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The impact of the COVID-19 pandemic on vaccine coverage in Kilifi, Kenya: A retrospective cohort study

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1. Background

The emergence of SARS-CoV-2 in late 2019 and the declaration of coronavirus disease 2019 (COVID-19) as a global pandemic on March 11th 2020 caused unprecedented disruption to the global economy and health service delivery [1–5]. During the first months of the pandemic, 52 countries that responded to a WHO pulse survey reported partial disruptions (5–50 % disruption) of routine immunization services while 10 reported complete disruption (disruption of >50 %) of these services [6]. The impact of COVID-19 on vaccine coverage has been described for 36 European member states, 15 African countries, Pakistan and Australia [7–17]. Many countries reported lower vaccine coverage or fewer immunization visits during the early months of the pandemic based on the number of vaccines doses administered and/or administrative vaccine records [9,18]. In Pakistan, a 52 % decline in doses of BCG administered was reported during a lockdown period between March 23rd 2020 and May 9th 2020 compared to a period 6 months before the pandemic [12–13]. In England, Measles-Mumps-Rubella (MMR) vaccine coverage decreased by 20 % during the first three weeks of the year 2020 compared to those age-eligible pre-COVID-19. After adjusting for known determinants of vaccination, the COVID-19 pandemic did not adversely affect the rate of vaccination within the KDSS.
in vaccines administered was reported for the period between March 1st 2020 and April 26th 2020 compared to the same period in 2019 [14].

In Kenya, the first case of SARS-CoV-2 infection was reported on March 12th 2020. A few days after this announcement, restrictions were implemented such as a ban on intercounty travel, a dusk to dawn curfew, reductions on gatherings and the number of passengers in public transport and a ban of the use of motorcycle transport [20]. Additionally, guidelines on the conduct of essential health services during the pandemic were released by the national emergency response committee and the Ministry of Health [17,21–22]. Vaccination was classified as an essential service and requiring counties were supplied with vaccine stock based on need [17]. Simultaneously, facilities were advised to strictly adhere to infection prevention control (IPC) and physical distancing measures as well as limit healthcare worker contact with community members. In each county, selected facilities were converted to COVID-19 case management facilities (isolation centres) and asked to limit in-patient services to COVID-19 patients. While these facilities were expected to maintain essential out-patient services, some health facilities reported reduced attendance of general out-patient services due to fear or stigma of COVID-19 by the communities they served but reported no difference in immunisation clinic visits [17]. In late 2020, Kenya experienced recurrent healthcare worker strikes which brought about additional disruption of health service delivery in the country [23–25]. During this time, most out-patient services like routine immunization clinics and antenatal care clinics were closed or operated for only a few hours a day.

This paper analyses data from a vaccine coverage survey conducted within the Kilifi Health and Demographic Surveillance System (KHDSS) [26] where vaccination coverage has been monitored among infants resident in it since 2008 [27]. It aims to validate the findings of the analysis of national administrative data that have been reported [16–17].

2. Methods

2.1. Study setting

Kilifi county is one of the poorest counties in Kenya and is predominantly rural [27]. Among the county’s residents, 40 % are within Kenya’s lowest wealth quintile according to the 2014 national DHS [28]. Additionally, 43 % of women in the county are unemployed and only 47 % have higher than primary school education.

The KHDSS covers an area of about 900 km²—partially or wholly covering five out of 8 of Kilifi County’s administrative sub-counties—and data collection is conducted at quarterly household visits [26]. It has an annual birth cohort of about 8,000 and at the time of sampling, the KHDSS had a total of slightly over 300,000 enumerated residents and 39,866 children aged less than 59 months.

2.2. Data collection

The vaccine coverage survey was conducted between April and July 2021. Stratified random sampling by age was used to generate a sample of 1500 children aged between 6 weeks and 59 months from the KHDSS database. This sample included 500 infants aged 6 weeks to 11 months, 500 children aged between 12 and 23 months and 500 children aged 24 to 59 months. If a child could not be found due to death or out-migration from the KHDSS, a back-up sample was used to identify children with similar characteristics to be included in the study.

At household visits, the primary caregiver to the selected child was identified, consented, and a short questionnaire was completed. Written vaccination records were collected from maternal and child health (MCH) booklets for participants with an available booklet. Vaccine records were also collected for participants whose vaccinations were recorded by health facility staff in non-MCH booklets.

This study was approved by the Kenya Medical Research Institute’s (KEMRI) Scientific and Ethics Review Unit (SSC 1433) and the University of Oxford’s Research Ethics Committee (OxTREC; 30–10).

2.3. Statistical analysis

All analyses presented here are confined to children born into, and continuously resident in, the KHDSS with written records of vaccination at the time of the survey. Two separate analyses were conducted. One for the third dose of the Pentavalent vaccine (Pentavalent – 3) and one for the first dose of the measles-containing vaccine (MCV-1). The Pentavalent vaccine confers immunity against diphtheria, tetanus, whooping cough, hepatitis B and *Haemophilus influenzae* type B while the measles–containing vaccine confers immunity against measles and rubella. The following exposures were defined based on when the participant became age-eligible for vaccination with either vaccine (i.e. the time period at which the participant became 14 weeks of age for Pentavalent-3 or 9 months of age for MCV-1):

- If a participant became age-eligible for vaccination before March 23rd, 2020, this was classified as the “pre-COVID period”.
- If a participant became age-eligible for vaccination between March 23rd, 2020, and March 22nd 2021, this was classified as the “COVID-19 year 1” period.
- If a participant became age-eligible for vaccination between March 23rd 2021, and June 25th, 2021 (the end of the survey), this was classified as the “COVID-19 year 2” period.

For this analysis, the COVID-19 Year 1 period begins on March 23rd; on this date, strict non-pharmaceutical interventions against COVID-19 were first implemented in Kenya. Additionally, the country experienced multiple pandemic-related healthcare worker strikes between October 2020 and February 2021 [16–17].

Participants without written records of vaccination were excluded from the analysis. Recall vaccination histories were not considered due to the risk of differential recall bias. Additionally, these histories would not allow for assessment of timeliness of vaccination. Coverage estimates were described for those with written records of vaccination for the two vaccines.

Survival analysis using Cox regression was used to evaluate the association between the time-period in which the participant became age-eligible for vaccination and the rate of vaccination with Pentavalent-3 within a month of age-eligibility for vaccination, in crude and adjusted analyses. The same was done for the rate of vaccination with MCV-1 within three months of age-eligibility for vaccination. Multivariable analyses adjusted for known determinants of vaccination within the KHDSS, identified a priori: distance to the nearest government health facility, primary carer’s age, primary carer’s education level and child’s birth order [29–31]. Other risk factors that were assessed for confounding and effect modification: primary carer [i.e., mother or not mother] and socio-economic status using a wealth index. These variables were defined as confounders if the crude and adjusted rate ratio differed by > 10 % and/or the stratum specific rate ratios differed by > 10 %.
The final model included the time-period of age eligibility for vaccination, parent’s socioeconomic status, primary caregiver, primary caregiver’s age group, distance to nearest health facility, birth order and primary caregiver’s education level and was built by a forward stepwise approach.

Secondary analyses were done to evaluate the association between the time-period in which the participant became age-eligible for vaccination and the rate of vaccination with either Pentavalent-3 or MCV-1 by 12 months of age regardless of timeliness of vaccination. The results of these analyses have been presented as supplementary data.

Kaplan-Meier graphs were plotted for each vaccine and Nelson Aalen graphs of cumulative hazards on the log-scale were used to assess the proportional hazards assumption. Data were analysed using Stata/IC™ 16.0 (Stata Corp, College Station, Texas, USA).

3. Results

A total of 1604 households were visited between April 21st 2021 and June 25th 2021; 1,341 (83.6 %) participants were included in the survey (Table 1, Table 2, Fig. 1). A total of 16.4 % of those visited either didn’t provide consent to participate, were not at home or had died at the time of the survey. A sensitivity analysis comparing those who were not included and those who were included showed no differences in the distribution by sociodemographic factors (sex and distance to nearest health facility) across the two groups. The distribution of those not included is detailed on Supplementary Table 1. The study sample included 3.4 % of all children aged 6 weeks–59 months within the KHDSS. Of these, 49.9 % were female. Participants included in the coverage survey were spread across 15 administrative locations within the KHDSS.

Among the participants, 97 % had their mother as the primary caregiver. Most primary caregivers were married (92 %) and had some primary school education (77 %; Table 1, Table 2). Close to half of the primary caregivers were aged between 26 and 35 years (49.0 %). Additionally, 41 % of the participants had more than three siblings and 37 % were the fourth child or later in terms of birth order. The majority (86 %), of all participants lived less than 4 km from the nearest government health facility with the average distance being 2.8 km. MCH booklets were available for 89 % of the participants while 1 % had other booklets with written records of their vaccinations. Only 10 % of the included participants had no written record of vaccination. Retention of vaccination booklets did not significantly differ by time-period of age-eligibility for vaccination. The distribution of those with vaccination records i.e., a MCH booklet or alternative booklet, was 89 % in the pre-COVID-19 period, 94 % in COVID-19 Year 1 and 96 % in the COVID-19 Year 2 time periods (Pearson Chi² test p value—0.001).

The proportion of children who had written records of having received Pentavalent-3 or MCV-1 within a month or three months of age-eligibility for vaccination respectively has been summarised in Table 3 by calendar year of age-eligibility for vaccination. A higher proportion of those age-eligible for vaccination with MCV-1 in 2021(98.2 %) had timely vaccination compared to those age-eligible for vaccination between 2017 and 2020 (Table 3). Of those age-eligible for vaccination with Pentavalent-3 in 2016, 93 % were vaccinated within a month of age-eligibility for vaccination. These proportions represent those with written records of vaccination only.

Table 1
Sociodemographic characteristics of participants in the Pentavalent-3 analysis based on their year of age-eligibility for vaccination with the vaccine.

|                             | Total sample | pre-COVID-19 | COVID-19 Year 1 | COVID-19 Year 2 | p value |
|-----------------------------|--------------|--------------|----------------|----------------|---------|
|                             | n            | %            | n              | %              | n       | %       |
| **Sex**                     |              |              |                |                |         |         |
| Female                      | 576          | 50.5         | 318            | 51.6           | 217     | 51.5    | 41       | 39.8    | 0.074   |
| Male                        | 564          | 49.5         | 298            | 48.4           | 204     | 48.5    | 62       | 60.2    |         |
| **Age category at time of survey** |            |              |                |                |         |         |
| 6w–11 m                     | 388          | 34.0         | 2              | 0.3            | 283     | 67.2    | 103      | 100.0   | <0.0001 |
| 12–23 m                     | 429          | 37.6         | 292            | 47.4           | 137     | 32.6    | 0        | 0.0     |         |
| 24–59 m                     | 323          | 28.4         | 322            | 52.3           | 1       | 0.2     | 0        | 0.0     |         |
| **Primary caregiver**       |              |              |                |                |         |         |
| Mother                      | 1110         | 97.4         | 596            | 96.8           | 413     | 98.1    | 101      | 98.1    | 0.372   |
| Not mother                  | 30           | 2.6          | 20             | 3.2            | 8       | 1.9     | 2        | 1.9     |         |
| **Primary caregiver’s age group** |            |              |                |                |         |         |
| 15 – 25 years               | 385          | 33.8         | 188            | 30.5           | 152     | 36.1    | 45       | 43.7    | 0.036   |
| 26 – 35 years               | 552          | 48.4         | 305            | 49.5           | 204     | 48.5    | 65       | 15.4    | 15       |
| 36 years and above          | 203          | 17.8         | 123            | 20.0           | 65      | 15.4    | 15       | 14.5    |         |
| **Primary caregiver’s education level** |            |              |                |                |         |         |
| None                        | 70           | 6.1          | 40             | 6.5            | 22      | 5.2     | 8        | 7.8     | 0.684   |
| Any primary                 | 873          | 76.6         | 476            | 77.3           | 322     | 76.5    | 75       | 72.8    |         |
| Secondary and above         | 197          | 17.3         | 100            | 16.2           | 77      | 18.3    | 20       | 19.4    |         |
| **Primary caregiver’s marital status** |            |              |                |                |         |         |
| Married                     | 1063         | 93.2         | 573            | 93.0           | 392     | 93.1    | 98       | 95.1    |         |
| Unmarried                   | 77           | 6.8          | 43             | 7.0            | 29      | 6.9     | 5        | 4.9     | 0.722   |
| **Birth order**             |              |              |                |                |         |         |
| First child                 | 274          | 24.0         | 142            | 23.1           | 109     | 25.9    | 23       | 22.3    | 0.692   |
| Second child                | 267          | 23.4         | 153            | 24.8           | 87      | 20.7    | 27       | 26.2    |         |
| Third child                 | 181          | 15.9         | 96             | 15.6           | 71      | 16.9    | 14       | 13.6    |         |
| Fourth child or higher      | 418          | 36.7         | 225            | 36.5           | 154     | 36.5    | 39       | 37.9    |         |
| **Distance to nearest health facility (kms)** |            |              |                |                |         |         |
| 0 – 2                       | 490          | 43.0         | 260            | 42.2           | 186     | 44.2    | 44       | 42.7    | 0.744   |
| 2 – 4                       | 499          | 43.8         | 272            | 44.2           | 185     | 43.9    | 42       | 40.8    |         |
| 4 – 8                       | 151          | 13.2         | 84             | 13.6           | 50      | 11.9    | 17       | 16.5    |         |
| **Socio-economic status**   |              |              |                |                |         |         |
| Poorest                     | 226          | 19.8         | 119            | 19.3           | 88      | 20.9    | 19       | 18.5    | 0.359   |
| Quintile 2                  | 249          | 21.8         | 138            | 22.4           | 93      | 22.1    | 18       | 17.5    |         |
| Quintile 3                  | 217          | 19.0         | 128            | 20.8           | 65      | 15.4    | 24       | 23.3    |         |
| Quintile 4                  | 251          | 22.0         | 129            | 20.9           | 95      | 22.0    | 27       | 26.2    |         |
| Richest                     | 197          | 17.4         | 102            | 16.6           | 80      | 19.0    | 15       | 14.5    |         |
The proportion of children vaccinated with either vaccine by 12 months of age by year of age-eligibility for vaccination, regardless of the timeliness of vaccination, has been described in Supplementary Table 2. Coverage of both vaccines seems to be gradually increasing.

3.1. Association between time-period of age-eligibility and vaccination with Pentavalent-3

In the analysis of Pentavalent-3, there were some differences in participant characteristics, by exposure group: more participants age-eligible for vaccination in COVID-19 Year 2 were male compared to the other two exposure groups. Additionally, a slightly higher proportion of these participants had their mother as the primary caregiver and these mothers were on average younger than mothers in the other two time-periods.

In crude analyses, those age-eligible for vaccination during COVID-19 Year 2 had higher rates of vaccination within a month of age-eligibility for vaccination, compared to those age-eligible for vaccination during the pre-COVID-19 period (HR 1.31, 95 % CI 1.06–1.63). However, the rates of vaccination among those age-eligible for vaccination in COVID-19 Year 1 did not differ from those of the pre-COVID-19 period (HR 1.03, 95 % CI 0.91–1.19). A log-rank test conducted after plotting a Kaplan-Meier graph for Pentavalent-3 revealed strong evidence against the null of no difference between the three curves (p = 0.0181; Table 4, Fig. 2).

In adjusted analyses, the point estimates still suggested higher rates of vaccination among those age-eligible for vaccination during COVID-19 Year 1 (aHR 1.03, 95 % CI 0.90–1.18) and those age eligible during COVID-19 Year 2 (aHR 1.33, 95 % CI 1.07–1.65), compared to those age-eligible during the pre-COVID-19 period (Table 4; Fig. 2). However, overall, there was no evidence of an association between period and timely vaccination after controlling for primary caregiver, distance to the nearest government health facility, primary caregiver's age, primary caregiver's education level and child’s birth order (LRT p value = 0.2026; Table 4).

3.2. Association between time-period of age-eligibility and vaccination with MCV-1

In the MCV-1 analysis, most of those age-eligible during the pre-COVID-19 period were 24 to 59 months old at the time of sampling, most of those in the COVID year 1 group were aged 12 to 23 months at the time of sampling and the COVID-19 Year 2 group were predominantly less than 11 months old.

In crude analyses, those age-eligible for vaccination during COVID-19 Year 1 and COVID-19 Year 2 had higher rates of vaccination within three months of age-eligibility for vaccination, compared to those age-eligible during the pre-COVID-19 period after crude analysis (HR 1.04, 95 % CI 0.89–1.22 and HR 1.35, 95 % CI 1.11–1.63, respectively). A log-rank test conducted after plotting a Kaplan-Meier graph for MCV-1 revealed strong evidence against the null of no difference between the three curves (p = 0.0064; Table 5, Fig. 3).

After adjusting for a priori risk factors, point estimates still suggested higher rates of vaccination within three months of age-eligibility for vaccination among those age-eligible for vaccination during COVID-19 Year 1 (aHR 1.04, 95 % CI 0.88–1.21) and those age-eligible during COVID-19 Year 2 (aHR 1.33, 95 % CI 1.07–1.65), compared to those age-eligible during the pre-COVID-19 period (Table 4; Fig. 2). However, overall, there was no evidence of an association between period and timely vaccination after controlling for primary caregiver, distance to the nearest government health facility, primary caregiver’s age, primary caregiver’s education level and child’s birth order (LRT p value = 0.2026; Table 4).

| Socio-demographic characteristics | Total sample | pre-COVID-19 | COVID-19 Year 1 | COVID-19 Year 2 | p value |
|----------------------------------|-------------|-------------|----------------|---------------|---------|
| Total sample                     |             |             |                |               |         |
| Sex                              |             |             |                |               |         |
| Female                           | 453         | 52.8        | 159            | 52.1          | 199     | 53.1    | 95      | 53.4    | 0.957   |
| Male                             | 405         | 47.2        | 146            | 47.9          | 176     | 46.9    | 83      | 46.6    |         |
| Age category at time of survey   |             |             |                |               |         |<0.0001 |
| 6w–11m                           | 148         | 17.3        | 1               | 0.3           | 3       | 0.8     | 144     | 80.9    |         |
| 12–23m                           | 405         | 47.2        | 10             | 3.3           | 361     | 96.3    | 34      | 19.1    |         |
| 24–59m                           | 305         | 35.5        | 294            | 96.4          | 11      | 2.9     | 0       | 0.0     |         |
| Primary caregiver                |             |             |                |               |         |         |
| Mother                           | 836         | 97.4        | 295            | 96.7          | 365     | 97.3    | 176     | 98.9    | 0.347   |
| Not mother                       | 22          | 2.6         | 10             | 3.3           | 10      | 2.7     | 2       | 1.1     |         |
| Primary caregiver’s age group    |             |             |                |               |         |         |
| 15–25 years                      | 276         | 32.2        | 88             | 28.9          | 123     | 32.8    | 65      | 36.5    | 0.413   |
| 26–35 years                      | 425         | 49.5        | 155            | 50.8          | 184     | 49.1    | 86      | 48.3    |         |
| 36 years and above               | 157         | 18.3        | 62             | 20.3          | 68      | 18.1    | 27      | 15.2    |         |
| Primary caregiver’s education level |         |             |                |               |         |         |
| None                             | 55          | 6.4         | 22             | 7.2           | 25      | 6.7     | 8       | 4.5     | 0.757   |
| Any primary                      | 663         | 77.3        | 237            | 77.7          | 287     | 76.5    | 139     | 78.1    |         |
| Secondary and above              | 140         | 16.3        | 46             | 15.1          | 63      | 16.8    | 31      | 17.4    |         |
| Primary caregiver’s marital status |         |             |                |               |         |         |
| Unmarried                        | 53          | 6.2         | 14             | 4.6           | 31      | 8.3     | 8       | 4.5     | 0.081   |
| Married                          | 805         | 93.8        | 291            | 95.4          | 344     | 91.7    | 170     | 95.5    |         |
| Birth order                      |             |             |                |               |         |         |
| First child                      | 214         | 24.9        | 78             | 25.6          | 86      | 22.9    | 50      | 28.1    | 0.241   |
| Second child                     | 199         | 23.2        | 81             | 26.7          | 86      | 22.9    | 32      | 18.0    |         |
| Third child                      | 136         | 15.9        | 39             | 12.8          | 67      | 17.9    | 30      | 16.9    |         |
| Fourth child or higher           | 309         | 36.0        | 107            | 35.1          | 136     | 36.3    | 66      | 37.0    |         |
| Distance to nearest health facility (kms) |     |             |                |               |         |         |
| 0–2                              | 362         | 42.2        | 127            | 41.6          | 158     | 42.1    | 77      | 43.3    | 0.957   |
| 2–4                              | 386         | 45.0        | 136            | 44.6          | 169     | 45.1    | 81      | 45.5    |         |
| 4–8                              | 110         | 12.8        | 42             | 13.8          | 48      | 12.8    | 20      | 11.2    |         |
| Socio-economic status            |             |             |                |               |         |         |
| Poorest                          | 171         | 19.9        | 55             | 18.0          | 79      | 21.1    | 37      | 20.8    | 0.945   |
| Quintile 2                       | 188         | 21.9        | 65             | 21.3          | 87      | 23.2    | 36      | 20.2    |         |
| Quintile 3                       | 164         | 19.2        | 63             | 20.7          | 67      | 17.9    | 34      | 19.1    |         |
| Quintile 4                       | 189         | 22.0        | 71             | 23.3          | 77      | 20.5    | 41      | 23.0    |         |
| Richest                          | 146         | 17.0        | 51             | 16.7          | 65      | 17.3    | 30      | 16.9    |         |

Table 2
Sociodemographic characteristics of participants in the MCV – 1 analysis based on their year of age-eligibility for vaccination with the vaccine.
age eligible during COVID-19 Year 2 (aHR 1.35, 95% CI 1.11–1.64), compared to those age-eligible during the pre-COVID-19 period (Table 5, Fig. 3). Overall, there was evidence of an association between period and timely vaccination after controlling for primary caregiver, distance to the nearest government health facility, primary caregiver’s age, primary caregiver’s education level and child’s birth order (LRT p value = 0.0065; Table 5).

Overall, the proportional hazards assumption held true for both the Pentavalent-3 and MCV-1 analyses. Similar results were observed for the secondary analyses evaluating the association between time-period of age-eligibility for vaccination and rate of vaccination with either Pentavalent-3 or MCV-1 by 12 months of age (Supplementary Table 3 and 4).

4. Discussion

The results presented provide evidence that the COVID-19 pandemic did not adversely affect vaccine coverage within the area covered by the KHDSS. These results are in keeping with those reported by Barasa et al [17] and Wambua et al [16] using Kenya national administrative vaccination data. The rate of vaccination with Pentavalent-3 and MCV-1 was slightly higher during

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**Table 3**

Proportion of participants vaccinated within a month of age-eligibility for vaccination with Pentavalent-3 and within 3 months of age-eligibility for vaccination with MCV-1 by year of age-eligibility for vaccination.

| Year of age-eligibility for vaccination | Proportion of participants vaccinated within a month of age-eligibility for vaccination with Pentavalent-3 and within 3 months for MCV-1 |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
|                                        | Pentavalent-3 | MCV-1 |
|                                        | 95% CI | 95% CI |
| 2016                                   | 93.2% (81.3, 98.6%) | –      |
| 2017                                   | 74.8% (66.0, 82.2%) | 85.5% (81.7, 94.9%) |
| 2018                                   | 88.5% (80.7, 93.9%) | 89.2% (81.9, 94.3%) |
| 2019                                   | 90.3% (86.2, 93.5%) | 91.9% (84.7, 96.4%) |
| 2020                                   | 87.1% (83.5, 90.1%) | 94.3% (91.5, 96.4%) |
| 2021                                   | 85.2% (78.9, 90.2%) | 98.2% (94.8, 99.6%) |
COVID-19 Year 1 and COVID-19 Year 2 compared to the pre-COVID-19 period although this was only significant for the two vaccines during COVID-19 Year 2.

Early predictions of the impact of COVID-19 on routine vaccine coverage globally warned of a drop in vaccine coverage in 2020, compared to expected levels\[18,32\]. For all regions, the drop in vaccine doses delivered was modelled to be highest during the early months of the pandemic, March to May, with a gradual recovery between May and December 2020\[32\]. In sub-Saharan Africa, similar patterns have been reported for 17 countries, including Angola, Senegal, Burundi, Gabon, Guinea and Nigeria, based on administrative coverage reports \[7,33–34\]. However, within the KHDSS, this was not apparent as coverage for the two vaccines remained high despite the pandemic and a healthcare worker strike during November and December 2020\[23–24\].

Barasa et. al and Wambua et. al have described the indirect effects of the pandemic and its related restrictions on health services in Kenya using interrupted time series analyses that start before the COVID-19 pandemic. While the Barasa et. al evaluated the indirect impact of the pandemic on health financing, supply chain, healthcare workforce, health infrastructure, health service provision and patient access comparing indicators from January 2019 to November 2020, Wambua et. al focused-on utilisation of immunization and outpatient services and compared data from January 2018 to March 2021. They both reported minimal to no disruption of immunisation services in the country and a gradual increase of administrative coverage estimates from early 2020 through 2021 [16–17]. Both reported declines in outpatient antenatal care visits, hospital admissions and hospital deliveries during the early months of the pandemic in 2020 and these recovered later during the year\[16–17\]. In qualitative key informant interviews conducted in Kenya, national and county officials reported minimal to no disruptions of supply chains and service provision during the first year of the COVID-19 pandemic due to multiple contingencies put in place\[17\]. These contingencies included but were not limited to supplying counties with extra vaccines and

Table 4
Association between time-period of age-eligibility for vaccination and vaccination within a month of age-eligibility with Pentavalent-3.

| Time-period of age-eligibility | Vaccination per person years | Vaccination Rate | Crude vaccination hazard ratio | 95 % CI 1Adjusted hazard ratio | 95 % CI 2LRT P value |
|--------------------------------|-----------------------------|-----------------|------------------------------|-------------------------------|-------------------|
| Pre-COVID                      | 526/212.9                   | 2.47            | 1                            | 1                             | 0.2026            |
| COVID-19 Year 1                | 365/130.9                   | 2.79            | 1.03                         | 0.91, 1.03                    | 1.18              |
| COVID-19 Year 2                | 97/30.3                     | 3.21            | 1.31                         | 1.06, 1.33                    | 1.07, 1.65        |
| Primary caregiver              |                             |                 |                              |                               |                   |
| Mother                         | 965/362.2                   | 2.66            | 1                            | 0.72                          | 0.52, 0.53        |
| Not mother                     | 23/11.8                     | 1.94            | 0.80                         | 1.30                          | 1.23              |
| Primary caregiver’s age group  |                             |                 |                              |                               |                   |
| 15–25 years                    | 336/123.4                   | 2.72            | 1                            | 1                             | 0.8165            |
| 26–35 years                    | 481/183.1                   | 2.63            | 1.00                         | 0.87, 1.02                    | 0.86, 1.20        |
| 36 years and above             | 171/67.5                    | 2.53            | 0.88                         | 0.74, 0.96                    | 0.76, 0.87        |
| Primary caregiver’s education level |                        |                 |                              |                               |                   |
| None                           | 51/24.0                     | 2.13            | 1                            | 1                             | 0.0046            |
| Primary                       | 754/290.9                   | 2.60            | 1.50                         | 1.13, 1.50                    | 1.12, 1.21        |
| Secondary and above            | 183/59.2                    | 3.09            | 1.87                         | 1.37, 1.69                    | 1.22, 1.36        |
| Birth order                    |                             |                 |                              |                               |                   |
| First child                    | 244/89.2                    | 2.73            | 1                            | 1                             | 0.7133            |
| Second child                   | 234/90.7                    | 2.58            | 0.97                         | 0.81, 0.97                    | 0.81, 1.16        |
| Third child                    | 153/59.8                    | 2.56            | 0.89                         | 0.73, 0.88                    | 0.71, 1.10        |
| Fourth child or higher         | 357/134.3                   | 2.66            | 0.86                         | 0.73, 0.93                    | 0.75, 1.15        |
| Distance to nearest health facility (kms) |            |                 |                              |                               |                   |
| 0–2                            | 431/159.8                   | 2.70            | 1                            | 1                             | 0.7951            |
| 2–4                            | 428/163.2                   | 2.62            | 0.92                         | 0.80, 0.96                    | 0.84, 1.10        |
| 4–8                            | 129/51.0                    | 2.53            | 0.89                         | 0.73, 0.95                    | 0.77, 1.16        |
| Socio-economic status          |                             |                 |                              |                               |                   |
| Poorest                        | 206/73.3                    | 2.81            | 1                            | 1                             | 0.0561            |
| Quintile 2                     | 216/79.0                    | 2.74            | 0.78                         | 0.64, 0.80                    | 0.66, 0.98        |
| Quintile 3                     | 185/70.4                    | 2.63            | 0.77                         | 0.63, 0.82                    | 0.66, 1.01        |
| Quintile 4                     | 218/81.1                    | 2.69            | 0.77                         | 0.63, 0.79                    | 0.65, 0.97        |
| Richest                        | 163/70.3                    | 2.32            | 0.71                         | 0.57, 0.73                    | 0.59, 0.87        |

1 Adjusted for primary caregiver, primary caregiver’s age group, primary caregiver’s education level, birth order, distance to nearest health facility and socio-economic status.

2 Likelihood Ratio Test p value.

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immunization supplies before the country’s COVID-19 case burden became high and postponing routine weighing services for children but advising mothers to return for all their vaccination visits.

There are some limitations to our analysis that warrant discussion, the study sample included a high proportion of respondents with some education (77 %) compared to the proportion of residents within the county reported to have some education according to a national demographic health survey conducted in 2014 (53 %) [28]). The representativeness of our sample is therefore uncertain and, as educated mothers are more likely to have their children vaccinated within the KHDSS [31], we may have overestimated vaccine coverage; however, the proportion of educated mothers did not differ between our comparison groups and our analysis of differences in vaccination coverage across time should still be valid. Additionally, the analysis was restricted to the 90 % of participants with a written record of vaccination. We do not know if this is representative of the KHDSS mothers because such data on card retention are not available. A more educated sample of mothers who have retained their vaccination cards may have resulted in an overestimate of vaccine coverage for the county. Card retention was higher in the COVID-19 Year 1 and COVID-19 Year 2 groups compared to the pre-COVID group. This is an expected finding as books may be gradually lost once a child completes all their recommended vaccines. The implication of this is a possible underestimation of coverage for the pre-COVID group but this would not affect the results of the COVID-19 Year and COVID-19 Year 2 groups in which card retention was high.

The proportion of participants vaccinated within a month of age-eligibility for vaccination with Pentavalent-3 by year of age-eligibility. The confidence intervals around these proportions overlap hence pointing to no evidence of a decline across the six years. Additionally, the Cox regression analyses refine the time periods of exposure. For example, not all participants born in 2020 are grouped in the COVID-19 Year 1 group. Consequently, proportions would differ from those in Table 3 which groups all participants eligible for vaccination in the same year together regardless of the pandemic related disruptions which were of different intensity depending on the month. Finally, the Cox regression model adjusts for known factors that determine vaccine coverage that may differ over time/ across the groups. After adjustment there is no negative impact of the pandemic on proportions of participants vaccinated.

The effect of survivor bias cannot be discounted in this study, mortality among children 0–4 years of age within the KHDSS was 5.4/1000 person years in 2015-18 [35]. If the study overestimated coverage in the pre-COVID-19 group due to survivor bias, this would have led us to underestimate the hazard ratios. There may have been greater increases in timely vaccination in the COVID-19 Year 1 and 2 than reported here. Due to the nature of this retrospective cohort, secular trends that have been increasing access to vaccination over time may have also biased our results. In the last 10 years the number of government health facilities within the KHDSS has increased from 8 to 21, and the average distance to nearest health facility has decreased from 4.9 to 2.3 km [30]. However, importantly, we found no difference in the distance to the nearest health facility across our comparison groups.

Our results support and add to existing evidence [16–17] on the impact of the pandemic on vaccine coverage in Kenya by giving a sub-national picture of the impact of the pandemic using coverage survey data.

This analysis used cross-sectional data to create two retrospective cohort studies which allowed for the investigation of the impact of the COVID-19 pandemic on timeliness of routine vacci-
nation in a period when conducting a prospective study would have been difficult due to the nature of the pandemic.

5. Conclusion

In conclusion, after adjusting for risk factors, we found no evidence that the COVID-19 pandemic disrupted vaccination coverage or timeliness of vaccination within a predominantly rural county in Kenya, consistent with national data.

Coverage of Pentavalent-3 and MCV-1 seem to be gradually increasing over time. Despite this, coverage for MCV-1 in the year 2020 (85%) was still below the WHO recommended 95% for the vaccine (Supplementary Table 2). Efforts to increase coverage of MCV-1 at the national and sub-national levels should be maintained to avoid adverse effects related to disruptions of these services in the future. Regular monitoring of trends in coverage within the KHDSS may be useful to identify disruptions in real time and aid planning of catch-up vaccination activities to improve and/or maintain recommended vaccination coverage.

Table 5

| Vaccination per person years | Vaccination Rate | Crude vaccination hazard ratio | 95 % CI 1 | Adjusted hazard ratio | 95 % CI 2 | LRT P value |
|-----------------------------|-----------------|------------------------------|-----------|-----------------------|-----------|------------|
| **Time period of age-eligibility** | | | | | | |
| Pre-COVID | 275/266.8 | 1.03 | 1 | 1 | 0.0065 | |
| COVID year 1 | 354/310.3 | 1.14 | 1.04 | 0.89, 1.04 | 0.88, 1.04 | |
| COVID year 2 | 174/141.8 | 1.23 | 1.35 | 1.11, 1.35 | 1.11, 1.35 | |
| **Primary caregiver** | | | | | | |
| Mother | 784/699.4 | 1.12 | 1 | 1 | 0.5729 | |
| Not mother | 19/19.6 | 0.97 | 0.83 | 0.53, 1.31 | 0.59, 1.31 | |
| **Primary caregiver’s age group** | | | | | | |
| 15 –25 years | 261/229.2 | 1.14 | 1 | 1 | 0.0031 | |
| 26 –35 years | 403/350.5 | 1.15 | 1.06 | 0.91, 1.12 | 0.93, 1.15 | |
| 36 years and above | 139/139.4 | 1.00 | 0.78 | 0.63, 0.95 | 0.64, 0.95 | |
| **Primary caregiver’s education level** | | | | | | |
| None | 50/46.6 | 1.07 | 1 | 1 | 0.8255 | |
| Primary | 618/556.6 | 1.11 | 1.11 | 0.83, 1.04 | 0.77, 1.04 | |
| Secondary and above | 135/115.8 | 1.17 | 1.28 | 0.93, 1.10 | 0.77, 1.10 | |
| **Birth order** | | | | | | |
| First child | 204/175.0 | 1.17 | 1 | 1 | 0.3354 | |
| Second child | 187/166.2 | 1.13 | 0.88 | 0.73, 1.08 | 0.72, 1.08 | |
| Third child | 127/115.6 | 1.10 | 0.85 | 0.68, 1.07 | 0.66, 1.07 | |
| Fourth or higher | 285/262.3 | 1.09 | 0.80 | 0.67, 0.96 | 0.67, 0.96 | |
| **Distance to nearest health facility (kms)** | | | | | | |
| 0–2 | 344/300.6 | 1.14 | 1 | 1 | 0.2164 | |
| 2–4 | 359/325.4 | 1.10 | 0.91 | 0.78, 1.05 | 0.80, 1.05 | |
| 4–8 | 100/93.0 | 1.07 | 0.81 | 0.65, 1.02 | 0.67, 1.06 | |
| **Socio-economic status** | | | | | | |
| Poorest | 161/140.3 | 1.15 | 1 | 1 | 0.6056 | |
| Quintile 2 | 173/158.7 | 1.09 | 0.86 | 0.70, 1.07 | 0.70, 1.09 | |
| Quintile 3 | 154/139.3 | 1.11 | 0.86 | 0.69, 1.07 | 0.69, 1.11 | |
| Quintile 4 | 180/157.9 | 1.14 | 0.88 | 0.71, 1.09 | 0.71, 1.11 | |
| Richest | 135/122.8 | 1.10 | 0.86 | 0.68, 1.08 | 0.69, 1.12 | |

1 Adjusted for primary caregiver, primary caregiver’s age group, primary caregiver’s education level, birth order, distance to nearest health facility and socio-economic status.  
2 Likelihood Ratio Test p value.
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CRediT authorship contribution statement

R.K. Lucinde: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. B. Karia: Methodology, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. N. Ouma: Methodology, Data curation, Writing - original draft, Writing - review & editing. D. Amadi: Methodology, Data curation, Writing - original draft, Writing - review & editing. A. Nyaguera: Methodology, Investigation, Writing - original draft, Writing - review & editing. D. A.G. Scott: Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing. K.E. Gallagher: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. E. Kagucia: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2022.10.074.

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Fig. 3. Vaccination within three months of age-eligibility for vaccination with MCV-1 by time period of age-eligibility for vaccination.
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