Vaccine 39 (2021) C89–C95

Contents lists available at ScienceDirect

Vaccine

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

Trends in measles incidence and measles vaccination coverage in Nigeria, 2008–2018 ☆

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ARTICLE INFO

Article history:
Available online 17 April 2021

Keywords:
Measles
Coverage
Epidemiology
Nigeria

ABSTRACT

Introduction: All WHO regions have set measles elimination objective for 2020. To address the specific needs of achieving measles elimination, Nigeria is using a strategy focusing on improving vaccination coverage with the first routine dose of (monovalent) measles (MCV1) at 9 months, providing measles vaccine through supplemental immunization activities (children 9–59 months), and intensified measles case-based surveillance system.
Methods: We reviewed measles immunization coverage from population-based surveys conducted in 2010, 2013 and 2017–18. Additionally, we analyzed measles case-based surveillance reports from 2008–2018 to determine annual, regional and age-specific incidence rates.
Findings: Survey results indicated low MCV1 coverage (54.0% in 2018); with lower coverage in the North (mean 45.5%). Of the 153,097 confirmed cases reported over the studied period, 85.5% (130,871) were from the North. Moreover, 70.8% (108,310) of the confirmed cases were unvaccinated. Annual measles incidence varied from a high of 320.39 per 1,000,000 population in 2013 to a low of 9.80 per 1,000,000 in 2009. The incidence rate is higher among the 9–11 months (524.0 per million) and 12–59 months (376.0 per million). Between 2008 and 2018, the incidence rate had showed geographical variation, with higher incidence in the North (70.6 per million) compare to the South (17.8 per million).
Conclusion: The aim of this study was to provide a descriptive analysis of measles vaccine coverage and incidence in Nigeria from 2008 to 2018 to assess country progress towards measles elimination. Although the total numbers of confirmed measles cases had decreased over the time period, measles routine coverage remains sub-optimal, and the incidence rates are critically high. The high burden of measles in the North highlight the need for region-specific interventions. The measles program relies heavily on polio resources. As the polio program winds down, strong commitments will be required to achieve elimination goals.

1. Introduction

The World Health Organization (WHO) defines measles elimination as "the absence of endemic measles virus transmission in a defined geographic area for a period of at least 12 months in the presence of a well performing surveillance system" [1]. The threshold for elimination is further defined as less than 1 confirmed measles case per 1 million population; to eliminate measles, countries need to achieve high (95%) two-dose vaccine

☆ This supplement was sponsored by the World Health Organization Country Office in Nigeria. The opinions expressed in this publication are those of the authors and are not attributable to the sponsors.

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https://doi.org/10.1016/j.vaccine.2021.03.095
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coverage. To determine whether a country or a WHO Region has achieved elimination, the regional verification commission considers 5 lines of evidence, including the population immunity, quality of surveillance, sustainability of the programme, genotyping evidence, and the disease epidemiology [1].

All six WHO regions have set measles elimination objective for 2020. The Americas eliminated the disease in 2016, but the high number of measles cases in Venezuela and Brazil in 2017 led the region to lose its measles elimination status in 2018 [2,3]. In the WHO African Region (AFR), accelerated measles control activities began in 2001 and in 2011, the region adopted the 2020 measles elimination target [4]. To complement routine immunization coverage and reduce immunity gaps, AFR Member States conducted periodic supplemental immunization activities (SIAs) to reach unimmunized children missed by routine vaccination services, improving measles-case management, and established a case-based measles surveillance [5]. Since 2001, significant progress has been achieved: the number of reported cases decreased by 86% from 520,102 in 2000 to 72,603 in 2017, and the percentage of children who received the 1st dose of Measles-containing-vaccine (MCV1) as recommended in the region increased from 53.0% to 70.0% during the same period of time [6].

Nigeria is the most populous nation in Africa and the seventh most populous in the world. The country occupies an area of 923,768 square kilometers. In terms of land mass and population size, the northern part of the country is larger than the southern part. Nigeria is affected by four climate types (e.g., Tropical rainforest, Savannah, tropical dry/Sahel and Highland climate). These climate types are different from the southern part to the northern part of Nigeria through the country's middle belt. The tropical rainforest climate can be found in the south of Nigeria, while the dry climate can mostly be seen in north of the country [7]. In Nigeria, the peak season for measles transmission begins in January and runs through May; the transmission peak is generally attained in the dry season in Sub-Saharan Africa.

Nigeria introduced measles vaccination into the routine immunization program in 1978 for children aged 9 months [8]. Also during the early measles control period, case-based measles surveillance was initiated in 2006 [9]. In 2011, the country endorsed the 2020 elimination goal of reduction of measles incidence to less than 1 case / 10^6 population per year, and achievement of at least 95% MCV1 coverage in routine immunization and during campaigns at both national and district levels. Measles surveillance performance indicator targets should be maintained and include obtaining a blood specimen from $\geq$ 1 suspected measles case in at least 80% of districts annually, and investigating 2 or more cases of non-measles febrile rash illness per 100,000 population annually [4]. During the early stages of implementing measles control activities, Nigeria conducted an initial "catch-up" campaign (target age: 9 months to 15 years; Administrative coverage: 96.0%) in late 2005, and a "follow-up" campaign (target age: 9 months to 4 years; Administrative coverage: 112.0%) in 2008. With routine MCV1 coverage of less than 50.0%, high incidence rate and the persistence of measles outbreaks, the country has been conducting nationwide mass vaccination campaigns every 2 years. The National MCV1 coverage was 33% in 2000, 44% in 2006, and 41% in 2007; the country saw its measles vaccination coverage slightly increasing from 53% in 2008 to 56% in 2010 [8]. The incidence of confirmed measles was 2 cases per million in 2006 and increased to 16 cases per million in 2007 and 68 cases per million in 2008 as more cases were captured by the recently-introduced system [10].

Previous studies have described progress toward measles elimination in Nigeria during 2005–2008 and 2012–2016 [9,11]. This study analyzes measles incidence over a 11-year period (2008–2018), and includes a detailed comparison of confirmed cases and incidence rate between the epidemiological blocks of North and South of Nigeria. The study also assesses immunization coverage by various surveys over the period.

2. Materials and Methods

2.1. Case-based measles surveillance

The Laboratory supported case-based surveillance for measles was introduced in Nigeria in 2006 following the initial measles "catch-up" campaigns. Measles surveillance is integrated with the polio acute flaccid paralysis (AFP) surveillance structure with the support of 4 national measles serological laboratories for Immunoglobulin (Ig) M antibodies. WHO case definitions for measles were used for classification [4]. When there is a suspected case or during suspected outbreaks, health workers conduct case-based investigations and take appropriate specimens for laboratory confirmation if necessary. Suspected measles cases are confirmed based on laboratory findings (IgM positive for measles), an epidemiologic link (linked to a lab-confirmed cases), or if it is clinically compatible and declared by a physician. Data elements collected by review of clinic records and interviews of suspected cases on the case-based surveillance database are name, address (i.e. rural vs urban, settlement/village, ward, district and state), date of birth/age, sex, date of rash onset, vaccination status, classification of cases (i.e. laboratory test results – positive or negative, epidemiologic linkage, and clinically compatibility), and outcome of the patient (i.e. survived or died) [12]. The measles case-based surveillance data from 2008 to 2018 were analyzed and used to calculate the incidence rates.

2.2. Data collection on immunization rates

The analysis of MCV1 coverage used survey data rather than administratively reported data. Between 2008 and 2018, Nigeria conducted four nationwide population-based surveys where household questionnaires were administered by interviewers to the household heads or caregivers. We extracted regional measles coverage data from the Nigeria Demographic and Health Survey (DHS) 2013 and 2018, the National Immunization Coverage Surveys (NICS) 2010 and NICS 2016/2017. The DHS 2013 and 2018 were national sample survey that collected information about maternal and child health and family planning services [13]. DHS provides data on immunization coverage for children 12–23 months of age by card and history. The NICS 2010 and 2016/2017 are cluster surveys that provide estimates for coverage (by card and recall) in vaccination antigens, including measles, for children between the ages of 12–23 months at national and at state level [14].

2.3. Statistical analysis

Annual incidence rates were calculated as the ratios between the number of measles cases and the mid-year population for the corresponding year as provided by the national population commission using a 3.2% growth rate. Age-specific annual incidences per 1,000,000 population were calculated by dividing the number of cases reported for that age group by corresponding population estimates. Statistical analysis and calculations were conducted using Stata version 15.

3. Results

3.1. Surveys of MVC1 coverage

According to the NICSs, MCV1 coverage in Nigeria was 49.2% in 2010, and declined to 42% in 2016/2017. NICSs results indicated lower coverage in the North compare to the South (36.0% vs 72.4% respectively). Based on the national level NDHS results, the percentage of children vaccinated for measles by 12 months of age increased from 42.1% in 2013 to 54.0% in 2018. The results showed that the 3 Northern zones had a lower MCV1 coverage (mean 45.5%) compare to the 3 Southern zones (mean 73.8%). From 2013 to 2018, MCV1 coverage increased in all 3 northern zones and 2 of 3 southern zones; North Central from 48.1% to 54.2%; North East, from 26.8% to 43.3%; North West from 22.3% to 39.1%; South East from 72.2% to 74.8%; South West (62.5% to 75.5% in 2018. MCV1 coverage declined in the South South states from 74.0%; 71.1%.

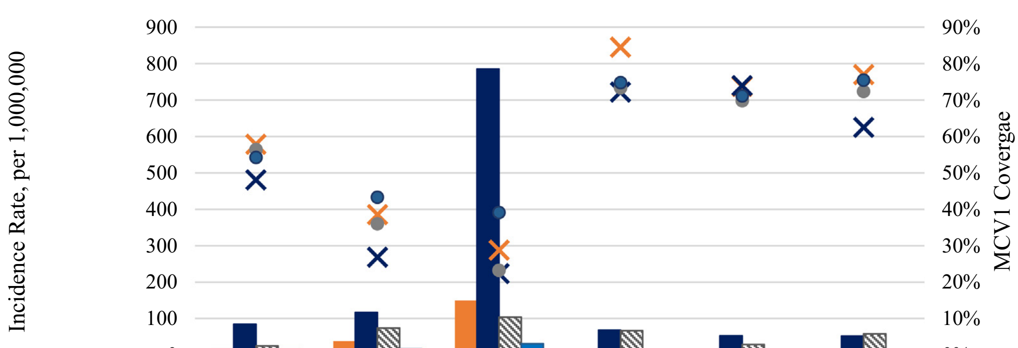
Fig. 1 shows the zonal MCV1 vaccination coverage and zonal measles incidence rates for 2010, 2013, 2016/2017 and 2018. Trend in measles incidences has decreased substantially in regions with increasing MCV1 coverage; regional incidence rate is higher when MCV1 coverage is low. Highest decline in measles incidence rate was seen in 2018 where MCV1 coverage was 54%.

3.2. Measles incidence

A total of 203,089 measles cases were reported to the surveillance system during the 11-year study period, of which 153,097 were confirmed (by laboratory, epidemiologically confirmed or clinically compatible). During 2008–2018, annual measles incidence varied from a low of 9.80 per 1,000,000 in 2009 to a high of 320.39 per 1,000,000 population in 2013 at the national level. For the Northern zones, mean annual incidence was 70.6 compared with 17.8 per 1,000,000 population for the Southern zones. Incidence varied from a high of 520.0 in 2013 in the Northern zones to a low of 11.9 in 2009. For the Southern zones, incidence varied from a high of 31.1 in 2016 to a low of 5.9 per million population in both 2009 and 2013 (Table 1 and 2).

Table 1 also presents age-specific incidence rate of confirmed measles cases between 2008 and 2018. Overall, the incidence rate is higher among the 9–11 months (524.0 per 1,000,000) and the 12–59 months (376.0 per 1,000,000). Throughout the period, in the northern zones, age-specific incidence was highest among 9–11 months with a median annual incidence of 378.4 per 1,000,000, followed by the 12–59 months (340.7 per 1,000,000) and the under 9 months (111.8 per 1,000,000). The lowest age-specific incidences were among those over 20 years (2.2 per 1,000,000), followed by those aged 15–19 years (8.3 per 1,000,000); although in 2012, the measles incidence for the over 20 years was higher than the 15–19 years age group from 2008 to 2018 (Table 2).

The measles incidence and the number of reported cases differed substantially between geographical zones (Table 2 **and** Fig. 2). Overall, the incidence rates and the number of confirmed cases are significantly higher in the North compare to the South. Of 153,097 confirmed cases over the entire period, 130,871 (85.5%) are from the 3 Northern zones and 22,226 (14.5%) from the 3 Southern zones. The number of confirmed cases in the North exceeded the number in the South every year. The mean annual number of confirmed cases for the North was 11,897 compared with 2021 for the South. The greatest number of confirmed cases in both zones occurred in 2013 when 50,684 were reported from the North and 4833 from the South. Over the 2008–18 period, a peak in the number of confirmed cases occurred every 2–3 years in 2011, 2013 and 2016. This pattern was also evident when comparing confirmed cases by North and South zones. After the 2011 and 2013 campaign the following years experienced a sharp drop in the number of confirmed cases from 19,475 to 6397 and from 55,517 to 6864 respectively. As campaigns have been carried out



	North Central	North East	North West	South East	South South	South West
2010 IR	16	37.5	149.3	7.4	7.9	6.9
2013 IR						
2016/2017 IR						
2018 IR	15.4	16.8	30.4	5.5	4.1	6.95
2010 MCV1						
2013 MCV1						
2016/2017 MCV1						
2018 MCV1						

MCV1 = first dose measles-containing vaccine
IR =Incidence Rate
Data Sources: NICS 2010 and 2016/2017, DHS 2013 and 2018

Fig. 1. Measles incidence and vaccination coverage for measles-containing vaccine by zone – Nigeria, 2010, 2013, 2016/2017 and 2018.

Table 1
Age-specific incidence rate of measles confirmed cases – Nigeria, 2008–2018.

Age Group	**2008 (8007)**	**2009 (1511)**	**2010 (8767)**	**2011 (19,475)**	**2012 (6397)**	**2013 (55,517)**	**2014 (6864)**	**2015 (12,435)**	**2016 (7129)**	**2017 (12,063)**	**2018 (4932)**	**Overall Incidence Rate**
	Incidence Rate (IR) per 1,000,000											
<9 Mo	97.07	13.20	106.28	222.87	43.14	525.73	61.76	117.70	160.47	86.87	66.51	97.07
9–11 Mo	342.40	73.60	384.56	752.47	160.64	2125.07	250.99	468.63	635.12	374.87	175.02	374.87
12–59 Mo	273.52	44.70	277.57	552.90	120.00	1657.09	151.43	310.98	404.95	254.95	91.52	273.52
5–9 Yrs	51.28	12.40	59.19	155.79	44.61	322.97	54.62	86.36	123.97	91.15	42.25	59.19
10–14 Yrs	12.90	3.10	10.37	31.61	22.70	65.97	21.29	21.74	29.99	28.43	13.67	21.74
15–19 Yrs	4.92	1.50	2.89	12.52	9.25	11.97	8.89	8.88	13.14	13.76	4.30	8.89
>20 Yrs	1.72	0.80	1.38	5.27	19.58	6.79	5.30	4.00	5.91	8.47	1.78	5.27
Annual IR	**53.73**	**9.80**	**55.24**	**118.91**	**37.98**	**320.39**	**38.54**	**67.97**	**91.22**	**62.63**	**24.98**	**55.24**

Annual IR per 1,000,000 is calculated for all ages; Overall incidence rate is the age-specific median (incidence) rate ratio.
Mo = months; Yrs = years; Confirmed cases = Immunoglobulin (Ig) M positive for measles + Epi-Linked + Clinical Compatible.

Table 2
Age-specific incidence rate and number of confirmed cases by year and by zones – Nigeria, 2008–2018.

North	No. of Confirmed Cases	Age Group														Overall Incidence Rate
		<9 Mo		9–11 Mo		12–59 Mo		5–9 Yrs		10–14 Yrs		15–19 Yrs		> 20 Yrs		
		Incidence Rate per 1,000,000 (% of total confirmed cases)														
2008	7101	91.3	(5.3)	301.7	(4.1)	340.7	(74.4)	70.3	(12.6)	14.4	(2.3)	4.7	(0.7)	1.2	(0.7)	65.3
2009	1041	8.9	(2.1)	69.5	(3.7)	55.1	(64.2)	17.3	(20.7)	4.1	(5.0)	1.6	(1.6)	0.7	(2.7)	11.9
2010	7673	159.2	(5.3)	574.6	(4.4)	451.6	(70.8)	97.3	(15.4)	16.6	(2.4)	4.7	(0.6)	2.1	(1.0)	89.1
2011	17,850	348.9	(5.3)	1178.1	(4.1)	909.0	(65.5)	254.1	(18.5)	48.6	(3.5)	18.7	(1.2)	8.0	(1.8)	193.3
2012	5585	58.2	(2.8)	188.4	(2.1)	189.4	(43.3)	70.7	(16.2)	37.3	(7.9)	15.1	(3.0)	35.3	(24.8)	61.4
2013	50,684	785.8	(4.6)	3138.5	(4.3)	2749.3	(74.0)	521.2	(13.9)	99.5	(2.5)	15.2	(0.3)	5.7	(0.5)	520.0
2014	4493	55.0	(3.5)	236.3	(3.4)	196.7	(58.7)	74.8	(22.3)	25.3	(7.0)	9.6	(2.4)	2.7	(2.5)	46.9
2015	10,044	166.5	(4.9)	634.6	(4.2)	496.2	(68.1)	130.6	(17.9)	23.7	(3.0)	8.3	(1.0)	2.0	(0.8)	102.0
2016	14,435	229.7	(4.8)	967.1	(4.6)	666.4	(65.4)	193.8	(19.0)	37.9	(3.5)	15.5	(1.3)	4.6	(1.4)	142.7
2017	7591	84.5	(3.6)	378.4	(3.6)	324.1	(64.4)	109.6	(21.7)	22.8	(4.2)	7.2	(1.2)	2.2	(1.3)	70.6
2018	4374	111.8	(8.2)	272.3	(4.5)	149.2	(51.6)	70.8	(24.4)	22.7	(7.2)	6.5	(1.9)	2.0	(2.1)	40.6
Overall	130,871	**111.8**	**(100)**	**378.4**	**(100)**	**340.7**	**(100)**	**97.3**	**(100)**	**23.7**	**(100)**	**8.3**	**(100)**	**2.2**	**(100)**	**70.6**
South																
2008	906	21.7	(6.6)	95.8	(6.5)	37.2	(46.9)	16.6	(19.1)	9.2	(9.7)	4.1	(4.1)	1.6	(7.1)	11.2
2009	470	15.9	(8.3)	72.2	(8.1)	26.5	(62.8)	4.6	(11.1)	1.0	(2.1)	0.8	(2.1)	0.8	(5.5)	5.9
2010	1094	34.5	(8.0)	144.1	(7.3)	61.4	(67.0)	10.3	(12.0)	2.2	(2.5)	0.8	(0.6)	0.4	(1.7)	12.6
2011	1625	43.1	(8.8)	157.2	(6.1)	77.8	(60.7)	22.3	(16.3)	4.8	(3.4)	2.4	(1.6)	1.1	(3.1)	17.8
2012	812	23.5	(7.3)	122.7	(8.4)	36.6	(51.0)	13.3	(18.3)	5.4	(6.9)	2.4	(2.7)	1.2	(5.4)	10.0
2013	4833	170.2	(8.6)	635.4	(7.2)	239.8	(56.1)	68.9	(16.1)	22.2	(4.8)	7.7	(1.5)	7.9	(5.7)	59.9
2014	2371	69.7	(7.3)	268.1	(6.3)	98.7	(48.0)	31.1	(15.1)	16.6	(7.5)	8.1	(3.4)	8.3	(12.5)	28.8
2015	2391	60.8	(6.4)	275.1	(6.6)	95.1	(47.0)	34.8	(17.2)	19.5	(9.0)	9.6	(4.1)	6.3	(9.7)	28.3
2016	2694	79.6	(7.7)	246.1	(5.4)	99.7	(44.9)	42.4	(19.1)	20.7	(8.6)	10.4	(4.0)	7.4	(10.3)	31.1
2017	4472	85.9	(5.1)	355.9	(4.9)	159.5	(44.5)	65.0	(18.1)	34.1	(8.8)	20.9	(5.0)	15.8	(13.6)	50.2
2018	558	12.8	(6.3)	61.4	(6.8)	21.4	(48.9)	7.9	(18.1)	2.9	(6.1)	1.6	(3.2)	1.5	(10.6)	6.1
Overall	22,226	**43.1**	**(100)**	**157.2**	**(100)**	**77.8**	**(100)**	**22.3**	**(100)**	**9.2**	**(100)**	**4.1**	**(100)**	**1.6**	**(100)**	**17.8**

Mo = months; Yrs = years

continually in the 2015–2018 period, there have been fewer cases confirmed cases than in 2011 and 2013 (Table 2). In exception of 2017 where the surveillance data showed that outbreaks occurred in the South and in the North, especially in the North East zone (i.e. Borno, Yobe and Adamawa states).

Of the total number of confirmed measles cases reported from 2008 to 2018, 108,310 (70.8%) were unvaccinated, 25,780 (16.8%) had received 1 dose of MCV, and 12,884 (8.4%) received 2 or more doses. The vaccination status of 6123 (4.0%) children are unknown. Among confirmed cases in children less than five years of age, more than 71.3% were not vaccinated. For cases between 10 and 19 years of age, between 60.3% and 64.5% are not vaccinated depending on age group and for those 20 years and older, 72.6% are not vaccinated. (Table 3).

Fig. 2 shows the temporal and spatial distribution of the incidence of measles. Between 2008 and 2018, the measles incidence rate was higher in the North compare to the South region of Nigeria. A frequent peak of the incidence was observed almost every 2 years. Moreover, we observed an important difference in the incidence between the North and the South from 2010 to 2013, and in 2016.

4. Discussion

The target for incidence for measles elimination is less than 1 measles case per 1 million population. Overall incidence rate in Nigeria is substantially above the target rate with the majority of cases being reported in the Northern region where measles immunization coverage rates are lower. Although the total numbers of confirmed cases have varied and a clear downward trend is not apparent, measles incidence in 2018 was lower than that in 2008 (24.98 vs 53.73 per 1,000,000). We do not have information on educational level and socioeconomic status of cases; Nevertheless, the high incidence among children 9–11 months and the high number of unvaccinated children particularly in the North indicates the continued need to develop regional strategies to increase MCV coverage through routine immunization (RI) programs and conduct periodic high quality mass campaigns.

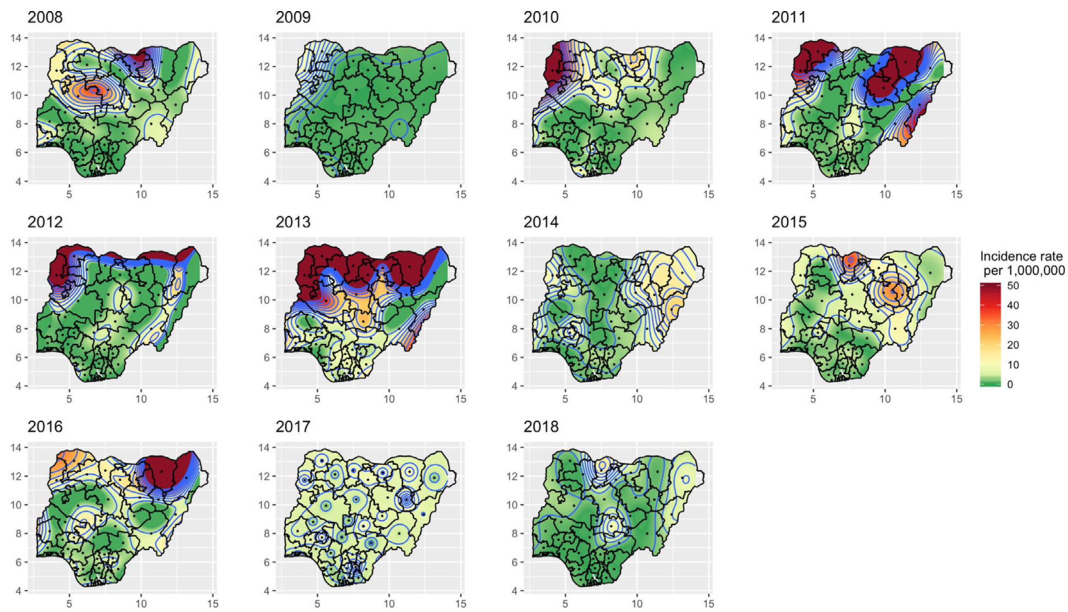


Fig. 2. Regional distribution of measles incidence over time – Nigeria, 2008–2018.

Table 3
Vaccination status of confirmed measles cases by age group – Nigeria, 2008–2018.

Age group	Vaccination Status, No. (%)								Incidence Rate	No. of confirmed cases
	0 Dose		1 Dose		2++ Dose		Unknown Doses			
<9 Mo	6051	(77.35%)	723	(9.24%)	631	(8.07%)	418	(5.34%)	137.0	7823
9–11 Mo	4821	(71.01%)	1126	(16.59%)	457	(6.73%)	385	(5.67%)	524.0	6789
12–59 Mo	71,532	(71.29%)	17,221	(17.16%)	7299	(7.27%)	4284	(4.27%)	376.0	100,336
5–9 Yrs	17,502	(68.45%)	4455	(17.42%)	2875	(11.24%)	738	(2.89%)	95.8	25,570
10–14 Yrs	3859	(64.46%)	1159	(19.36%)	797	(13.31%)	172	(2.87%)	24.2	5987
15–19 Yrs	1178	(60.32%)	395	(20.23%)	328	(16.79%)	52	(2.66%)	8.5	1953
>20 Yrs	3367	(72.58%)	701	(15.11%)	497	(10.71%)	74	(1.60%)	5.6	4639
Overall	108,310	(70.75%)	25,780	(16.84%)	12,884	(8.42%)	6123	(4.00%)	80.3	153,097

Annual IR per 1,000,000 is calculated for all ages;
Confirmed = IgM positive for measles + Epi-Linked + Clinical Compatible;
No. = Number; Mo = months; Yrs = years

In addition to routine immunization for MCV at 9 months of age, Nigeria conducted four national vaccination campaigns against measles in the period of 2008–2018. In 2011, the country conducted a measles campaign targeting children 9–59 months of age, vaccinating 28,483,907 children and achieving administrative coverage of 91.0%. An additional follow-up campaign was implemented in 2013 and the post-campaign coverage survey (PCCS) showed an overall coverage of 74.5%. As the PCCS result was way below the set targets of 95%, the decrease in numbers of confirmed cases in 2014 may not only be due to vaccination. The next follow up campaign was implemented in 2015/2016; the PCCS reported a national figure of 84.5% (below the set targets of 95.0%). The 2017/2018 measles follow-up vaccination campaign targeted over 40,000,000 children, and the PCCS was 87.5%. Campaigns have been effective in reducing the number of confirmed cases; however, the decrease in confirmed cases is short lived and followed by a resurgence of measles cases (particularly in the North). Furthermore, coverage surveys indicate that routine vaccination with MCV1 is insufficient to prevent measles circulation and a short time interval between the campaigns is required based on the accumulation of susceptible children over time [15]. Low RI coverage, high number of children missed during SIAs (PCCS data) and the cumulative number of children susceptible to measles are known factors associated with the occurrence of measles outbreaks [16].

In 2018, the population of Nigeria was estimated at 197,451,204 and the country birth cohort was approximately 8 million children. As only 42.0% of children (NICS 2017/2018) aged 9 months received measles vaccination through routine immunization, an estimated 5,144,000 children (64.3%) remained susceptible to measles; while only 2,856,000 children (8,000,000 × 0.42 × 0.85 vaccine effectiveness) in each birth cohort of 8,000,000 children were protected against the disease. Thus, with a large number of newly susceptible children each year, incidence rates are highest in the under-five age groups and measles outbreaks are more likely to occur every one to two years. As MCV1 coverage is higher in the Southern regions compared to Northern part of the country these effects are more pronounced in the North. Given the significant regional variation in measles epidemiology, there is a need for region-specific interventions. Moreover, because of the substantial costs of outbreak control, documenting measles disease burden is needed to obtain national commitments to measles control and defining strategies for measles elimination [17,18]. Mathematical model of the dynamics of measles can identify areas of low immunity that are at higher risk for measles outbreak as well as to guide in determining the timing and geographic areas to be targeted by the next campaigns[19].

In our analysis, the percentages of confirmed cases vaccinated respectively with one or two doses are high. With a median vaccine effectiveness (VE) of 85% [1], vaccination failures may occur in up to 10–15% of infants vaccinated at age 9 months. The introduction of a second dose of measles containing vaccine (MCV2) increases population immunity by improving coverage among those who may not have received MCV1 and protecting those who failed to seroconvert after the first dose. In studies of revaccination among school entry-age children who did not develop immunity after their first dose of measles vaccine, 95% were found to develop approximately protective immunity after the second dose [20]. Nevertheless, a systemic review that evaluated the effect of age at administration of MCV1 on protection against measles found that while two-dose vaccination coverage is most critical to interrupt measles transmission, older age at first vaccination may be necessary to maintain the high level of population immunity needed [21]. Other possible reasons for the high percentages of confirmed cases vaccinated may include problems with the cold chain or vaccine administration. A two-stage cluster survey of 563 children in famine emergencies in Ethiopia found a low measles VE of 66.9% in children 9–36 months old [22].

To eliminate measles by 2020, AFRO countries were recommended to introduce MCV2 into the RI schedule [1]. By December 2018, 26 countries in the Region have introduced MCV2, and the remaining countries are expected to introduce MCV2 into their RI programs in the coming years [23]. In-line with WHO/AFRO guidelines, Nigeria introduced MCV2 to children from 15 to 23 months of age into the RI schedule in the South in 2019, and is in the process of introducing the second dose in the North in end of 2020 and early 2021. A post-introduction evaluation (PIE) exercise, is planned to be conducted within 6 months after the introduction to evaluate the impact of the MCV2 introduction on the Nigerian Expanded Program on Immunization system.

Apart from the analysis of epidemiological trends to assess progress toward elimination, sero-survey studies could be used to measure the level of population protection against measles, determine population immunity and identify areas for catch-up vaccination activities. Previous studies show that high-quality sero-surveys allow clear characterization of the distribution of immunity at a particular time point, and are useful to improve immunity in localized areas [24]. For example, in a study conducted in Zambia and published in 2019, the sero-survey revealed that the levels of population immunity to measles are sufficient to interrupt measles virus transmission in the absence of pockets of susceptible. The study also found levels of population immunity to be higher than expected given the levels of measles immunization coverage, likely reflecting exposure to wild-type viruses and underreporting of vaccination [25].

This report is subject to at least four limitations. First, vaccination target population data may not be accurate reflection of the actual number of eligible children present localized administrative levels. The last national population census was conducted in 2006 and the country has been continuously using projected population figures by a factor of 3.2 growth rate. Coverage data may not reflect the actual proportion of the target population vaccinated. Second, surveillance data substantially underestimates disease incidence, because not all cases are notified. Thirdly, the vaccination status of confirmed measles cases relies on recall in absence of a vaccination card, and can lead to over- or under-estimation of coverage and vaccination status. In some cases, if the caregiver has forgotten or lost the vaccination card, vaccination history data were collected at the health facility/vaccination center from the register record or, in some hard-to-reach areas, from the community leaders. The final limitation is that some demographic variables (i.e. sex, wealth index, maternal education etc.) were not examined to determine if the measles vaccination coverage disparities in the zones/geographic areas is significantly associated with these demographic variables.

In-line with the country's 2017–2020 Measles Elimination Strategic Plan, the Nigerian National Verification Committee (NVC) for Measles Elimination was established in end of 2017 for the monitoring of progress toward measles elimination. The 2018 NVC annual report highlighted program weaknesses that must be addressed notably on surveillance for early notification of cases, routine immunization and efforts toward ownership of the measles elimination activities. The measles program in Nigeria relies heavily on the Global Polio Eradication Initiative (GPEI) strategies, structure and assets, including staff and physical infrastructure. As the polio program is drawing to a close, strong political and financial commitments from both governmental and partners will be required in order to achieve elimination goals.

CRediT authorship contribution statement

Anne Eudes Jean Baptiste: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Balcha Masresha:** Conceptualization, Methodology, Writing - review & editing. **John Wagai:** Writing - review & editing, Visualization. **Richard Luce:** Writing - review & editing, Visualization. **Joseph Oteri:** Writing - review & editing, Validation. **Boubacar Dieng:** Writing - review & editing, Validation. **Samuel Bawa:** Writing - review & editing. **Obianuju Caroline Ikeonu:** Writing - review & editing. **Martin Chukwuji:** Writing - review & editing. **Fiona Braka:** Writing - review & editing, Validation. **E.A.M. Sanders:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Susan Hahné:** Conceptualization, Methodology, Formal analysis, Writing - review & editing, Visualization. **Eelko Hak:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Visualization.

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.

Acknowledgments

Special gratitude goes to the National Primary Health Care Development Agency (NPHCDA), State and LGA Health Teams across the country, World Health Organization Nigeria country office and field staff. We gratefully acknowledge the Disease Surveillance Notification Officers for their contributions upon which this report is based.

Research data for this article

Some of the data sets used in this paper are publicly available via the sources referenced in the manuscript (e.g., Nigeria Demographic and Health Survey 2013 and 2018, the National Immunization Coverage Surveys (NICS) 2010 and NICS 2017/2018). Others are confidential and the authors do not have the permission to share these data.

Financial support

This work was supported by the World Health Organization, Nigeria Country Office.

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