Status of the COVID-19 Pandemic in Kenya: Evidence from serological and clinical surveillance, and predictive modelling

INTRODUCTION

Kenya is on the 24th week of the COVID-19 pandemic since the first confirmed case on the 13th of March 2020. Evidence on the current status of the pandemic and predictions on the outlook are useful in informing government response. In this brief, we integrate and summarize the latest findings from three linked packages of work that KEMRI-Wellcome Trust is conducting arising from a request from and collaboration with the Ministry of Health. These are 1) serological surveillance, 2) clinical surveillance, and c) predictive modelling of COVID-19.

SERO-SURVEILLANCE OF SARS-CoV-2 IN KENYA

What antibody testing can tell us about COVID-19

- Active virus infection can be detected by running PCR tests on nose/throat swab samples. The test stays positive for about two weeks.
- Whether a person has been infected before can be detected by testing the blood for antibodies. Antibodies are thought to stay positive for several months
- Testing a sample of the population for antibodies tells us how many people have already been exposed to the virus at some time in the past.

Antibody test development and validation

- KEMRI-Wellcome has established an antibody test based on protocols developed by collaborators in the USA
- We optimized the assay using blood samples obtained before the COVID-19 pandemic (negative controls), and blood samples obtained from PCR confirmed SARS-CoV-2 positive cases (positive controls).
- Sensitivity of the assay was 83·0% (95% CI: 59·0-96·0%) and specificity was 99·0% (95% CI 98·1-99·5%)

Blood donor samples

- The ideal way of estimating exposure to COVID in the Kenyan population would be visiting randomly selected homesteads to collect and then test blood samples. This has not been practical under current restrictions.
- Blood donors are a convenient sample of the community.
- Blood donors may differ from the general population (such as age, sex and health status), so we may not be representatively sampling the Kenyan population.
- The blood samples used in this analysis were donated between 30/04/2020 and 16/06/2020 (median 27/05/2020)

Key Messages

- Antibody testing of 3098 blood donor samples that were donated between 30/04/2020 and 16/06/2020 (median 27/05/2020) found adjusted prevalence of antibodies to SARS-CoV-2 was 5.2%
- Seroprevalence was highest in the 3 largest urban Counties; Mombasa (9.3%), Nairobi (8.5%) and Kisumu (6.5%).
- Clinical surveillance of severe acute respiratory infections found that County hospitals have not experienced a surge in hospital admissions compared with previous years.
- The surveillance also observed that the number of inpatient deaths has remained relatively stable during the pandemic.
- Predictive modeling found that the pandemic peaked on May 30th in Mombasa County and July 10th in Nairobi. The rate of new infections is now declining in these two counties.
- The modelling also predicts that about 40.9% (CI 24.3%-54.7%) of the Nairobi population, and 33.8% (CI 23.7-46.5%) of the Mombasa population would be have been infected with SARS-CoV-2 at the beginning of August 2020.
- Such levels of virus exposure are predicted to be associated with herd immunity in these urban populations.
- It is likely that transmission will increase in the future (a second wave) if population mobility continues to rise, transmission continues in less risky sub-populations, or if immunity is short lived, leading to a rebound in reported cases.
- We expect that by end of December 2020 cumulatively, less than 1000 deaths in Kenya will be attributed to COVID-19.
- In addition to the two main Kenyan city counties, the rate of new infections in the counties neighbouring Nairobi (Kajiado, Kiambu and Machakos) and Mombasa also peaked before August 2020.
- However, the infection rate is predicted to still be rising in other more rural counties, most notably in Rift valley, Eastern and North Eastern counties.
- Because of the lag between infection and the observability of the infected person (whether by PCR test, serology test, or death), we estimate that both daily PCR positive test detections and daily observed deaths attributed to COVID-19 across all of Kenya peaked in early August 2020.

Key findings from sero-surveillance

- We estimate that 1 in 20 adults in Kenya had SARS-CoV-2 antibodies during the study period (table 1). By the median date of our survey, only 2093 COVID-19 cases and 71 deaths had been reported through the national screening system.
- The adjusted prevalence of antibodies to SARS-CoV-2 among 3098 blood donors in Kenya aged 15-64 years was 5.2% (95% CI 3.7, 7.1%).
- Seroprevalence was highest in the 3 largest urban Counties; Mombasa (9.3% [95% CI 6.4, 13.2%)], Nairobi (8.5% [95% CI 4.9, 13.5%]) and Kisumu (6.5% [95% CI 3.3, 11.2%]).
- The analysis should be interpreted with caution given the limitations previously acknowledged. e.g. if blood donors are more mobile and more exposed than the general population then we would over-estimate the exposed population.
- Many more samples including sources outside blood donors are required to make confident conclusions. These include asymptomatic and symptomatic PCR-positive cases, frontline workers in the health and non-health care sectors, ANC clients and ultimately, from the general population.

Table 1: SARS-CoV-2 IgG antibody seroprevalence estimates by participant characteristics and geography in 8 regions

	All samples	Seropositive samples	Crude seroprevalence % (95% CI)	Kenya population (2019 Census)	Directly standardized seroprevalence % (95% CI)	Bayesian population weighted seroprevalence % (95% CI)	Bayesian population weighted, test-adjusted seroprevalence % (95% CI)
Age							
15 - 24 years	808	49	6·1 4·5 - 7·9	9,733,174	6·3 4·0 - 8·6	5·1 3·7 - 6·9	**5·3 3·5 - 7·8**
25 - 34 years	1242	66	5·3 4·1 - 6·7	7,424,967	4·3 2·5 - 6·2	4·9 3·6 - 6·4	**5·1 3·5 - 7·3**
35 - 44 years	714	50	7·0 5·2 - 9·1	4,909,191	6·3 3·3 - 9·3	5·9 4·3 - 8·1	**6·2 4·1- 9·3**
45 - 54 years	263	9	3·4 1·6 - 6·4	3,094,771	1·3 0·0 - 3·4	3·8 1·9 - 6·0	**3·9 1·5 - 6·7**
55 - 64 years	71	0	0	1,988,062	0 0	3·4 0·7 - 6·2	**3·7 0·7 - 7·0**
Sex							
Male	2540	146	5·7 4·9 - 6·7	13,388,243	4·8 3·9 - 5·7	4·4 2·9 - 6·2	**4·5 2·6 - 7·2**
Female	558	28	5·0 3·4 - 7·2	13,761,922	4·6 2·7 - 6·5	5·5 4·4 - 6·8	**5·8 4·3 - 7·8**
Regions							
Central	105	7	6·7 2·7 - 13·2	3,452,213	5·5 1·2 - 9·9	5·6 2·9 - 10·0	**5·9 2·6 - 11·6**
Mombasa	550	51	9·3 7·0 - 12·0	792,072	8·5 6·1 - 10·9	8·3 6·1 - 10·9	**9·2 6·4 - 12·9**
Other Coast	973	39	4·0 2·9 - 5·4	1,671,097	2·2 1·0 - 3·4	3·7 2·6 - 5·1	**3·7 2·2 - 5·6**
Eastern / N. Eastern	242	11	4·5 2·3 - 8·0	5,176,080	4·4 2·4 - 6·3	4·3 2·5 - 7·0	**4·4 2·0- 7·8**
Nairobi	235	21	8·9 5·6 - 13·3	3,002,314	5·8 2·3 - 9·3	7·6 4·9 - 11·2	**8·4 4·9- 13·2**
Nyanza	442	30	6·8 4·6 - 9·5	3,363,813	6·1 3·8 - 8·4	6·0 4·2 - 8·4	**6·3 3·9 - 9·6**
Rift Valley	481	8	1·7 0·7 - 3·3	7,035,581	1·0 0·0 - 2·3	2·1 1·1 - 3·6	**1·9 0·7 - 3·8**
Western	70	7	10·0 4·1 - 19·5	2,656,995	11·5 4·4 - 18·7	7·0 3·5 - 13·1	**7·7 3·3 - 15·5**
Total	3,098	174	5·6 4·8 - 6·5	27,150,165	5·4 42· – 66·	4·9 3·9 - 6·2	**5·2 3·7 - 7·1**

CLINICAL SURVEILLANCE OF SEVERE ACUTE RESPIRATORY INFECTIONS IN KENYA

Sentinel surveillance can provide high-quality data to allow for timely and accurate monitoring of COVID-19 in Kenya and provide an early warning signal of the likelihood of the pandemic to overwhelm the capacity of the health system. Assuming that admission to hospital is a good proxy for severity, the number of hospitalised cases of severe acute respiratory infection (SARI) may be indicative of the disease burden in the population. In April 2020, sentinel clinical surveillance for SARI was established in 14 government county hospitals[*] as an extension of an existing partnership between KEMRI-Wellcome Trust Research Programme (KWTRP), Ministry of Health (MOH), Kenya Paediatric Association, and participating county hospitals across the country known as the Clinical Information Network. The exercise involved (1) extraction of data from archived medical records dating back to January 2018 and (2) prospective follow up of admitted adult patients until discharge.

* **14 county hospitals** - Bungoma CRH, Busia CRH, Embu CRH, Homabay CRH, Kakamega CRH, Kiambu CRH, Kisumu CH, Kitale CRH, Machakos CRH, Mama Lucy K Hospital, Mbagathi CRH, Migori CRH, Naivasha CH, Kilifi CRH

Key findings from clinical surveillance

- County hospitals have not experienced a surge in hospital admissions compared with previous years (figure 1).
- Approximately one in three patients admitted to the sentinel surveillance hospitals presented with signs of severe acute respiratory illness. This ratio has remained constant over the period of the surveillance.
- There was a notable decline in admissions shortly after the reporting of the first case of COVID-19 in Kenya and the subsequent introduction of containment measures.
- The number of hospital admissions has been increasing since May, but on average, the inpatient numbers remain lower than the numbers observed at a similar period in 2018 and 2019.
- The number of inpatient deaths has remained relatively stable during the pandemic.

Figure 1: Trends in hospital admissions and deaths in hospital-based sentinel surveillance sites from January 2018 to July 2020

PREDICTING THE EXTENT OF THE PANDEMIC IN KENYA BASED ON SEROLOGICAL AND PCR TEST DATA

We used data from the following sources to model SARS-COV-2 transmission across all counties in Kenya: (1) national PCR test data provided by the Kenya MOH Emergency Operations Centre (EOC), (2) data from the blood donor sero-prevalence survey previously described, and (3) Google mobility data(available on-line). This modelling aims at supporting public health planning in Kenya by predicting where and when demand for pandemic-related health care is expected to increase, peak and subsequently decline. We also estimate the percentage of all individuals infected with SARS-COV-2 who die from the disease (the crude infection-to-fatality ratio (IFR)).

Key findings from predictive modelling

- In Mombasa County, COVID-19 new infections peaked on May 30th 2020 (95% CI - May 21st - June 12th). In Nairobi County COVID-19 new infections peaked later, on and July 10th 2020 (95% CI - June 29th - July 22nd). The rate of new infections is now declining in these two counties (figure 2).
- The modelling suggests that the observed PCR test data and data from the sero-prevalence survey can be traced back to a small number of infected individuals on 21st February, before the first confirmed case in Kenya.
- This was followed by rapid growth of transmission in both counties (Nairobi and Mombasa) during early March 2020 (early March reproductive ratio (R) and doubling time estimates were: R = 2.01 and doubling time 4.55 days in Nairobi, and R = 2.23 and doubling time 3.85 days in Mombasa).
- After March, and correlating with the introduction of containment measures and reduction in mobility evidenced in Google mobility data, the transmission curve flattened substantially in April (April 16th reproductive ratio and doubling times: R = 1.04 and doubling time 93.5 days in Nairobi, R = 1.18 and doubling time 22.7 days in Mombasa).
- From April through May and June and into July, the Google mobility data and case data strongly suggest that the containment measures imposed by the government became steadily less effective over time and this resulted in predicted rise in R and epidemic growth (figure 3).
- As of the beginning of August 2020 we estimate that about 40.9% (CI 24.3%-54.7%) of the Nairobi population, and 33.8% (CI 23.7-46.5%) of the Mombasa population would be have been infected with SARS-COV-2.

- Such levels of exposure are predicted to be associated with herd-immunity in these urban populations given the estimated reproductive numbers and risk characteristics in the population.
- It is likely that transmission will increase in the future (a second wave) if population mobility continues to rise, transmission continues in less risky sub-populations or if immunity is short lived, leading to a rebound in reported cases.
- The estimated infection fatality rate (IFR) Nairobi is 0.013% and that for Mombasa county is 0.02%. This means that 1.3 - 2 out of every 10,000 infected individuals are likely to die in Nairobi and Mombasa county, which is much lower than what is observed in Europe and the USA.
- We expect that by end of December 2020 cumulatively, less than 1000 deaths in Kenya will be attributed to COVID-19.
- In addition to the two main Kenyan cities, the rate of new infections in the counties neighbouring Nairobi and Mombasa (Kajiado, Kiambu and Machakos) also peaked before August 2020 (figure 4).
- However, the infection rate is predicted to still be rising in other more rural counties, most notably in Rift valley, Eastern and North Eastern counties.
- Because of the lag between infection and the observability of the infected person (whether by PCR test, serology test, or death), we estimate that both daily PCR positive test detections and daily observed deaths attributed to COVID-19 across all of Kenya peaked in early August 2020.
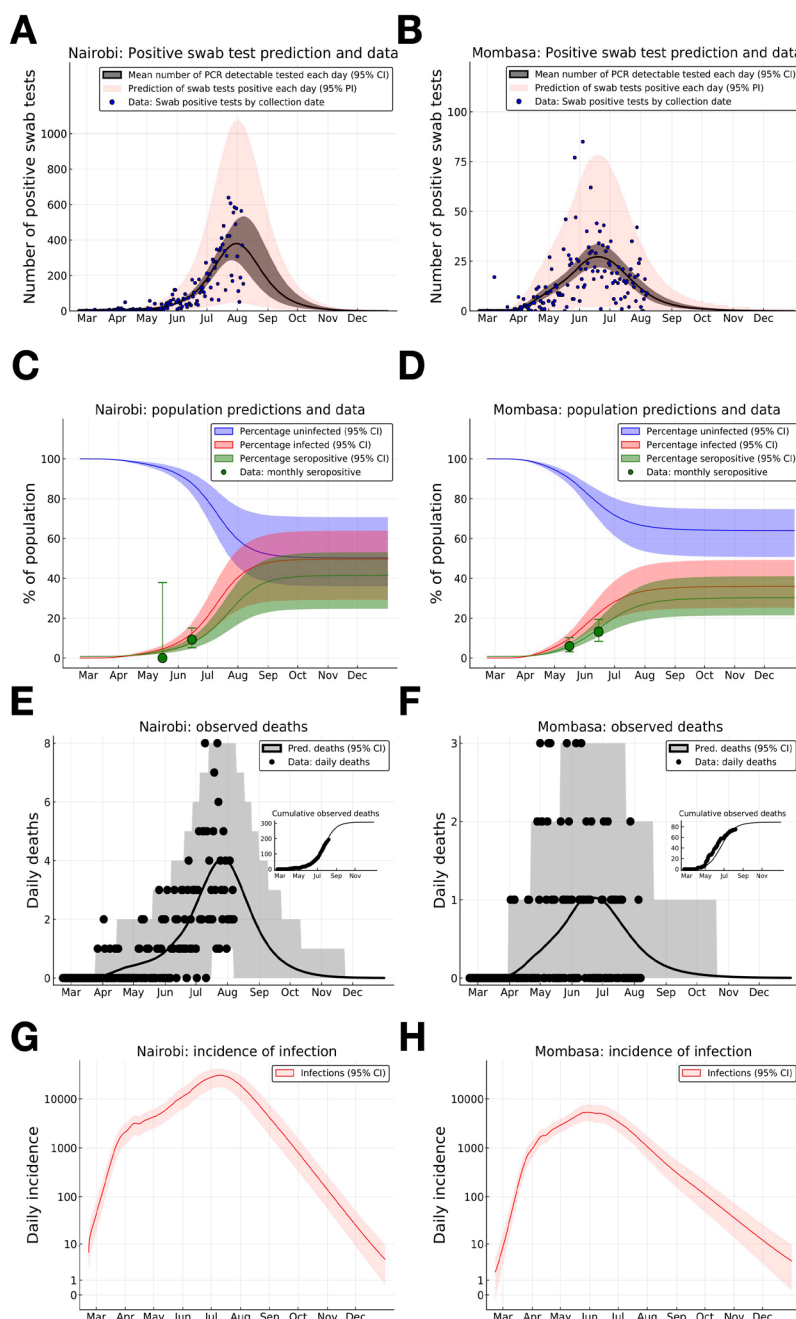

Fig. 2. SARS-CoV-2 deaths, PCR positive swab tests, and seroprevalence in Nairobi and Mombasa, Kenya, with model forecasting. (A) & **(B)** Daily reported positive PCR positive swab tests (*blue dots*) for Nairobi **(A)** and Mombasa **(B)**, model prediction of mean daily detection of new PCR-positive swab tests by date of sample collection (*black curve*), and the model prediction interval for observed daily PCR-positive swab tests including inferred day-to-day variation in detection (*pink shading*). **(C)** & **(D)** Monthly seropositivity of Kenya National Blood Transfusion Service (KNBTS) blood donors in Nairobi **(C)** and Mombasa **(D)** (*green dots*), model predictions for population percentage of seropositivity (*green curve*), exposure to SARS-CoV-2 (*red curve*), and uninfected (blue curve). **(E)** & **(F)** Daily deaths with a positive SARS-CoV-2 test in Nairobi **(E)** and Mombasa **(F)** by date of death (*black dots*), and model prediction for daily deaths (*black curve*). Inset plots in **(E)** and **(F)** indicate cumulative reported deaths and model prediction. **(G)** & (H) Model estimates for rate of new infections per day in Nairobi **(G)** and Mombasa **(H)**. Background shading indicate 95% central credible intervals.
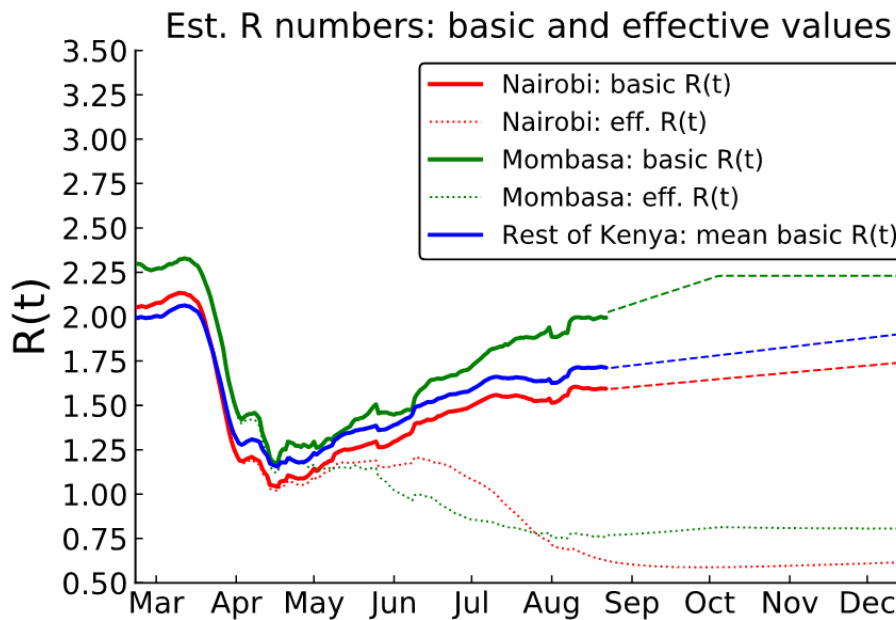
Fig. 3. Basic and effective reproductive numbers for Nairobi, Mombasa and mean Kenyan values (outside of Nairobi and Mombasa). The basic reproductive number shows changes in mobility affecting the number of other cases an infected person is expected to generate over time in a susceptible population (solid lines indicate data, dashed lines indicate a projection from their trend). The effective reproductive number (dotted curves) includes the effect of diminishing number of susceptibles in the county (shown for Nairobi and Mombasa only since this differs strongly from county to county).
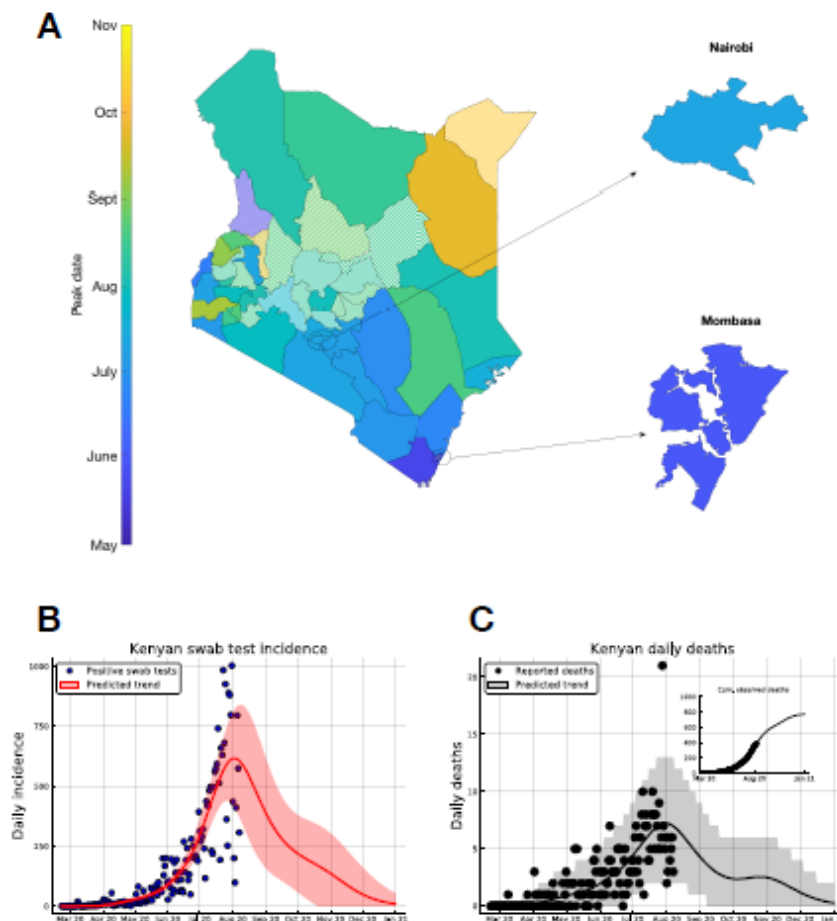
Fig. 4. Predicting peak timing of transmission rate by Kenyan county, and forecasting of Kenya-wide PCR positive swab tests and reported deaths. **(A)** Posterior mean for date of transmission rate peak by Kenyan county. Solid shaded counties had sufficient data to infer model parameters with generic weak priors. Candy-striped shaded counties had model parameters inferred with strong priors derived from posterior distributions of parameters for other counties. Inset plots focus on Nairobi and Mombasa cities. **(B)** Kenya total positive swab tests collected by day of sample (blue dots) with model prediction of daily positive swab test trend (red curve). **(C)** Kenya total reported deaths with a positive swab test (black dots), with model prediction of reported death rates (black curve). Inset plot indicates cumulative reported deaths with model prediction of cumulative deaths.

Summary

- Our modelling analysis indicates that even though the restriction imposed by government likely reduced the pandemic transmission in Kenya, their effect was short-lived
- As a result we predict that a substantial proportion of the Kenyan population in the main urban and neighbouring counties have been infected with SARS-CoV-2 and are likely to have at least temporary immunity.
- This indicates that the focus of the Kenyan epidemic should now shift from the cities into the rural communities.
- Our finding also suggests that Kenya may have escaped the huge morbidity and mortality burdens reported in other countries
- Revised estimates of the size and timing of demand for health care, including hospital beds, PPE and oxygen should now be undertaken
- Enhanced surveillance data on hospital bed use and mortality (e.g through countrywide Demographic Surveillance Systems) are a key requirement for past and future pandemic assessment

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