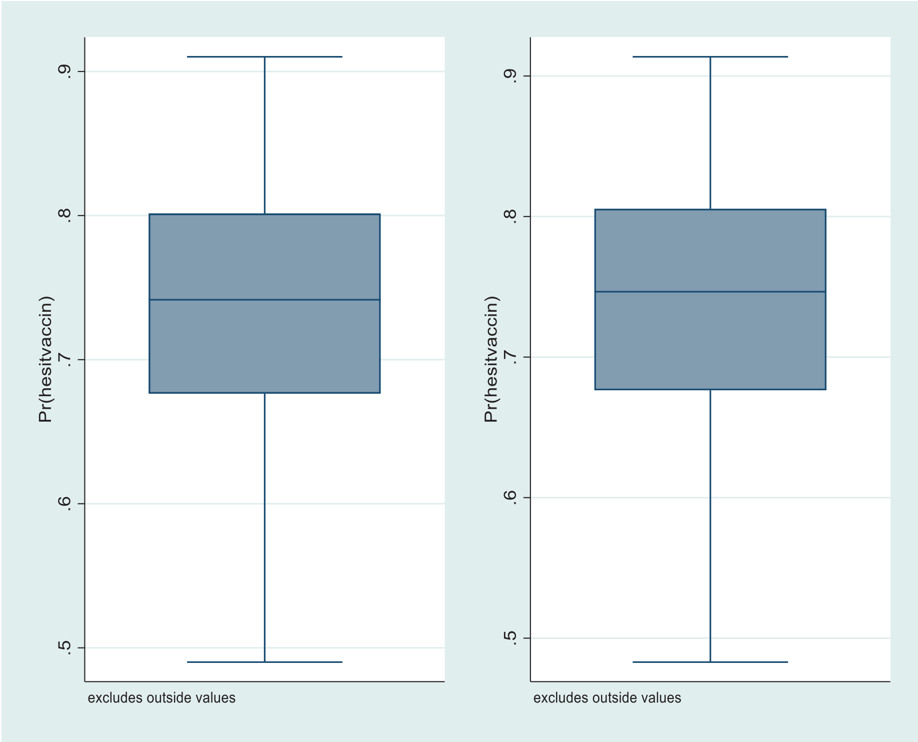
In the end, the analysis of the results shows that the situation of being single, a high level of education in French, the non-respect of the barrier gestures of wearing a face mask and washing hands are the factors that favour vaccine hesitation in the greater Abidjan area.

The **Erreur ! Source du renvoi introuvable.** presents the distribution of the p robabilities predicted in the estimation of the Logit 1 and Logit 2 models in the first and fourth quarters of 2021 in the greater Abidjan area. The result is that the probability of being vaccinated in the first quarter is between 0.21 and 0.91 for Logit 1 and 0.24 and 0.91 for Logit 2.

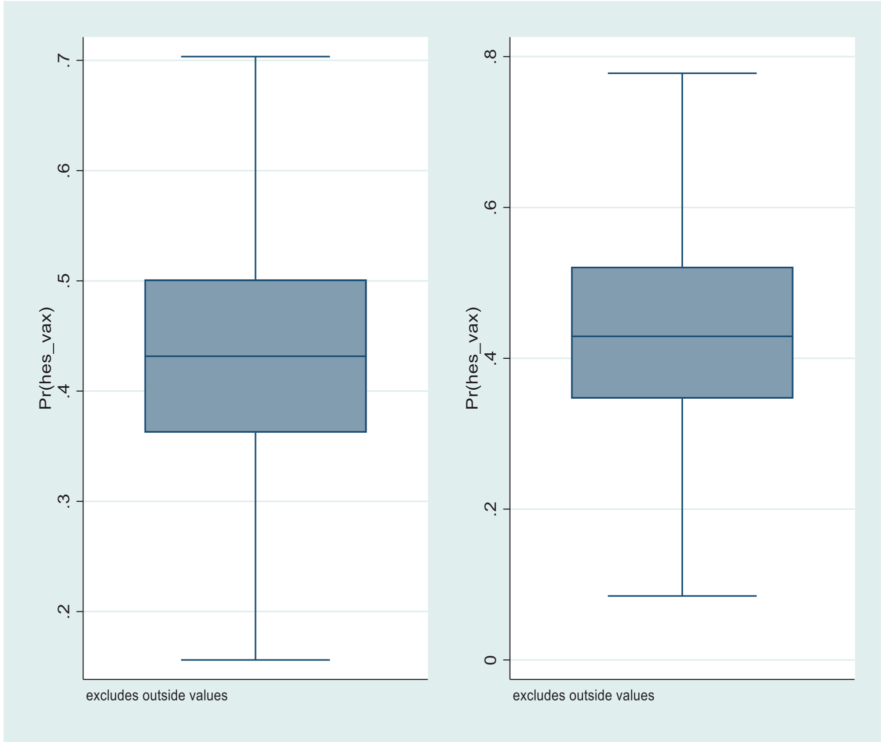
In the fourth quarter, it ranges from 0.08 to 0.75 for Logit 1 and 0.06 to 0.83 for Logit 2. It can be seen that the probability of being vaccinated is lower in the last quarter than in the first quarter. Thus, individuals have a lower propensity to be vaccinated in the fourth 2021. There is therefore an increase in the reluctance to be vaccinated against COVID-19 in Greater Abidjan.

Graph 25 Distribution of predicted probabilities in the estimation of the Logit 1 and Logit 2 model in the first and fourth quarter of 2021

NSI survey: First quarter 2021



CAPEC survey: Fourth quarter



Source: INS data, CAPEC

A comparison of the predicted probabilities shows that the maximum probability before the launch of the campaign is estimated at 0.91, while after it the maximum probability is 0.75 (cf.). The probability has decreased overall between the first quarter and the last quarter of the year 2021. This result indicates a change in the behaviour of individuals towards vaccination. This change in the probability of being vaccinated could be explained by the change in the population's perception of the vaccine. Indeed, the mass of information received via information channels other than the traditional ones has modified the level of perception of the population with regard to the vaccine. Misinformation has led to a reduction in people's confidence in the vaccine. This could explain the drop in the probability of being vaccinated before and after the launch of the mass vaccination campaign.

Finally, several findings emerge from this comparative analysis:

- The behaviour of individuals changed before and after the launch of the vaccination campaign. The probability that individuals in the greater Abidjan region will accept to be vaccinated decreased between the two periods considered.
- Explanatory factors for reluctance to be vaccinated are: marital status, attitude towards barrier measures, household size, source of information on COVID-19.
- Household size has a positive influence on the probability of being vaccinated.
- Compliance with barrier measures such as wearing face masks and hand washing had a significant positive impact on the decision to vaccinate.

Individuals who observe these barrier measures have a higher propensity to be vaccinated compared to those who do not observe them.

Individuals with primary, lower secondary and tertiary levels of French education are more reluctant to be vaccinated compared to individuals with no French education.

6. Conclusion and Recommendations

In view of the increase in the number of new cases of COVID-19 during the last quarter of 2021, the UNDP country office in Côte d'Ivoire requested this study to analyse the predictability of a possible new wave of the disease in Côte d'Ivoire and to examine the population's vaccination behaviour.

The methodology used is based on time series modelling and on a SIR type model, an epidemiological model, calibrated based on recent data from Côte d'Ivoire and depending on whether the contamination rate is exogenous or endogenous, and on econometric modelling: logistic modelling. The logistic modelling consisted of a comparative analysis of the behaviour of individuals in the greater Abidjan area with regard to vaccination against COVID-19. These models complement the descriptive analysis carried out on the variables presenting the recent health and vaccination situation in Côte d'Ivoire with regard to COVID-19. The main findings of the study are as follows:

Since the detection of the first positive case, Côte d'Ivoire has experienced 3 waves of COVID-19 infection. The first wave coincides with the first peak of contamination in the beginning of the pandemic. The second wave relates to the peak observed with the delta variant and the third wave the peak caused by the omicron variant.

The COVID-19 pandemic in Côte d'Ivoire is relatively under control. As soon as the first positive case was detected, the Ivorian authorities put in place a series of measures that have proven to be effective in eliminating the effects of the coronavirus. Thus, the country has demonstrated a high average rate of recovery from COVID and a low mortality rate.

Nevertheless, there has **been a clear increase in the number of active cases**, despite a relative decrease over the period of the analysis. Consequently, the population will have to be twice as vigilant and scrupulously observe the barrier measures recommended by the health authorities.

In addition, **the vaccination situation is clearly improving**. More and more people are being vaccinated against COVID-19.

The forecast of the variables of interest does not show an upward trend suggesting the imminent occurrence of a new wave of COVID-19. Indeed, the number of COVID-19 positive cases, cured cases and active cases would show similar evolutions with trajectories that are more or less identical to the trends of the historical values.

Running the epidemiological model with the exogenous infection rate through three scenarios-*(i) we assume that the population susceptible to contracting the (S) disease is not vaccinated, (ii) we take into account the proportion of the population that is fully vaccinated, and (iii) we incorporate the concept of a waning immunity to account for the fact that cured and vaccinated individuals can contract the disease* again-reveals that :

- without the vaccine, new and larger waves of covid-19 are to be expected.
- Vaccination and adherence to barrier measures are an effective way to prevent the occurrence of new waves of infection.

By making the contamination rate endogenous in a second analysis in the SIR-type model, the results show that Côte d'Ivoire should expect a possible wave of COVID-19 contamination around July 2022.

People's behaviour towards vaccination has changed since the launch of the mass campaign. The likelihood of being vaccinated has decreased.

The probability of being vaccinated depends on marital status, household size, compliance with certain barrier measures (wearing a protective mask, hand washing, social distancing).

Household size has a positive influence on the probability of being vaccinated.

Observing barrier measures such as wearing a face mask or washing hands has a significant positive influence on the decision to be vaccinated. Individuals who observe these barrier measures have a higher propensity to be vaccinated compared to those who do not observe them.

Individuals with primary, lower secondary and tertiary levels of French education are more reluctant to be vaccinated compared to individuals with no French education.

In view of these results, the following recommendations are made:

To the State:

- Strengthening of the measures put in place for the vaccination of the population: the State officially launched the mass vaccination campaign in March 2021 in Abidjan. The arrangements put in place for vaccination initially concerned people at risk, then people aged over 18 yrs and finally the campaign was extended to people over the 12 yrs. The number of tests acquired increased and the cumulative number of doses of vaccine received increased. The State, with the support of technical and financial partners, has extended the vaccination campaign beyond the city of Abidjan. This campaign has enabled more than 11% of the population to receive the first dose of vaccine. Côte d'Ivoire plans to vaccinate more than 50% of its eligible population by the end of December

2022. This will involve filling gaps in the supply chain, logistics, infrastructure and training. It will also increase the procurement and deployment of vaccines and the storage capacity of health districts and strengthen the supply system, including ensuring the maintenance of a cold chain through the rehabilitation of regional cold stores. These actions will help to strengthen the immunisation capacity of the entire health system.

- Continue awareness and information campaigns on COVID-19 and compliance with barrier measures. This will involve intensifying information campaigns using traditional channels (radio, television), offering spots in several national languages, carrying out awareness campaigns for target groups (young people, women, opinion leaders, religious guides, NGO leaders). It will also be necessary to carry out campaigns to combat misinformation about COVID-19.

To the People

- Get vaccinated to reduce the risk of a new wave of COVID-19 in Côte d'Ivoire. Vaccination is a way to prevent the risk of infection with the coronas virus. The State has made efforts with the support of technical and financial partners to acquire several doses of vaccine. Vaccination is free of charge and all populations are invited to go to a vaccination centre or to a centre authorised to give the vaccine to receive the doses of vaccine against COVID. The State should reassure the population about the health situation and the seriousness of the disease.

- Respect the barrier measures to reduce the transmission rate of COVID-19. Wearing a face masks, hand washing, and social distancing are measures to prevent contamination and transmission of the virus in the population.

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Annexes

Annex 1

Table 6 Unit Root Tests

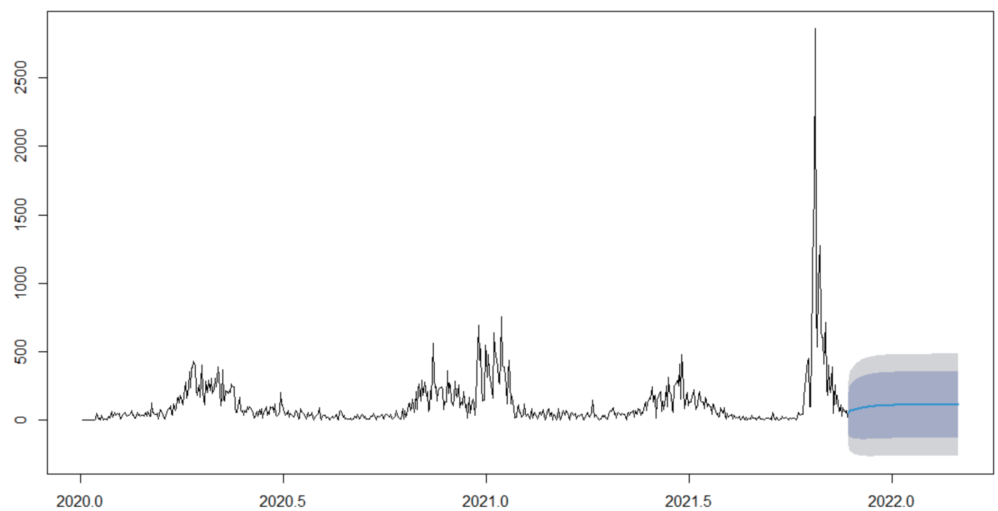
Variables	ADF		PP		KPSS		Order of integration
	Level	First difference	Level	First difference	Level	First difference	
Positive	-7.8686* (-2.86)	-	-9.5052* (-2.8661)	-	0.14 (0.146)		I(0)
Cured (Reovery)	-8.047* (-2.86)	-	-10.1858* (-2.8661)	-	0.1581* (0.146)	-	I(0)
Deaths	-8.3211 (-2.86)	-	-16.1525 (-2.8661)	-	0.2506* (0.146)	-	I(0)
Active cases	-3.2883* (-2.86)	-	-3.0517 (-2.8661)	-	0.3915 (0.463)	-	I(0)

Note: "*" indicates rejection of the null hypothesis at the 5% significance level

Annex 2: Forecasting using the Box and Jenkins (1980) method

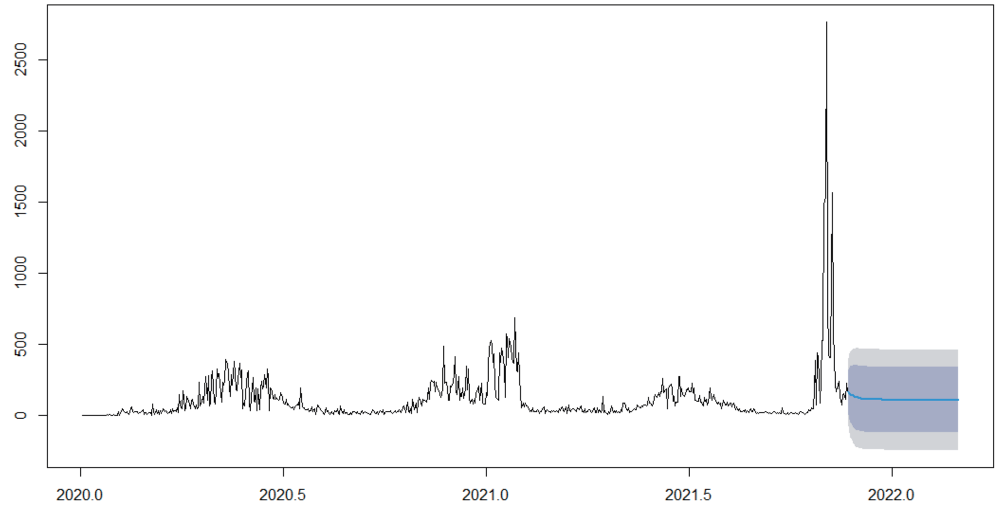
Positive cases

Forecast of positive cases from ARIMA (1,0,3)



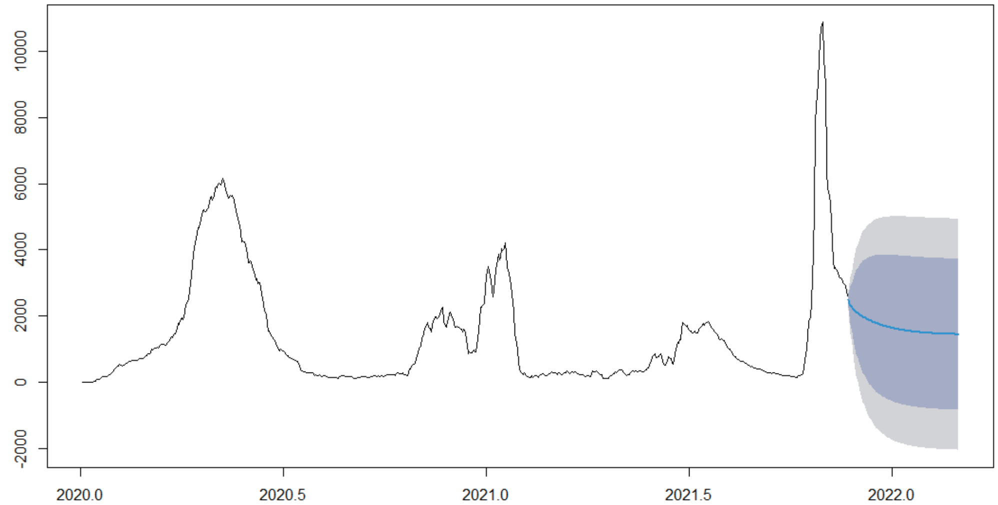
Cured Cases (recovery cases)

Prediction of cured cases from ARIMA (1,0,1)



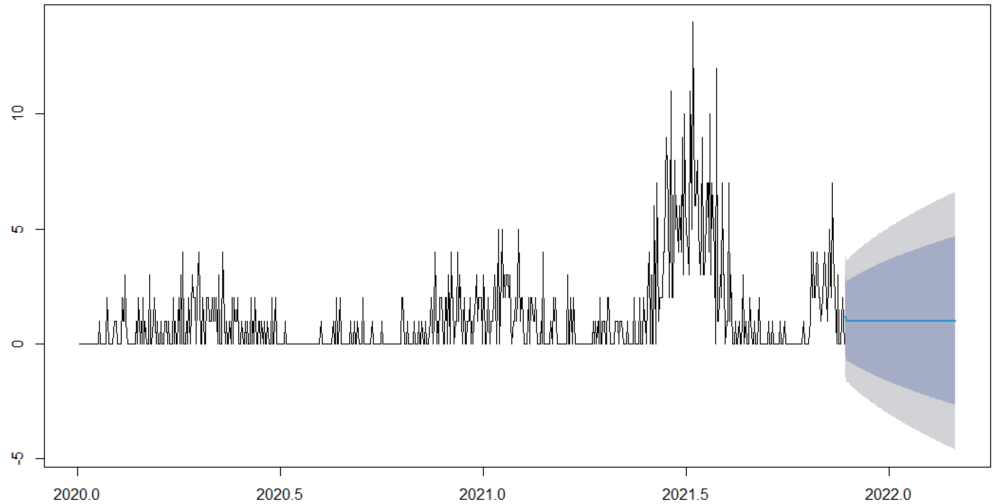
Active cases

Prediction of active cases from ARIMA(5,0,1)



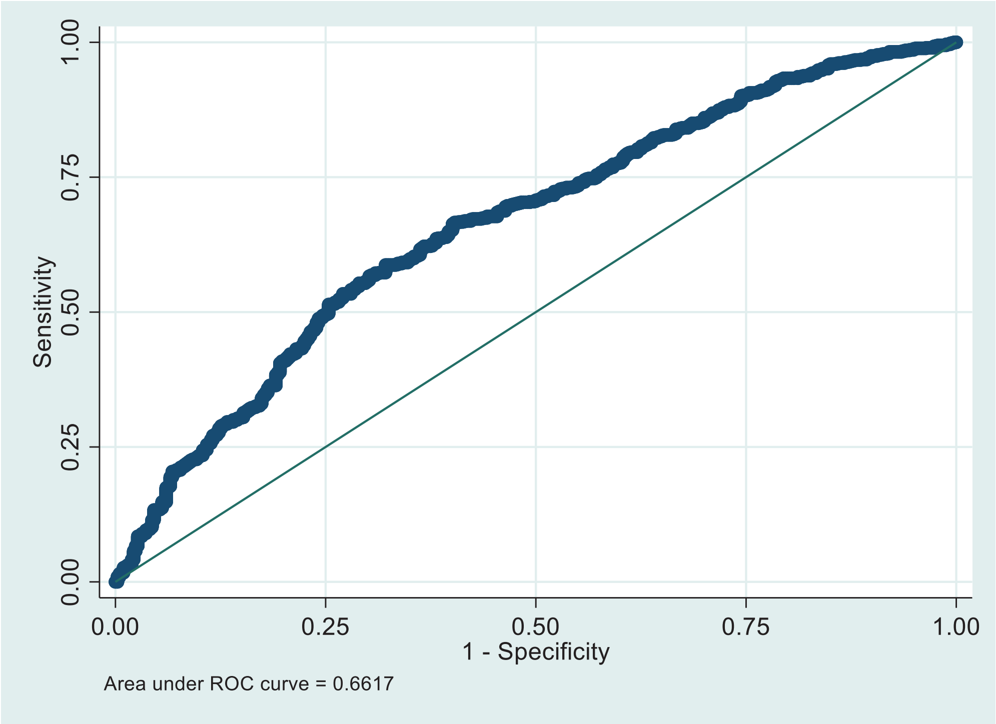
Cases of death

Prediction of deaths due to COVID-19 from ARIMA (0,0,2)

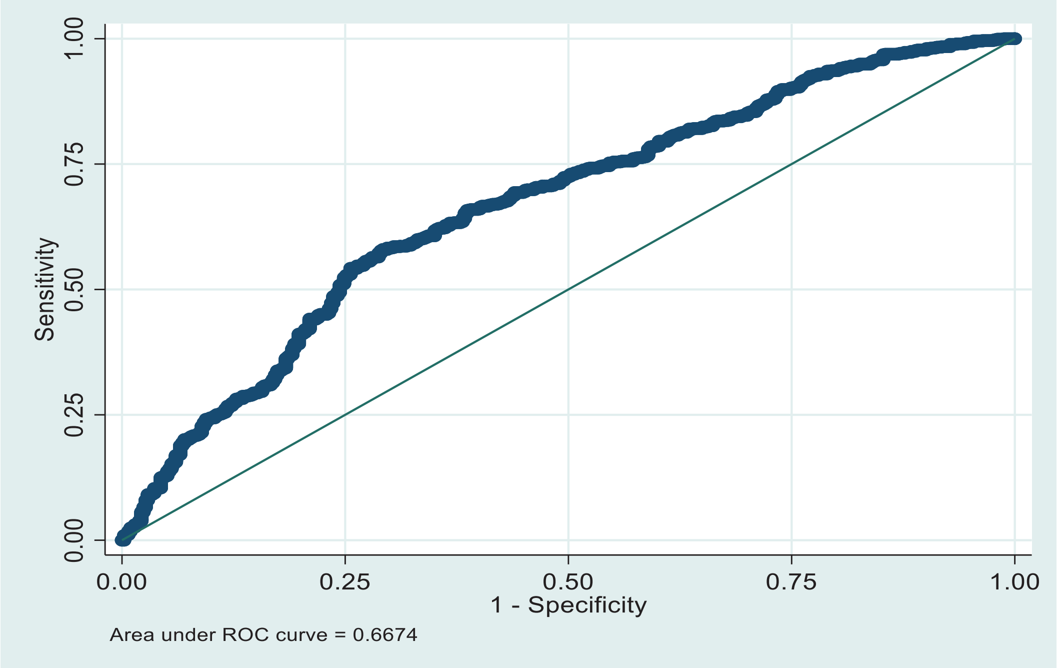


Annex 3

ROC curve - logit 1 model (first quarter)

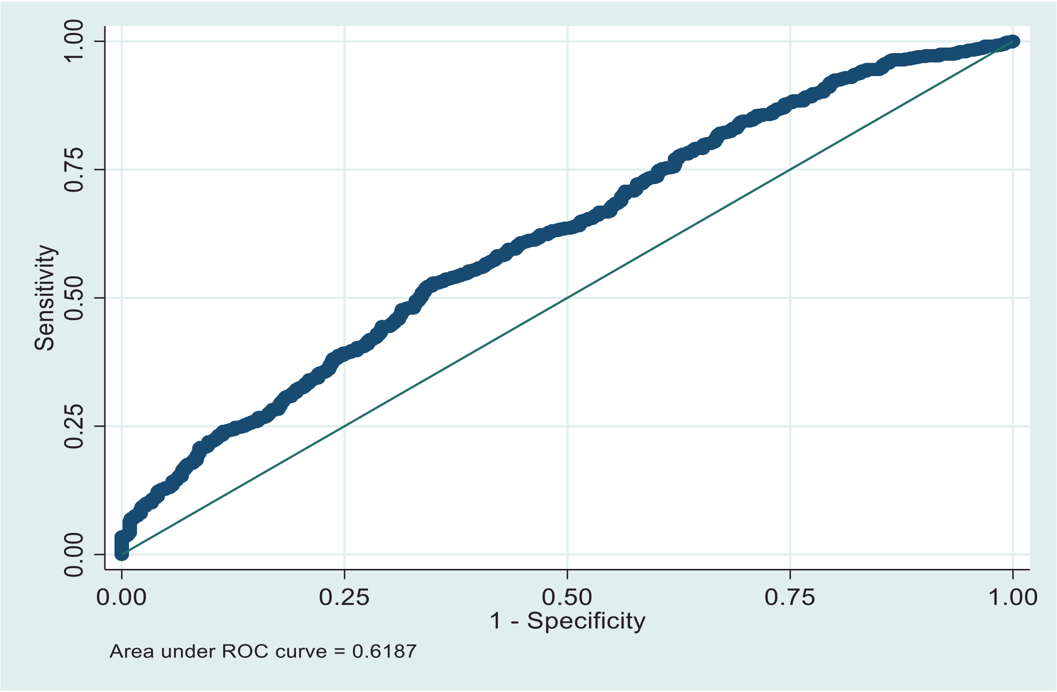


ROC curve - logit 2 model (first quarter)

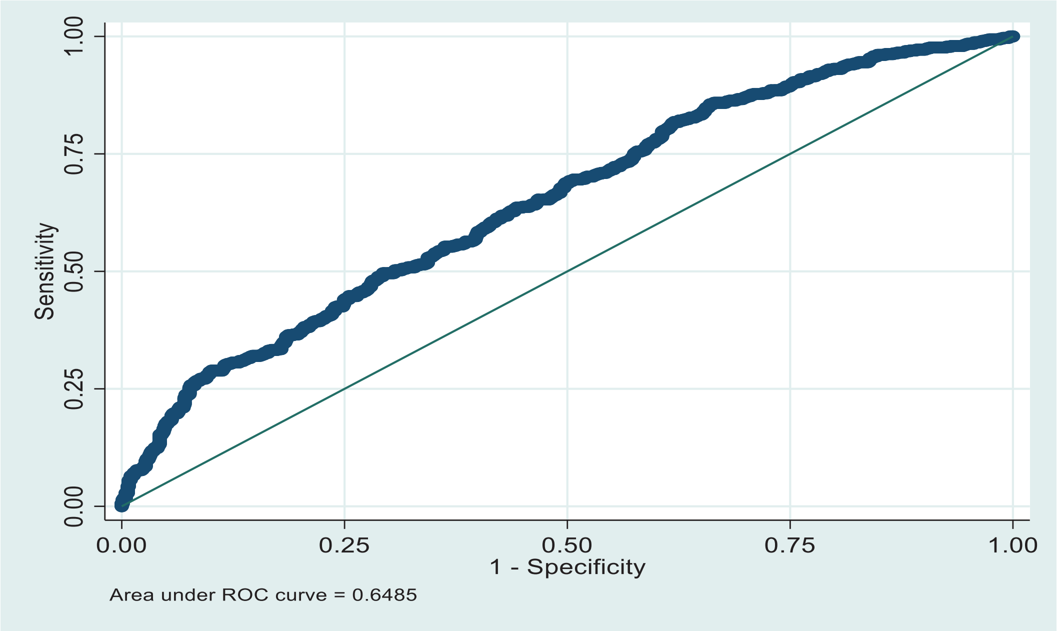


Annex 4

ROC curve - Logit1 model in Q4 2021



ROC curve - Logit 2 model in Q4 2021



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