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Modern Statistical Methods for Infectious Diseases to Analyse Covid-19 Pandemic Data in Rwanda

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Abstract: *The corona-virus ailment 2019(COVID-19) took tens of millions of lives and disrupted dwelling requirements at individual, societal, and international levels, causing penalties globally. Understanding its epidemic curve and Spatio-temporal dynamics is indispensable for the development of tremendous public fitness plans and responses and the allocation of resources. Thus, we performed the analysis of the epidemiological dynamics and spatio-temporal patterns of the COVID-19 pandemic in Rwanda. Using the surveillance bundle in R software version 4.0.2, we implemented endemic-epidemic multivariate time sequence methods for infectious diseases to analyze COVID-19 facts with the aid of Rwanda Biomedical Center, under the Ministry of Health, from March 15, 2020, to January 15, 2021. The COVID-19 pandemic came in waves in Rwanda and showed a heterogeneous spatial distribution across districts. The Rwandan authorities answered effectively and successively through the implementation of more than a few health measures and intervention policies to reduce the transmission of the disease. Analysis of the three factors of the mannequin confirmed that the most affected districts displayed epidemic elements inside the area, whereas the impact of epidemic elements from spatial neighbors had been skilled via the districts that surround the most affected districts. The contamination followed the disorder endemic vogue in other districts. The epidemiological and Spatio-temporal dynamics of COVID-19 in Rwanda show that the implementation of measures and interventions contributed appreciably to minimize COVID-19 transmission inside and between districts. This accentuates the essential name for endured intra-and inter-business enterprise and community engagement nationwide to make a certain effective and efficient response to the pandemic.*

Keywords: *Modern statistical methods, infectious disease, COVID 19 pandemic*

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1. Introduction

In late December 2019, a case of an unidentified disorder was reported in Wuhan, China. Subsequently, the outbreak of the disease developed into a world pandemic, which was declared by means of the World Health Organization (WHO) on March 11, 2020. This unidentified disease, which manifests as severe pneumonia signs with excessive fever, was named "Corona-Virus Disease 2019" (COVID-19) by World Health Organisation (WHO) (Shi et at al., 2020). COVID-19 is prompted with the aid of the infection of the human vascular and respiratory systems by way of the extreme acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This kind of virus, which is in the identical family as SARS-CoV and the Middle East respiratory syndrome, has an intermediate host and is then transmitted to humans. Since its emergence to date

(January 15, 2021), the COVID-19 pandemic has disrupted living requirements at the individual, societal, and international levels, and brought 2,039,464 deaths out of 95,520,875 instances in 191 countries/regions (Benimana et al., 2021). The first case of COVID-19 in Africa was mentioned on February 14, 2020, in Egypt. It was expected that the outbreak of the sickness would severely have an effect on the continent due to the fragile healthcare infrastructure of most African countries, the concomitant presence of non-communicable and communicable illnesses in a number of regions in the continent, and the household socio-demographic characteristics of the severe African population (Bwire et al., 2022).

In Rwanda, the first case of COVID-19 was reported by the Ministry of Health on March 14, 2020 from an indian citizen living in Rwanda and was visited Mumbai (India) few days before (Semakula, et al., 2023). After two months, imported cases (returning residents, travelers, and cross-border truck drivers and their assistants) contributed to two-thirds of the whole 289 confirmed cases. As of January 16, 2021, the disease had killed one hundred forty human beings out of 10,850 validated cases (Semakula et al., 2023).

2. Literature Review

Corona Virus Disease 2019 known as COCID-19 is a novel virus which firstly appeared in Wuhan city of China in December 2019 (Ntambara et al., 2023.). The virus attacks the respiratory system and provokes flu-like symptoms comprising cough, fever, sneezing and ends up by severe pneumonia resulting in various organs complication and respiratory failure linked to death (RoR, 2020). This virus was profoundly spread in china, continues to all parts of Asia and the whole globe based on the movement of people, equipment as well as materials. The disease was continuing to spread and on January 30, 2020 World Health Organization (WHO) called all nations for public health international emergency. Therefore, it took two months where on 11th Mach, 2020, World Health Organization declared the virus as a global pandemic (Ntambara et al., 2023).

The severe Acute Respiratory Syndrome Coronavirus 2 is transmitted by direct contact with an infected respiratory droplet as well as aerosols during sneezing, coughing or during conversation when the distance is less than two meters and this is the same when a person is in contact with infected person's immediate surroundings (Ntambara et al., 2023).

In Africa, the Corona Virus Disease 2019 (COVID 19) was firstly reported on 14 February 2020. From this date up to June 2021 the report shows that more than 5.1 million cases as well as 136,000 deaths were described and this was somehow accelerated by the lack of health care infrastructure in many African Countries. However, in that June 2021, Africa only represents 3 % of worldwide cases and that indicates the less severe epidemiological image of COVID 19 in the African continent (Tessema and Nkengasong, 2021). Correspondingly, many waves of COVID 19 infections were discovered and grown worldwide and by the end of 2021 Africa has experienced four waves of infections but the continent used the surveillance strategies to control this pandemic with the purpose of preventing the spread of disease (COVID 19) (Semakula et al., 2023).

In Rwanda, the first case was reported on 14 March 2020 and this case was detected during preparedness and response measures (Bigirimana et al., 2021). The confirmation of COVID 19 in Rwanda was done before any confirmed case of COVID 19 in Africa. Rwanda had already set up an early warning system and was done in January 2020. This system encompassed travelers' temperature screening and recording at the borders for easy public health tracing. Also, fantastic lockdown measures, contact tracing and monitoring procedures, and extended COVID-19 testing, in addition to the warmer climatic prerequisites and the younger populace shape of the continent, contributed to the control of the epidemic (Semakula et al., 2023).

Correspondingly, Rwanda has used proactive measures against COVID 19. Based on common measures implemented elsewhere, the government of Rwanda has also proactively implemented these measures with the purpose of public health protection. The measures applied include social distancing, face masks, public hand-washing and distribution of hand sanitizers. In addition, temperature screening accompanied by community sensitization as well as systematic infection testing were daily implemented. Based on the results of tests prevailed, partial or national lock-downs were applied as containment measures. The country augmented the entry-point screening, boosting national reference laboratory abilities, improving infection prevention and control practices via district rapid response teams, managing tested cases properly, up surging hazard communication and Rwandan neighborhood engagement, and making sure the provision of operational support and logistics (Karim et al., 2021).

However, Rwanda has experienced different waves of COVID 19 as it was also spread worldwide. The high incidence rate of COVID 19 was observed in the central part of Rwanda in three district of capital city (Semakula et al., 2023).

In addition, a mutant COVID-19 strain, which was moving in the United Kingdom was announed in December 2020. The number of established cases is increasing every day, with higher increases recorded among elderly suffers and/or those with underlying health challenges (Gorbalenya. et al., 2020). As of 19 December 2021, Rwanda counts 102,231 cases of COVID 19 in the population and the female comprised 51% of the cases. Also, the country recorded 1125 deaths where the case of fatality rate was 1.1% and the majority were males 53% (Semakula et al., 2023).

Fortunately, COVID-19 vaccines had been developed by a number of pharmaceutical companies, and vaccination had already begun in developed international locations such as the United States, Canada, and the United Kingdom. As of 1 April 2022, worldwide 64.5% of the population has received at least on dose of vaccine, however in low-income countries it is equals to 14.5%. On the other hand, over 60% of the whole population was vaccinated in Rwanda (Binagwaho and Mathemos, 2022).

3. Methodology

Rwanda is positioned in Central Africa, immediately south of the equator between latitude 1◦ 4′ and 2◦ 51′ S and longitude 28◦ 63′ and 30◦ 54′ E. According to the 2012 Fourth Rwanda Population and Housing Census, the country is subdivided into four (Northern, Southern, Eastern, and Western) geographically situated provinces plus Kigali town (the capital, in the center). These provinces break up into thirty (30) districts, the most essential administrative regions of Rwanda's decentralization system, sectors (416), cells (2148), and villages (14,837), which cowl a 26,338 km2 location that houses 10,515,973 inhabitants (Dehling and Sinsch, 2023).

For the analysis, we used COVID-19 facts collected from March 15, 2020, to January 15, 2021, for a total of ten months. We used the time-series models of cumulative and everyday numbers of proven COVID-19 instances and deaths supplied via the Rwanda Biomedical Center (RBC) under the Ministry of Health.

Rwanda Biomedical Center (RBC) revises and updates the information each and every day after amending for likely errors, and the records are posted on the RBC website and the reliable Twitter account of the Ministry of Health. Regarding the population data, the 2012 Fourth Rwanda Population and Housing Census, which is the most recent, was used. For the document of COVID-19 data, Kigali city, which includes the Gasabo, Kicukiro, and Nyarugenge districts, was once viewed one district named 'Kigali'. Therefore, the map covered 28 districts.

3.1 Statistical analysis

In this study we used a simple systematic review protocol. PubMed and RevMan were searched using the terms and Boolean operators: (infection fatality rate) and (COVID-19 OR SARS-CoV-2). Using PubMed database keywords were developed and searched and would usually be excluded from systematic review, given that the papers included are not been peer-reviewed, during the pandemic it has been an important source of information and contains many of the most recent estimates for epidemiological information about COVID-19. Inclusion criteria for the studies were: - Published in English - Regarding COVID-19/SARS-CoV-2 (i.e. not SARS-CoV-1 extrapolations) presented an estimated infection-fatality rate.

We carried out the endemic-epidemic multivariate time series methods for infectious illnesses proposed with the aid of Held et al. and accelerated as developed a variety forms in various papers. The composition of the equation represents the model with matter information for the range of new cases ya, t, from areal units a = 1, …, A at time collection t = 1, …, T, which has a terrible binomial distribution with mean μa, t and over-dispersion parameter ψa > 0, where μa, t = λa, tya, t—1 + φa,t wr,ayr,t—1 + νa,t, λa, t, φa,t , νa, t > 0 (1)

r=1⁄μa and the conditional variance of νa, t is μa, t (1 ψaμa, t).

The weights wr, a are assumed to be recognized and determine how cases between other areas are related. We define the weight as 1 if place r is the first-order local with place a, and 0 otherwise. This wide variety displays the geographical information only so that the weight is not time dependent. According to Held et al. (2014), the first two terms capture occasional outbreaks in area a. The first component, which is known as 'within-epidemic', describes the effect of the disease's temporal dynamics to the anticipated variety of infections within district a. It carries the number of infections recorded in the identical district on the preceding day (time t – 1) ya, t—1, which impacts the suggestion of the distribution μa, t based totally on the price of the multiplicative coefficient λa, t > zero and this λa, t varies among the districts via skill of a random effect which approves of heterogeneous conduct in the evolution of the infections.

The 2nd component, which is called 'between-epidemic', fashions the impact of neighboring districts through counting in the average incidence of infections yr, t—1 of districts r on the previous day (time t – 1) which are neighbors of district a. The weighted common of incidence fees introduced into the mannequin as the coefficient wr, a is high-quality if either district a and district r have the equal border or if both share a border with the identical district, while wr, a is zero otherwise. The multiplicative coefficient φa, t, which determines the magnitude effect of the average incidence price of the neighboring districts on the expected range of infections μa, t, differs among districts in line with the population and unobserved heterogeneity in the transmission of the virus.

The last aspect va, t, which is called the 'endemic component', describes a steady temporal sample and district-wise contribution to the wide variety of infections, as soon as the within-epidemic and between-epidemic effects are accounted for, whilst heterogeneity among districts is introduced into the mannequin by means of potential of a random effect. The proportions of within-epidemic (autoregressive), between- epidemic (Spatio-temporal), and endemic aspects are the average of λa, tya, t 1/μa, t, φa, t wr, ayr, t 1/μa t, and va, t/μa, t over time, respectively.

The three averaged proportions are supplied in shown figures, the within-epidemic component,λa, tya, t—1 is marked in blue, and the between-epidemic element φa,t wr,ayr,t 1 is marked in orange, and the endemic element va, t is marked in gray. Meyer et al. (2020) proposed the decomposed Eq. (1) in log-linear sorts in all three different components:

log λa,t) = γa(λ), (2)

log φa,t) = γa(φ), (3)

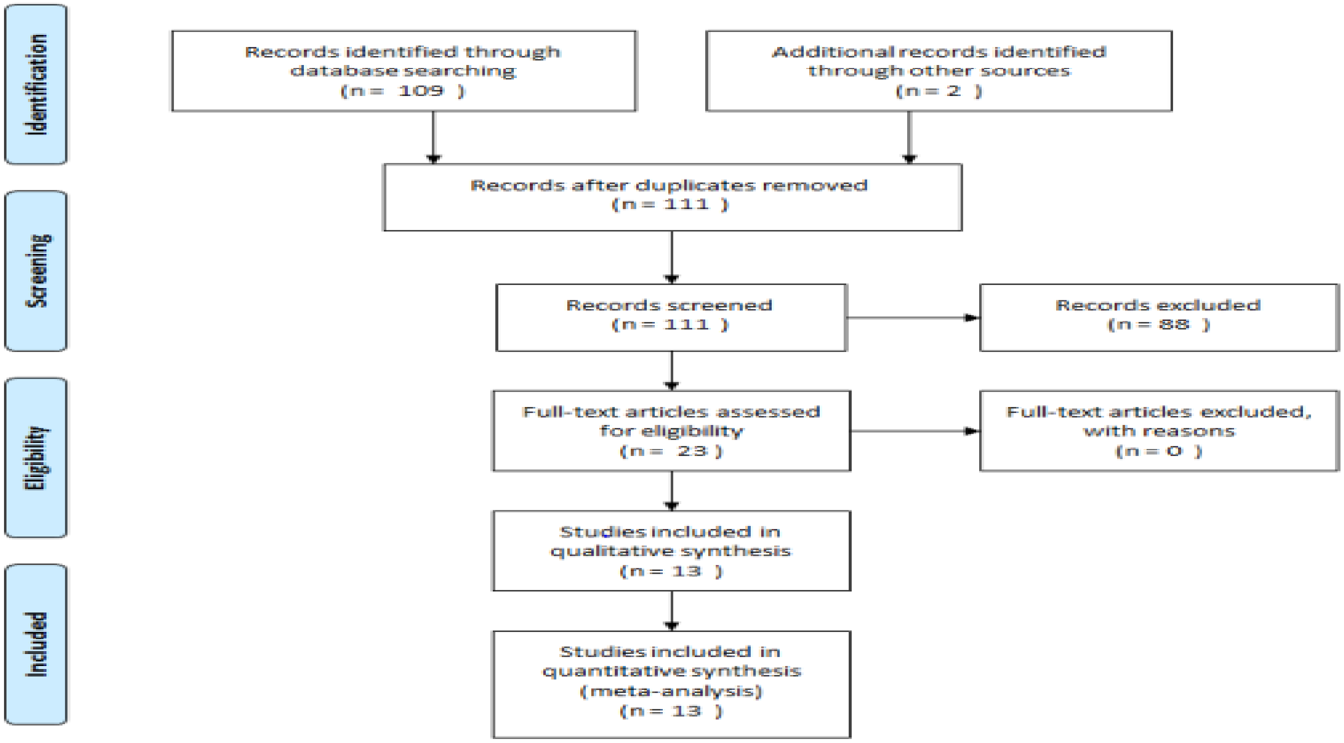
log va,t) = γa(v) + log ea,t), (4)

Where λa, t is the auto-regressive effect in vicinity a and ea, t is the population fraction in location a at time t. The three elements {γa(λ), γa(φ), γa(v) in Eqs. (2) to (4) describe areal unit-specific intercepts following ordinary distributions which are represented by {γa(λ)~ iid N γ(λ), σ2), γa(φ)~ iid N γ(φ), σ2), γa(v)~ iid N γ(v), σ2)} Ac-

transmission of COVID-19, the Rwandan authorities set up a multi- disciplinary crew in late January 2020 to complicated preventive and responsive measures, continually communicate risk, and engage the community. After the first confirmed case was reported, the Rwanda government via the Ministry of Health at first implemented preventive measures for a two-week period to in addition curb the transmission of COVID-19. The measures included the closure of all schools and greater training institutions, worship places, and nightclubs; post- ponement of massive gatherings; restriction of needless movements; and the use of the 114 toll-free variety to document suspected COVID-19 symptoms.

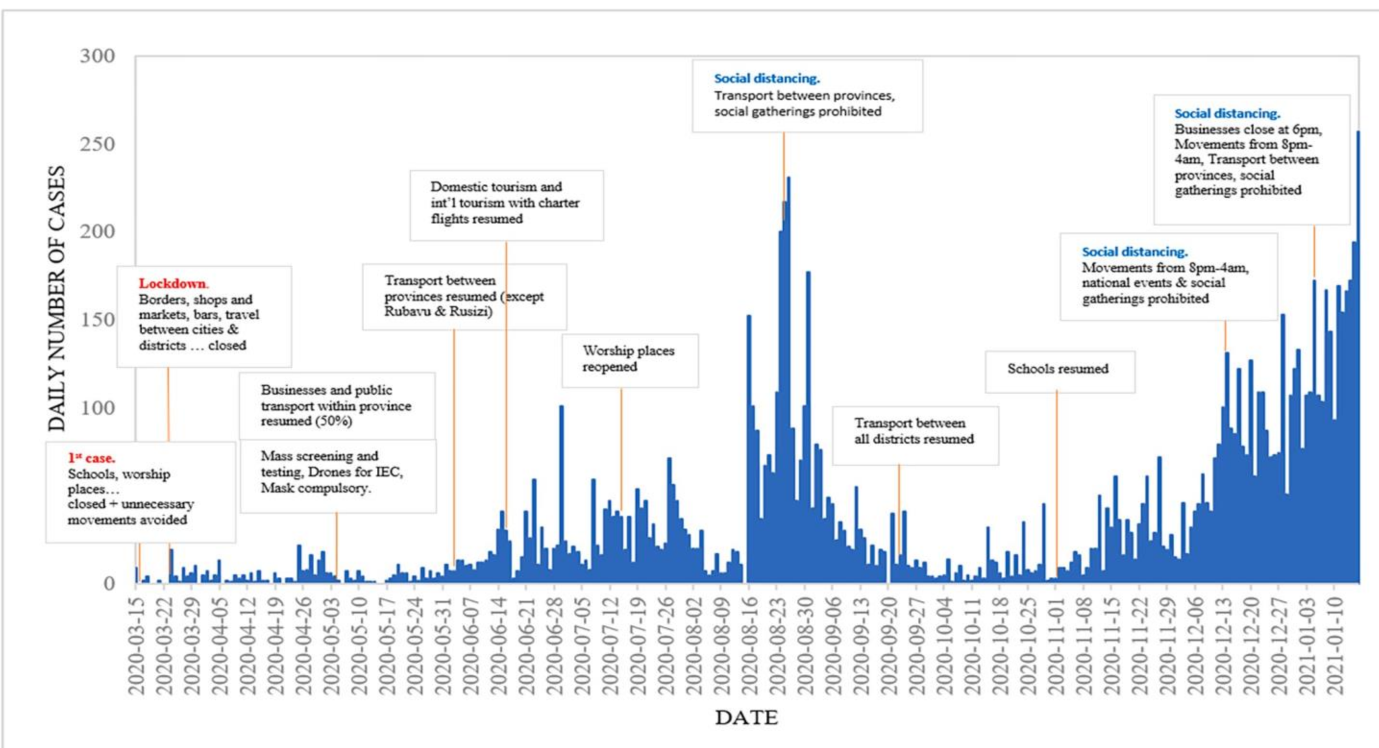
All analysis and data transformation were performed in R software version 4.0.2. The meta-analysis was performed using the command for continuous estimates. Initial searches identified 109 studies in both databases. Searches on Google and social media revealed a further two estimates to include in the study. There were no duplicates specifically, however two preprints had been published and so appeared in slightly different forms in both databases. After screening titles and abstracts, 88 studies were removed. 23 papers were assessed for eligibility

For inclusion into the study, resulting in a final 13 to be included in the qualitative synthesis and meta-analysis.



A PRISMA flow diagram of the search methods

Fig. 1. Daily COVID-19 confirmed cases in Rwanda with various policy interventions from March 15, 2020



To January 15, 2021. In addition to lockdown and other preventive measures including social distancing, ban on social gatherings, and transport between provinces and/or districts prohibition had of great effect in the control of the COVID-19 pandemic in Rwanda.

4. Results and Discussion

A descriptive evaluation of COVID-19 coverage responses over time Fig.1 suggests the policy response to the COVID-19 outbreak over time in Rwanda, starting from the beginning of the pandemic. To restrict the measures, such as restriction of public transportation and non-vital travel between cities, and closure of shops, markets, bars, and non-essential businesses. With the resource of the police force, these lockdown measures were observed until May 3, 2020, when the full lockdown ended and curfew measures had been established.

In June 2020, home travel and global tourism for traffic with charter flights resumed nearly in all provinces besides Rubavu and Rusizi districts. International flights resumed on August 1, 2020. Since then, the Rwandan government continued to raise or reinstate lockdown/restrictions periodically in extraordinary districts and villages primarily based on the consequences of non-stop chance assessment. To halt the first wave of the outbreak, which passed off in mid-August and primarily in Kigali city, mass gatherings and public transport between Kigali and different districts were tested and sensitized. After an excellent decline in cases, transport between all districts and provinces resumed on September 25, 2020 and schools resumed in November 2020 based on levels of education. Following the upward push in COVID-19 instances and deaths in late November 2020, the authorities tightened existing health measures to further include the unfolding of the disease. In mid-December 2020, all countrywide events had been postponed, and all social gatherings had been prohibited in public and non-public settings. Specific measures were carried out in Musanze district, which was once experiencing an unusual upsurge in COVID-19 instances for three weeks. In the first week of January 2021, in addition to the existing measures, public and non-public transportation to and from Kigali city, and between exceptional districts, was prohibited without med ical and imperative services. In addition, all commercial enterprise organizations had been directed to close operations by using 6 pm each day for two weeks. Upon assessment of the persistent unparalleled upward push in cases, deaths, and transmission rates in communities, especially in Kigali city, the capital used to be put underneath lockdown, and citizens in the other components of the United States have been urged to drastically cut back social interactions and limit moves to solely those for quintessential services.

General description of the epidemic curve in Rwanda from March 15, 2020, to January 15, 2021, the variety of confirmed instances recorded in Rwanda was 10,573 (male: 6,777; female: 3,796). The COVID-19 epidemic curve and its respective time-varying replica numbers (Rt) are depicted in Fig. 2, whereas the geographical distribution of the cumulative COVID-19 incidence is introduced in the map in Fig. 3. Since the report of the first proven COVID-19 case, Rwanda has skilled two waves of the pandemic. The first wave came about in mid-August 2020 and hit its height on August 26, 2020. This wave usually happened in the central section of Rwanda (capital: Kigali city) and the southwestern phase of the country (Rusizi District). The outbreak in Kigali town was associated with the two large markets in Kigali (Kigali metropolis market and Nyabugogo market), whereas that in Rusizi District used to be associated to the motion of truck drivers to/from Bukavu and each day trip of Rwandans to Bukavu, a city in the neighboring Democratic Republic of Congo. Other increases in instances recorded in the country, mainly in the capital city, had been associated with villages underneath lockdown, high-risk isolated clusters, and the Kigali Transit Center cluster. After a two-month length of first-rate reduction in cases considering late November 2020, the country started experiencing the second wave of the pandemic since people had started to let their shield down and stopped adhering to health measures and guidelines.

Fig. 2 suggests the international locations in Africa and the geographical distribution of the cumulative incidence of COVID-19 in Rwanda. The figure displays a clear heterogeneous spatial pattern, with the central region in Kigali town (Gasabo, Kicukiro, and Nyarugenge districts) having the absolute best cumulative incidence in case of (5.4 cases per 1000 people), followed by Rusizi (southwest region) (2.4 instances per a thousand people) and Rubavu (northwest region) (1.5 instances per a thousand people) districts. These districts were the most affected boroughs, whereas Rutsiro, Nyaruguru, and Ruhango districts tended to have low incidence compared to other districts.

The detailed range of validated instances in every district is in the supplementary desk.

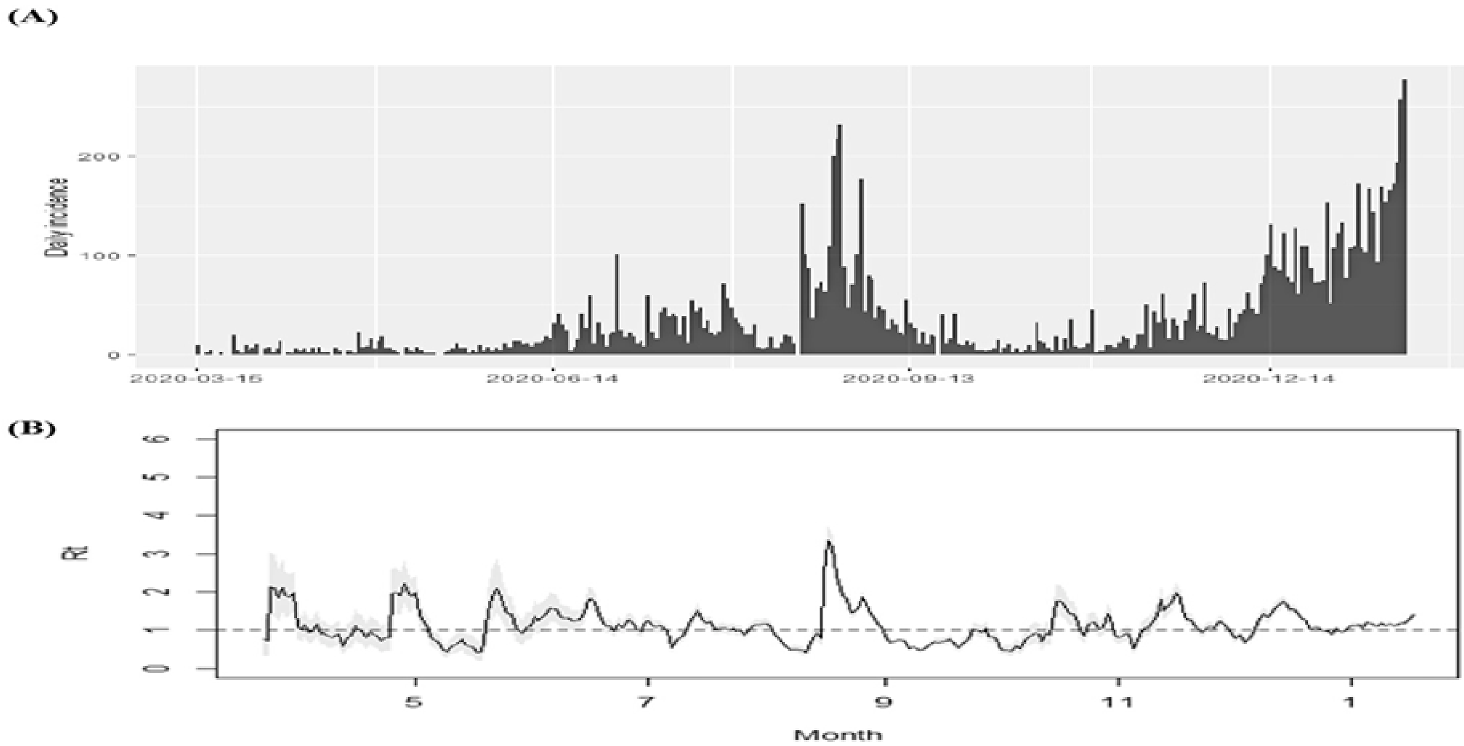


Fig. 2. Epidemic curve of COVID-19 confirmed cases in Rwanda from March 15, 2020 – January 15, 2021. (A) Daily incidence cases due to COVID-19. (B) The basic reproduction number (R_T) of COVID-19. Rwanda experienced two waves of the COVID-19 pandemic in mid-August and late November 2020 respectively.

The burden of cases/deaths refers to the variety of cases/deaths of a given age group in a completely wide variety of instances or deaths. Regarding the range of demonstrated cases, human beings in their 20s and 30s account for more than half of the whole burden of COVID-19 infection in Rwanda. This is due to the fact the demographic structure of Rwanda indicates that there are considerably greater younger humans in Rwanda than the elderly. It is remarkable that the total burden of COVID- 19 decreases with increasing age. Regarding the range of deaths, the male burden in the total number of COVID-19 deaths is approximately three times higher than the burden of ladies (74.6% vs. 25.4%). Adding to the truth that guys have weaker immune systems than females, any other practicable reason for this statistic is that men tend to be more exposed to the virus due to daily-life socio-economic elements like employment exposures than their counterparts.
The results additionally showed that human beings aged 60 years and above account for more than 1/2 of the total burden of COVID-19 deaths in Rwanda. This is comparable to the re- ported effects of COVID-19-related mortality in countless other countries, which point out that the mortality fee is excessive among the aged.
The effects of the present learn about are comparable to these of some previous studies, which indicated higher odds of morbidity and mortality among males than females. The wide variety of tested instances and deaths per million people used to be 1005.4 and 13.1, respectively, whereas the wide variety of validated cases as a share of assessments used to be 1.3 in 74.6 tests per thousand people.

Spatio-temporal endemic-epidemic modeling

Fig. 3 offers the estimated expected wide variety of infections of three components, a) within-epidemic impact (autoregressive), b) between-epidemic effects (Spatio-temporal), and c) endemic effects. The figures exhibit that only a few districts in general affected via the pandemic (Kigali, Rusizi, and Rubavu), are basically influenced via the epidemic transmission inside the area (map (A) on the top). In a few districts that adjoin the capital city, Kigali, the transmission of COVID-19 is explained through the epidemic tendency from neighboring districts (map (B) in the middle), whereas the infection did path the endemic sample in essence in the majority of the closing districts (map (C) at the bottom).
In order to test the goodness-of-fit, we

used probability critical transformation (PIT) and we found out that it is shut to a uniform distribution [34].We ave selected the fine prediction performance as our mannequin and we stated, in addition, important points in the supplementary figure (Fig. S2). The point and 95% self-belief intervals estimate of every parameter are as follows: within-epidemic (1.05, 95% CI: 1.50 to 0.59), between-epidemic (4.58, 95% CI: 5.62 to 3.54), endemic (0.93, 95% CI: 0.23 to 1.63), and overdispersion parameter (6.60, 95% CI: 6.00 to 7.19).

Fig.4 portrays the estimated common number of cases in accordance to the model, accompanied by using the found range of cases in the Rwandan districts. It shows consistency with the effects proven in Fig. 3 and relates to the coverage intervention outlined in Fig. 1.

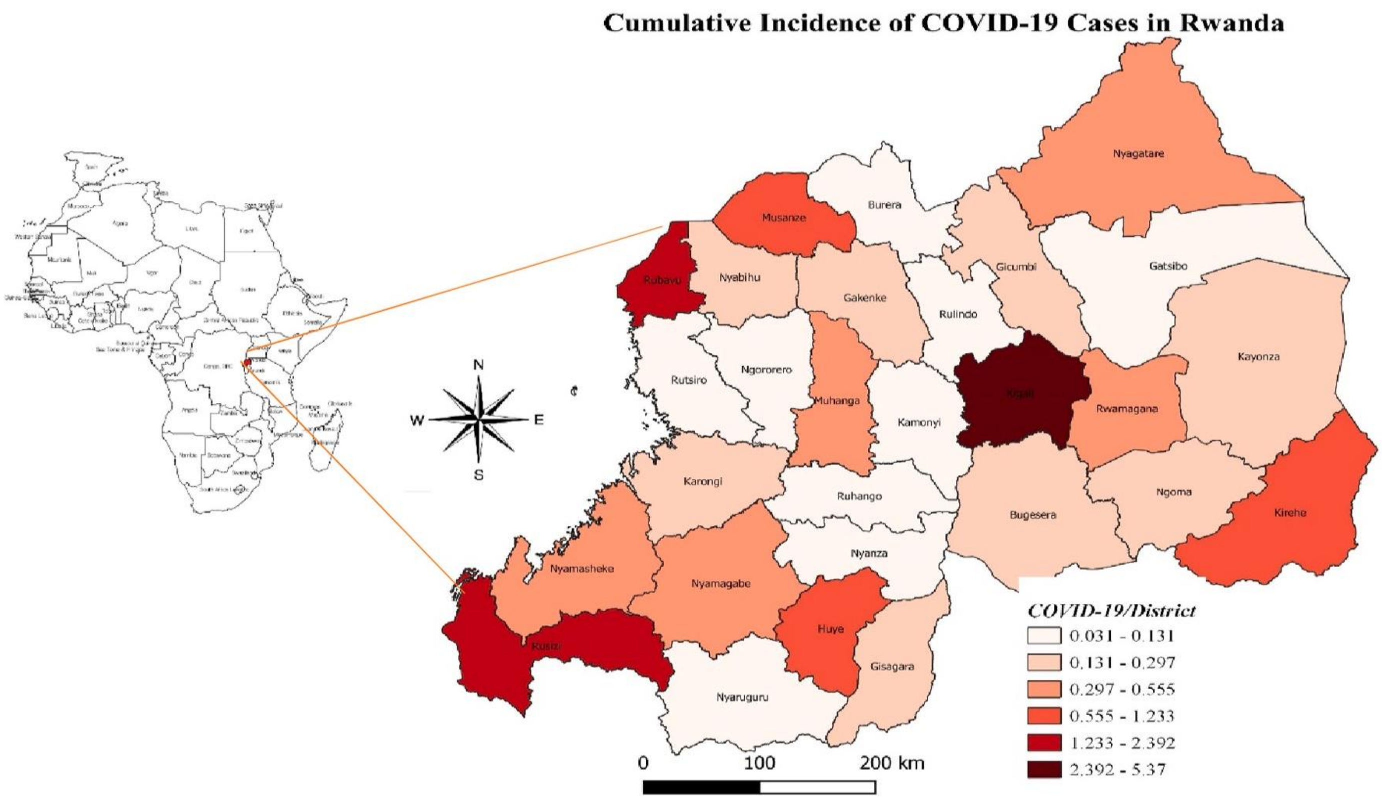


Fig. 3. Left. Map showing the location of the countries in Africa and the red area indicates Rwanda location. Right. Cumulative incidence of COVID-19 cases per 1000 people by district in Rwanda, March 15, 2020 –January 15, 2021. Kigali city, Rusizi, and Rubavu had the highest COVID-19 cumulative incidence in the country whereas Rutsiro, Nyaruguru, and Ruhango districts had the lowest cumulative incidence. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Table 1.

Number of COVID-19 confirmed cases, deaths and their absolute burden in Rwanda.

MALES FEMALES

Age group (yrs)	Number of confirmed cases	(% share)	Number of deaths	(% share)	Number of deaths	(% share)
< 20	1292	(12.2)	0	(0.0)	2	(1.4)
20-29	3094	(29.3)	3	(2.2)	3	(2.2)
30-39	3071	(29.0)	5	(3.6)	2	(1.4)
40-49	1754	(16.6)	17	(12.3)	8	(5.8)
50-59	814	(7.7)	20	(14.5)	3	(2.2)
60-69	355	(3.4)	23	(16.7)	7	(5.1)
70-79	133	(1.3)	21	(15.2)	5	(3.6)
80 and above	60	(0.5)	14	(10.1)	5	(3.6)
	10573		103	(74.6)	35	(25.4)

Confirmed cases per million people 1005.4
Confirmed deaths per million people 13.1
Confirmed cases as a proportion of tests 1.3
Test per thousand people 74.6

Note: Percentages of share representing the absolute burden of age group-specific and sex-specific in a total number of COVID-19 cases or deaths.

The world is currently experiencing the third wave of the COVID-19 pandemic, which will be recorded as a fundamental catastrophe for cutting-edge humans.

Transmission of COVID-19 is unpredictable and continues to exhibit repeated will increase and decreases. In this study, we statistically analyzed COVID-19 facts collated over 10 months in Rwanda via modeling COVID-19 epidemiological dynamics and Spatio-temporal patterns, resulting in the observation of differences in the time and space-specific dynamics of COVID-19. Our results published that the districts most affected through the disorder were predominantly influenced by the epidemic infections inside the area, whereas few districts that are neighboring to the capital metropolis had been affected via the epidemic effect from neighboring districts; the majority of the closing districts followed the endemic trend. This proof is in concord with the fitness measures and interventions carried out to curb the spread of the disease.

The first wave of the pandemic, which passed off in mid-August, hit ordinarily Kigali city, and given the social distancing measures implemented throughout that period, the capital town skilled endogenic transmission and an incredible reduction in range of established cases. Rusizi District was once additionally affected through this wave. The authorities prohibited both public and private transportation to and from the district and public transport within the district to manage the infection. This isolation resulted in a discount in the wide variety of verified cases and the predominance of epidemic transmission inside the area. Rwamagana and Gicumbi districts experienced the epidemic element with the aid of borrowing it from the neighboring Kigali city. However, the two districts skilled the epidemic issue within the area after the prohibition of transportation between provinces in late August 2020.

The second wave of the pandemic started out in late November and hit many districts of the country, normally due to a two-month period of super decrease in cases that brought about human beings to let them defend down and cease following health measures and guidelines. Kigali endured to experience an important increase in the range of COVID-19 cases. Rubavu district additionally experienced this wave more often than not owing to residents returning from the neighboring Democratic Republic of Congo and contact with contaminated people in Musanze district. Another primary motive of this wave used to be the spike in the spread of the sickness in prison clusters in the country, together with Nyarugenge jail in Kigali, Huye jail in Huye district, and Muhanga and Rwamagana prisons in their respective districts.

After comparing the consequences of studies that analyzed the contemporary kingdom of the COVID-19 pandemic in Africa the use of spatial or Spatio-temporal analysis, we determined that one learn about verified that climatic conditions (wind speed) have a fantastic relationship with the unfolding of COVID-19 the usage of a generalized additive model. Another learns about confirmed that the pandemic varies geographically throughout the continent, with high incidence in neighboring nations mainly in West and North Africa.

Those preceding studies normally discovered the current reputation of COVID-19 in Africa. Another learn about indicated that the geographic variability and Spatio-temporal unfold of COVID-19 have been found in Libya, North Africa. Unlike previous studies, it is meaningful that our learning about focused on Rwanda and we assessed the modern popularity and sample of the COVID-19 pandemic thinking about policy intervention in time and space. Understanding the epidemic curve and Spatio-temporal dynamics of COVID-19 will momentously help public health decision-makers to strengthen fine public fitness plans and responses. Our findings are in accordance with the results of the assessment of the measures and interventions carried out to drastically limit COVID-19 transmission in the community, both inside and between Rwandan districts. Additionally, the findings of this learn about can be used in future lookups on ailment modeling in time and space.

This find out about has certain limitations, which be noted. First, although we mentioned the policy response vis-à-vis COVID-19 and modeled the unfolding of COVID-19 in Rwanda, the fact that the variety of proven COVID-19 instances in Rwanda is usually now not as high as that in different international locations should be taken into account in the consideration of our results. Thus, we had to model the spread of infections in a few districts that had notably larger numbers of instances than others. Second, we should now not analyze the burden of sex in the whole wide variety of cases and behavior as an extra superior and particular evaluation because the dataset no longer consists of information on established COVID-19 cases in accordance with sex. Other constraints to think about are the confined records and studies about the repute of COVID-19 in the Democratic Republic of Congo, the effect of the Republic of Tanzania's denial of the existence of COVID- 19, and the country's refusal to follow public fitness measures towards COVID-19 and report the range of tested COVID-19 instances to neighboring countries, consisting of Rwanda, and to the world.

Furthermore, the lack of individual mobility statistics in the existing learn about was once any other hassle to advanced Spatio-temporal analyses closer to public fitness response at both person and population levels. However, this evaluation of the effects of the epidemic, endemic, spatio- temporal analyses, and coverage intervention in each location in Rwanda is considered big to grasp and assess the effectiveness of the implemented coverage interventions by means of the authorities of Rwanda, modeling the fashion of COVID-19 epidemics in time and space by using identifying when and which districts are greater affected than others and letting public fitness decision-makers intervene at national and nearby level.

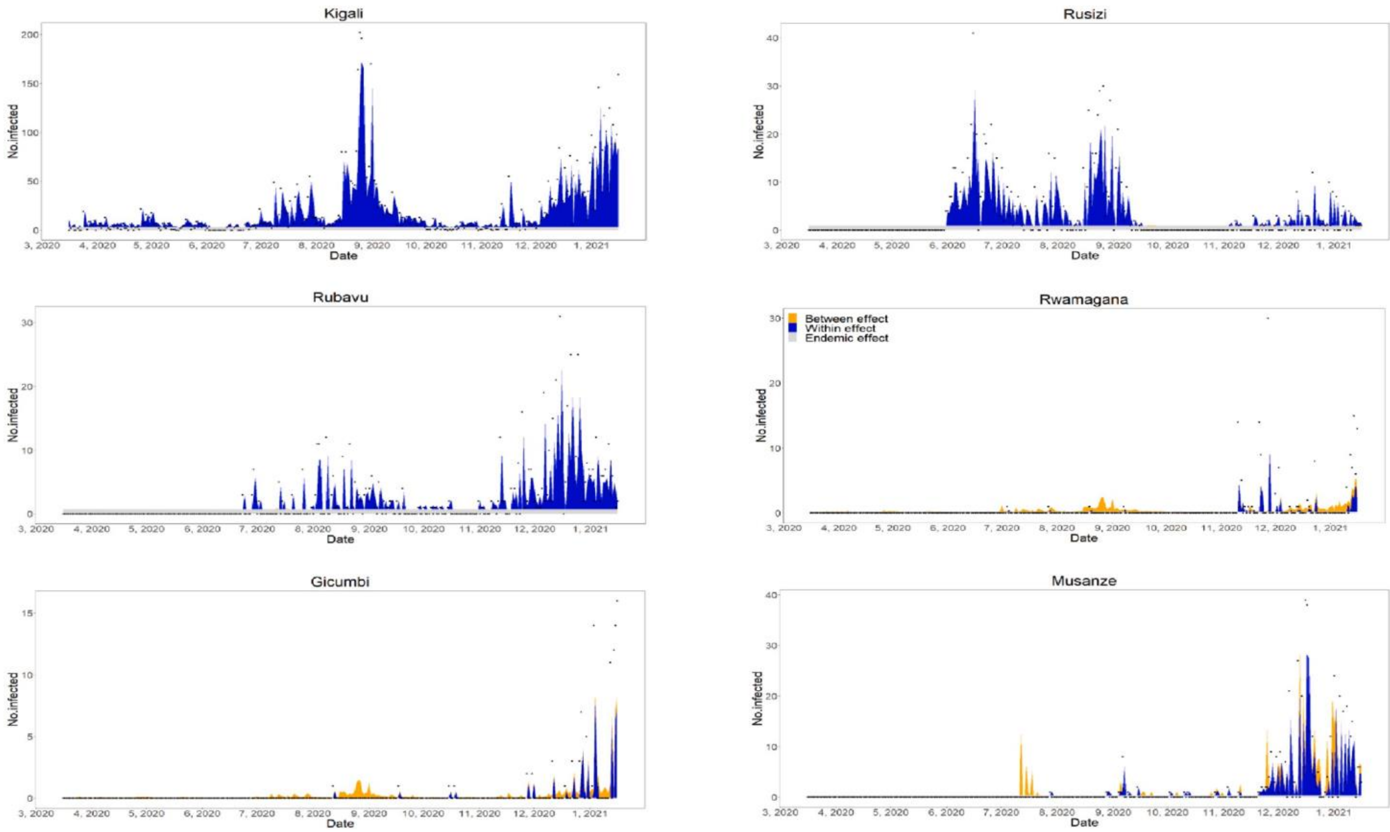


Fig. 4. Plots of three components (spatiotemporal, autoregressive, and endemic) in six districts in Rwanda. The dots represent the number of daily confirmed cases. The blue color represents the within-epidemic component (autoregressive). The orange color characterizes the between-epidemic component (spatiotemporal). The gray color shows the endemic component. Kigali, Rusizi, and Rubavu (districts most affected by COVID-19) experienced the domination of within-epidemic component while Gicumbi, Rwamagana, and Musanze districts showed the between-epidemic component predominance. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5. Conclusion and Recommendations

In the current study, the analysis of the epidemiological and spatio- temporal dynamics of the COVID-19 pandemic in Rwanda confirmed that the pandemic is being regulated and controlled to some extent via the government's efforts and the cooperation of the citizens. A week after the first case was once suggested in Rwanda, the government carried out whole nationwide lockdown till May 3, 2020. Since then, the authorities continued easing and/or reinstating of local lockdown measures or restrictions, advised mandatory use of face masks in public at all times, and initiated other health measures and suggestions to include the unfolding COVID-19. Nationwide emphasis on vaccination, persevered intra- and inter-organization, neighborhood engagement, and intervention coverage have to be crucially accentuated to control and contain this pandemic. Additionally, grasp and modeling the epidemical and Spatio-temporal dynamics of COVID-19 can aid public health decision-makers in the allocation of sources and the development of wonderful public health plans and responses at the nearby stage to make a certain tremendous and environment-friendly responses to this pandemic.

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