Vaccine 41 (2023) 666–675

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

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

R.K. Lucinde [a,*], B. Karia [a], N. Ouma [a], D. Amadi [a], C. Nyundo [a], C. Mataza [b], A. Nyaguara [a], J.A.G. Scott [a,c], K.E. Gallagher [a,c,1], E. Kagucia [a,1]

[a] KEMRI-Wellcome Trust Research Programme (KWTRP) Centre for Geographic Medical Research - Coast (CGMRC), Kilifi, Kenya
[b] Kilifi County, Department of Health, Kilifi, Kenya
[c] Faculty of Epidemiology and Population Health, London School of Hygiene and Tropical Medicine, UK

ARTICLE INFO

Article history:
Received 27 July 2022
Received in revised form 24 October 2022
Accepted 26 October 2022
Available online 1 November 2022

Keywords:
COVID-19
Vaccine
Coverage
Routine immunization

ABSTRACT

The COVID-19 pandemic caused unprecedented disruption in health service delivery, globally. This study sought to provide evidence on the impact of the pandemic on vaccine coverage in Kilifi County, Kenya. We conducted a vaccine coverage survey between April and June 2021 within the Kilifi Health and Demographic Surveillance System (KHDSS). Simple random sampling was used to identify 1500 children aged 6 weeks–59 months. Participants were grouped into three retrospective cohorts based on when they became age-eligible for vaccination: before the pandemic, during the first year, or during the second year of the pandemic. Survival analysis with Cox regression was used to evaluate the association between the time-period at which participants became age-eligible for vaccination and the rate of vaccination within a month of age-eligibility for the third dose of pentavalent vaccine (Pentavalent-3) and within three months of age-eligibility for the first dose of Measles vaccine (MCV-1). A total of 1,341 participants were included in the survey. Compared to the pre-COVID-19 baseline period, the rate of vaccination within a month of age-eligibility for Pentavalent-3 was not significantly different in the first year of the pandemic (adjusted hazard ratio [aHR] 1.03, 95 % confidence interval [CI] 0.90–1.18) and was significantly higher during the second year of the pandemic (aHR 1.33, 95 % CI 1.07–1.65). The rate of vaccination with MCV-1 within three months of age-eligibility was not significantly different among those age-eligible for vaccination during the first year of the pandemic (aHR 1.04, 95 % CI 0.88–1.21) and was 35 % higher during the second year of the pandemic (95 % CI 1.11–1.64), 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 KHDSS.

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 country's lockdown [19]. In Africa, countries with previously high coverage e.g. Senegal, Rwanda and Eritrea reported they had maintained their pre-COVID levels of service delivery between January and June 2020 while countries like CAR, Guinea and South Sudan reported coverage hadn't recovered to pre-pandemic levels by June 2020 [7]. In one facility in Sierra Leone, a 50–85 % decrease

* Corresponding author at: KEMRI-Wellcome Trust Research Programme (KWTRP), Centre for Geographic Medical Research–Coast (CGMRC), P.O Box 230, 80108 Kilifi, Kenya.

E-mail address: RLucinde@kemri-wellcome.org (R.K. Lucinde).

[1] These authors contributed equally.

https://doi.org/10.1016/j.vaccine.2022.10.074
0264-410X/© 2022 The Authors. Published by Elsevier Ltd.

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 km^2–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 caregiver's age, primary caregiver's education level and child's birth order [29–31]. Other risk factors that were assessed for confounding and effect modification: primary caregiver (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 Chi^2 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	%	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	43	41.8	
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									
Unmarried	77	6.8	43	7.0	29	6.9	5	4.9	0.722
Married	1063	93.2	573	93.0	392	93.1	98	95.1	
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	22.6	27	26.2	
Richest	197	17.4	102	16.6	80	19.0	15	14.5	

Table 2
Sociodemographic characteristics of participants in the MCV − 1 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	%	n	%	
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									
6w–11m	148	17.3	1	0.3	3	0.8	144	80.9	<0.0001
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	

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 for 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

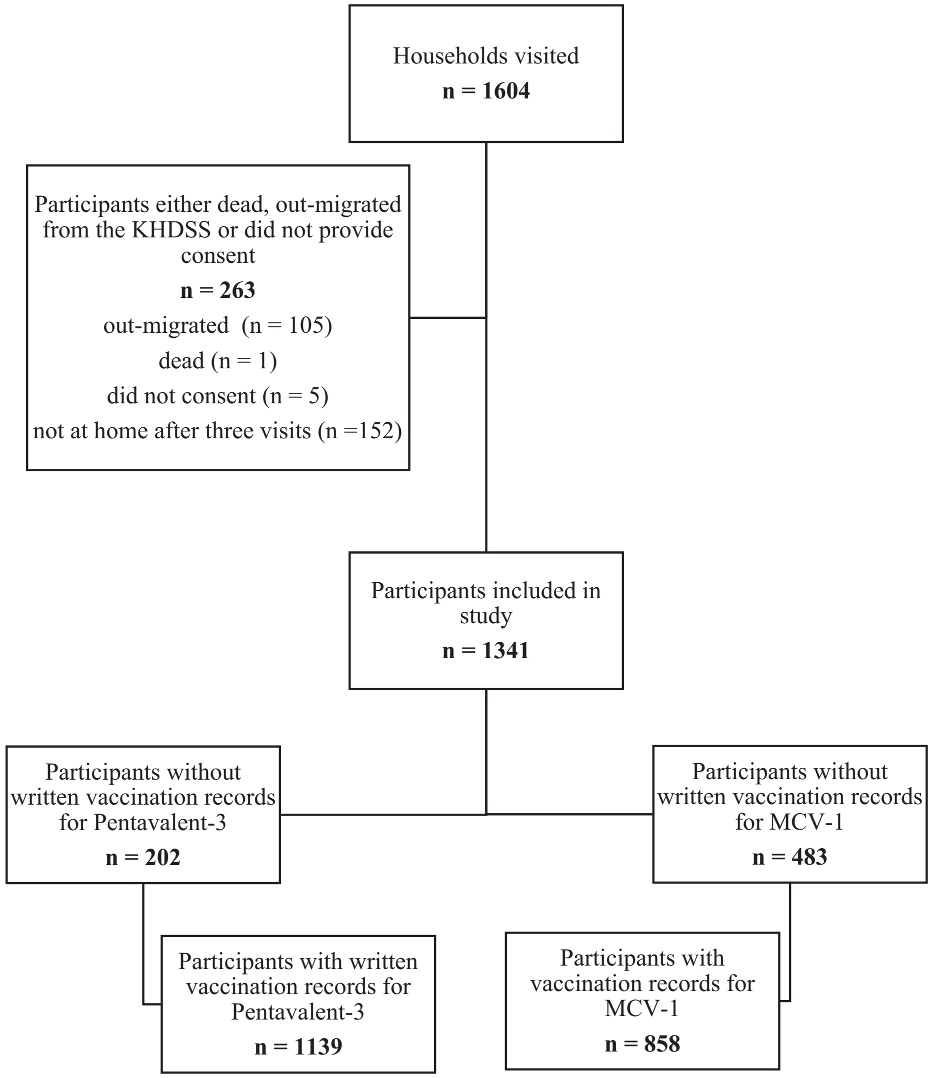

Fig. 1. Breakdown of participants included in study. This figure represents the breakdown of participants included in the study. Of the 1604 households visited, 1341 participants were included in the study. From the 1341, participants with no written record of receiving either Pentavalent-3 or MCV-1 on their MCH or alternative booklet were also excluded. These excluded participants include those who did not have an MCH or alternative booklet as well.

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 for Pentavalent-3 and within 3 months for MCV-1	
	Pentavalent-3 n (95 % CI)	MCV-1 n (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 %)

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

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

	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	526/212.9	2.47	1		1		0.2026
COVID-19 Year 1	365/130.9	2.79	1.03	0.91, 1.19	1.03	0.90, 1.18	
COVID-19 Year 2	97/30.3	3.21	**1.31**	1.06, 1.63	1.33	1.07, 1.65	
Primary caregiver							
Mother	965/362.2	2.66	1		1		0.2944
Not mother	23/11.8	1.94	0.72	0.48, 1.10	0.80	0.52, 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, 1.14	1.02	0.86, 1.20	
36 years and above	171/67.5	2.53	0.88	0.74, 1.06	0.96	0.76, 1.21	
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, 2.00	1.50	1.12, 2.01	
Secondary and above	183/59.2	3.09	1.87	1.37, 2.55	1.69	1.22, 2.36	
Birth order							
First child	244/89.2	2.73	1		1		0.7133
Second child	234/90.7	2.58	0.97	0.81, 1.16	0.97	0.81, 1.17	
Third child	153/59.8	2.56	0.89	0.73, 1.09	0.88	0.71, 1.10	
Fourth child or higher	357/134.3	2.66	0.86	0.73, 1.02	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, 1.05	0.96	0.84, 1.10	
4–8	129/51.0	2.53	0.89	0.73, 1.09	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, 0.94	0.80	0.66, 0.98	
Quintile 3	185/70.4	2.63	0.77	0.63, 0.94	0.82	0.66, 1.01	
Quintile 4	218/81.1	2.69	0.77	0.63, 0.93	0.79	0.65, 0.97	
Richest	163/70.3	2.32	0.71	0.57, 0.87	0.73	0.59, 0.91	

[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.

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

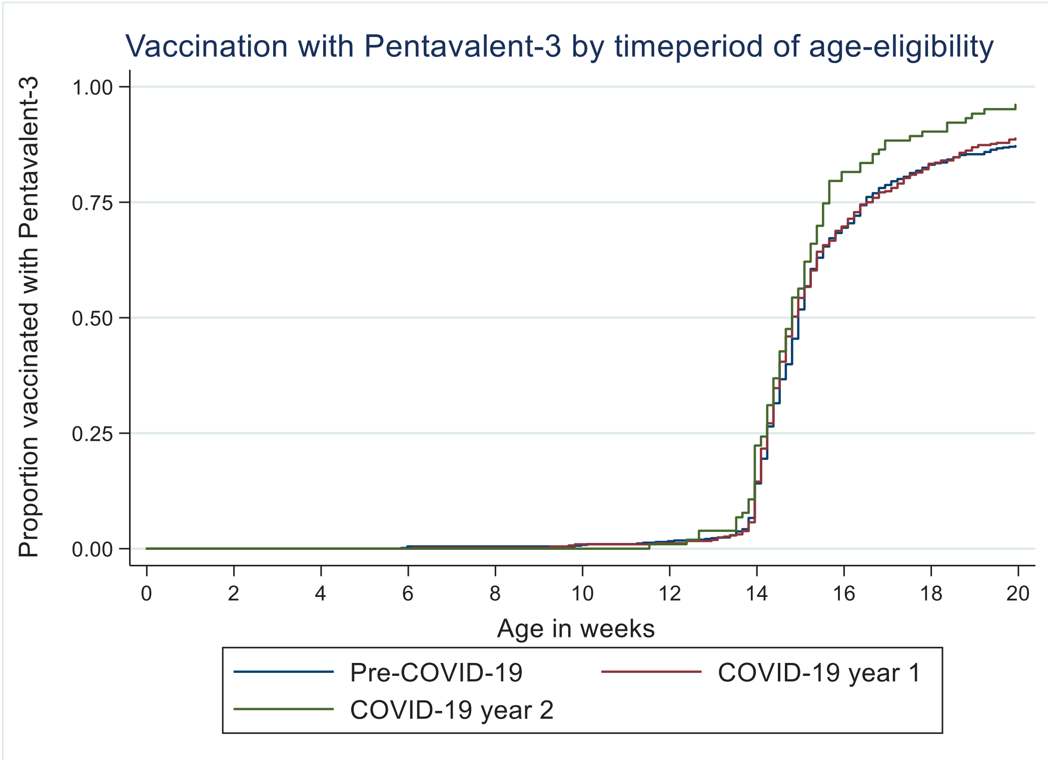

Fig. 2. Vaccination within a month of age-eligibility for vaccination with Pentavalent-3 by time period of age-eligibility for vaccination.

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 for vaccination as displayed in Table 3 may give the reader the impression that the proportions seemed to reduce in the year 2020 and 2021. This contrasts with the Cox regression results presented in Tables 4 and 5. One of the reasons for the difference is that the proportions in Table 3 are crude proportions of children vaccinated 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-

Table 5
Association between time-period of age-eligibility for vaccination and vaccination within three months of age-eligibility with MCV-1.

	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, 1.22	1.04	0.88, 1.21	
COVID year 2	174/141.8	1.23	1.35	1.11, 1.63	1.35	1.11, 1,64	
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	0.96	0.59, 1.54	
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, 1.24	1.12	0.93, 1.35	
36 years and above	139/139.4	1.00	0.78	0.63, 0.95	0.83	0.64, 1.08	
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, 1.48	1.04	0.77, 1.40	
Secondary and above	135/115.8	1.17	1.28	0.93, 1.78	1.10	0.77, 1.56	
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	0.88	0.72, 1.09	
Third child	127/115.6	1.10	0.85	0.68, 1.07	0.84	0.66, 1.06	
Fourth or higher	285/262.3	1.09	0.80	0.67, 0.96	0.85	0.67, 1.07	
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	0.93	0.80, 1.09	
4–8	100/93.0	1.07	0.81	0.65, 1.02	0.84	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	0.88	0.70, 1.09	
Quintile 3	154/139.3	1.11	0.86	0.69, 1.07	0.88	0.69, 1.11	
Quintile 4	180/157.9	1.14	0.88	0.71, 1.09	0.89	0.71, 1.11	
Richest	135/122.8	1.10	0.86	0.68, 1.08	0.88	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.

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.

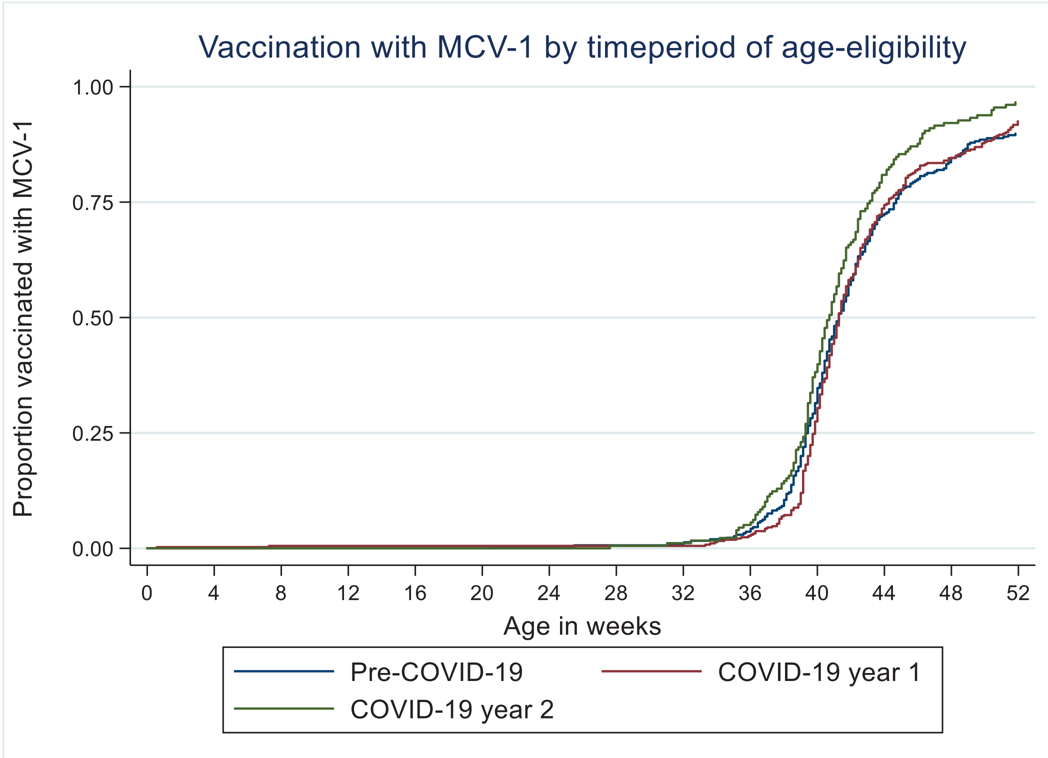

Fig. 3. Vaccination within three months of age-eligibility for vaccination with MCV-1 by time period of age-eligibility for vaccination.

Funding

PCVIS is funded by Gavi, the Vaccine Alliance. J. Anthony. G. Scott is funded through a Wellcome Trust Fellowship–098532.

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. Nyaguara:** Methodology, Investigation, Writing - original draft, Writing - review & editing. **J.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.

References

[1] Cucinotta D, Vanelli M. WHO declares COVID-19 a pandemic. Acta Bio Medica: Atenei Parmensis 2020;91(1):157.

[2] Nelson R. COVID-19 disrupts vaccine delivery. Lancet Infect Dis 2020;20(5):546.

[3] Huhn N. The impact of Covid-19 on routine immunization. Available from: https://www.outbreakobservatory.org/outbreakthursday-1/12/10/2020/w9hy6szcowmz14zc8npyml92x9k8mb.

[4] Mburu CN, Ojal J, Chebet R, Akech D, Karia B, Tuju J, et al. The importance of supplementary immunisation activities to prevent measles outbreaks during the COVID-19 pandemic in Kenya. BMC Medicine 2021;19(1):35.

[5] Lassi ZS, Naseem R, Salam RA, Siddiqui F, Das JK. The impact of the COVID-19 pandemic on immunization campaigns and programs: a systematic review. Int J Environ Res Public Health 2021;18(3):988.

[6] World Health Organization. Pulse survey on continuity of essential health services during the COVID-19 pandemic: interim report, 27 August 2020. 2020 27 August 2020. Report No.: WHO/2019-nCoV/EHS_continuity/survey/2020.1.

[7] Masresha BG, Luce Jr R, Shibeshi ME, Ntsama B, N'Diaye A, Chakauya J, et al. The performance of routine immunization in selected African countries during the first six months of the COVID-19 pandemic. Pan Afr Med J 2020;37(Suppl 1):12.

[8] England PH. Impact of COVID-19 on childhood vaccination counts to week 17 in 2021, and vaccine coverage to March 2021 in England: interim analyses. 11th May 2021.

[9] Europe WHOW-ROf. Varied impact of COVID-19 on routine immunization in the European Region. 16 July 2021.

[10] Ackerson BK, Sy LS, Glenn SC, Qian L, Park CH, Riewerts RJ, et al. Pediatric vaccination during the COVID-19 pandemic. Pediatrics 2021;148(1): e2020047092.

[11] Moraga-Llop FA, Fernández-Prada M, Grande-Tejada AM, Martínez-Alcorta LI, Moreno-Pérez D, Pérez-Martín JJ. Recovering vaccine coverage lost due to the COVID-19 pandemic. Vacunas (Engl Ed) 2020;21(2):129–35.

[12] Haqqi A, Zahoor S, Aftab MN, Tipu I, Rehman Y, Ahmed H, et al. COVID-19 in Pakistan: impact on global polio eradication initiative. J Med Virol 2021.

[13] Chandir S, Siddiqi DA, Mehmood M, Setayesh H, Siddique M, Mirza A, et al. Impact of COVID-19 pandemic response on uptake of routine immunizations

in Sindh, Pakistan: an analysis of provincial electronic immunization registry data. Vaccine 2020;38(45):7146–55.
[14] Buonsenso D, Cinicola B, Kallon MN, Iodice F. Child healthcare and immunizations in sub-Saharan Africa during the COVID-19 pandemic. Front Pediatr 2020;8:517.
[15] Hull BP, Hendry AJ, Dey A, Bryant K, Radkowski C, Pellissier S, et al. The impact of the COVID-19 pandemic on routine vaccinations in Victoria. Med J Aust 2021;215(2):83–4.
[16] Wambua S, Malla L, Mbevi G, Kandiah J, Nwosu A-P, Tuti T, et al. Quantifying the indirect impact of COVID-19 pandemic on utilisation of outpatient and immunisation services in Kenya: a longitudinal study using interrupted time series analysis. BMJ Open 2022;12(3):e055815.
[17] Barasa E, Kazungu J, Orangi S, Kabia E, Ogero M, Kasera K. Indirect health effects of the COVID-19 pandemic in Kenya: a mixed methods assessment. BMC Health Serv Res 2021;21(1):740.
[18] World Heath Organization. WHO and UNICEF warn of a decline in vaccinations during COVID-19. Available on https://www.who.int/news/item/15-07-2020-who-and-unicef-warn-of-a-decline-in-vaccinations-during-covid-19. 2020.
[19] McDonald HI, Tessier E, White JM, Woodruff M, Knowles C, Bates C, et al. Early impact of the coronavirus disease (COVID-19) pandemic and physical distancing measures on routine childhood vaccinations in England, January to April 2020. Eurosurveillance 2020;25(19):2000848.
[20] COVID-19 PfE-BRt. Finding the balance: Public health and social measures in Kenya. 2021. Report No.: Survey 4.
[21] Aluga MA. Coronavirus Disease 2019 (COVID-19) in Kenya: preparedness, response and transmissibility. J Microbiol Immunol Infect 2020;53(5):671–3.
[22] Ministry of Health K. Interim guidance on continuity of essential health services during the COVID-19 Pandemic. 2020.
[23] Wasike A. Kenyan doctors call off strike, nurses keep protesting. 2020 24 December 2020.
[24] KWTRP. Health Worker Strikes in Kenya; How can we prevent them and reduce their negative effects when they happen? And what Covid-19 considerations? Policy Brief. KEMRI-Wellcome Trust Research Programme; 2020.
[25] Masresha BG, Luce Jr R, Shibeshi ME, Ntsama B, N'Diaye A, Chakauya J, et al. The performance of routine immunization in selected African countries during the first six months of the COVID-19 pandemic. Pan Afr Med J 2020;37(Suppl. 1):12.
[26] Scott JAG, Bauni E, Moisi JC, Ojal J, Gatakaa H, Nyundo C, et al. Profile: The Kilifi Health and Demographic Surveillance System (KHDSS). Int J Epidemiol 2012;41(3):650–7.
[27] Adetifa IM, Bwanaali T, Wafula J, Mutuku A, Karia B, Makumi A, et al. Cohort Profile: The Kilifi Vaccine Monitoring Study. Int J Epidemiol 2016;46(3). 792-h.
[28] Kenya National Bureau of Statistics, Ministry of Health/Kenya, National AIDS Control Council/Kenya, Kenya Medical Research Institute, Population NCf, Development/Kenya. Kenya Demographic and Health Survey 2014. Rockville, MD, USA; 2015.
[29] Adetifa IMO, Karia B, Mutuku A, Bwanaali T, Makumi A, Wafula J, et al. Coverage and timeliness of vaccination and the validity of routine estimates: insights from a vaccine registry in Kenya. Vaccine 2018;36(52):7965–74.
[30] Ndiritu M, Cowgill KD, Ismail A, Chiphatsi S, Kamau T, Fegan G, et al. Immunization coverage and risk factors for failure to immunize within the Expanded Programme on Immunization in Kenya after introduction of new Haemophilus influenzae type b and hepatitis b virus antigens. BMC Public Health 2006;6(1):132.
[31] Moïsi JC, Kabuka J, Mitingi D, Levine OS, Scott JA. Spatial and socio-demographic predictors of time-to-immunization in a rural area in Kenya: Is equity attainable? Vaccine 2010;28(35):5725–30.
[32] Causey K, Fullman N, Sorensen RJ, Galles NC, Zheng P, Aravkin A, et al. Estimating global and regional disruptions to routine childhood vaccine coverage during the COVID-19 pandemic in 2020: a modelling study. The Lancet 2021;398(10299):522–34.
[33] Shet A, Carr K, Danovaro-Holliday MC, Sodha SV, Prosperi C, Wunderlich J, et al. Impact of the SARS-CoV-2 pandemic on routine immunisation services: evidence of disruption and recovery from 170 countries and territories. The Lancet Global Health 2022;10(2):e186–94.
[34] Causey K, Mosser JF. Learning from the COVID-19 pandemic to strengthen routine immunization systems. PLoS Med 2022;19(2):e1003934.
[35] Otiende M, Bauni E, Nyaguara A, Amadi D, Nyundo C, Tsory E, et al. Mortality in rural coastal Kenya measured using the Kilifi Health and Demographic Surveillance System: a 16-year descriptive analysis [version 1; peer review: 1 approved, 1 approved with reservations]. Wellcome Open Research. 2021;6 (327).