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Child vaccination in sub-Saharan Africa: Increasing coverage addresses inequalities

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ABSTRACT

Background: Vaccines have substantially contributed to reducing morbidity and mortality among children, but inequality in coverage continues to persist. In this study, we aimed to examine inequalities in child vaccination coverage in sub-Saharan Africa.

Methods: We analysed Demographic and Health Survey data in 25 sub-Saharan African countries. We defined full vaccination coverage as a child who received one dose of bacille Calmette-Guérin vaccine (BCG), three doses of diphtheria, pertussis, and tetanus vaccine (DTP 3), three oral polio vaccine doses (OPV 3), and one dose of measles vaccine. We used the concentration index (CCI) to measure wealth-related inequality in full vaccination, incomplete vaccination, and zero-dose children within and between countries. We fitted a multilevel regression model to identify predictors of inequality in receipts of full vaccination.

Results: Overall, 56.5% (95% CI: 55.7% to 57.3%) of children received full vaccination, 35.1% (34.4% to 35.7%) had incomplete vaccination, while 8.4% (95% CI: 8.0% to 8.8%) of children remained unvaccinated. Full vaccination coverage across the 25 sub-Saharan African countries ranged from 24% in Guinea to 93% in Rwanda. We found pro-rich inequality in full vaccination coverage in 23 countries, except for Gambia and Namibia, where we found pro-poor vaccination coverage. Countries with lower vaccination coverage had higher inequalities suggesting pro-rich coverage, while inequality in unvaccinated children was disproportionately concentrated among disadvantaged subgroups. Four or more antenatal care contracts, childbirth at health facility, improved maternal education, higher household wealth, and frequently listening to the radio increased vaccine uptake.

Conclusions: Continued efforts to improve access to vaccination services are required in sub-Saharan Africa. Improving vaccination coverage and reducing inequalities requires enhancing access to quality services that are accessible, affordable, and acceptable to all. Vaccination programs should target critical social determinants of health and address barriers to better maternal health-seeking behaviour.

1. Introduction

Vaccination is among the most effective and safest public health interventions preventing 2 to 3 million child deaths each year [1,2]. Vaccines have made a major contribution to the decline of some of the most dangerous diseases and eradication of smallpox [3]. Over the past few decades, the expansion of childhood vaccination services has helped achieve significant milestones in child health indicators by reducing illness, disability, and death from several infectious diseases [1]. Worldwide, substantial progress has been made to decrease child mortality in the last two decades, with vaccination playing a crucial role in reducing under-five deaths from 12.5 million in 1990 to 5.3 million in 2018 [4].

However, extreme disparities in child mortality continue to exist across regions, within and between countries [4]. The sub-Saharan African region has the highest under-five mortality rate globally and accounts for 52% of this age group's total deaths. In 2018, the region had an average under-five mortality rate of 78 deaths per 1,000 live births, which translates to 1 in 13 children dying before their fifth birthday [4]. This rate is 16 times higher than the average ratio of 1 in 199 children in high-income countries. The majority of these deaths are preventable or can be

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treated using affordable and simple interventions such as vaccination, clean water and sanitation, adequate nutrition, and appropriate care by a trained health care provider as needed [4,5].

This disparity between high and low-income countries can be reduced if all children have equal access to the benefits of vaccines regardless of their geographic, socioeconomic, or demographic status [2,6]. However, this is not always the case; in many countries, children are under-vaccinated or unvaccinated [7]. As a result, vaccine-preventable diseases remain a cause of morbidity and mortality in many low- and middle-income countries (LMICs) [4].

Over the past few decades, while vaccination services have shown progress in sub-Saharan Africa, basic childhood vaccination coverage remains low in many countries in the region [8]. The majority of these countries are struggling or unable to reach the most disadvantaged segments of their populations [9]. In 2019, 19.7 million children remained under-vaccinated or unvaccinated for DPT 3 vaccine worldwide, of whom 48% were in Africa [9]. The majority of these children lived in Nigeria, Ethiopia, the Democratic Republic of Congo, Angola, and Guinea [7,9].

Ensuring equitable access to vaccination services for all children is a critical target of the Sustainable Development Goals (SDGs) [10]. Addressing systematic disparities in access to child vaccination requires careful assessment, monitoring, and targeted interventions. This paper aims to address this gap by systematically examining inequalities in child vaccination coverage within and between 25 sub-Saharan African countries. In addition, we identified the predictors of inequality among receipts of full vaccination.

2. Methods

2.1. Data

We used the latest Demographic and Health Survey (DHS) data from 25 sub-Saharan African countries. We included all DHS that were conducted from 2013 to 2020. We excluded countries with surveys before 2013, as it may not represent countries' current vaccination coverage. The DHSs are nationally representative, large sample size surveys conducted in over 90 LMICs [11]. DHS samples are stratified by geographic region and by rural or urban areas within each region. The DHS uses a stratified two-stage cluster sampling design. In the first stage of selection, the enumeration areas or primary sampling units (PSUs) are selected using probability proportional to size (PPS) within each stratum. In the second stage, a complete household listing is conducted in each of the selected clusters. Following the listing of the households a fixed number of households are selected by equal probability systematic sampling in the selected cluster.

Standard questionnaires are used across all countries to ensure comparability of data [11,12]. Countries are expected to adopt the full standard model questionnaire, but they can add questions of particular interest. However, questions in the model can be deleted if they are irrelevant in a particular country. The DHS uses standard sampling methods and design across all countries. The sampling methods and design have been described elsewhere [11]. The sample used for the current analysis was limited to children aged 12 to 23 months at the time of the survey, yielding a final sample of 55,102 caretaker/mother–child pairs.

2.2. Measures

Our primary outcome variable of interest is the receipt of all vaccinations, which we defined as a child who had all recommended basic vaccines by the age of 12 months. Ideally, a child should receive BCG at birth, OPV 3 with an optional dose at birth and mandatory doses at 6, 10, and 14 weeks; DTP 3 at 6, 10, and 14 weeks; and one dose of measles vaccine at 9 months. To estimate the proportion of fully vaccinated children, we created a composite variable for children who had received all of these vaccines at the age of 12 months. *Incomplete vaccination* was defined as a child missing at least one dose of any of the vaccines; and *zero-dose children,* are those who had not received any doses of vaccines. Missed opportunities for vaccination was defined as an occasion when a child who is eligible for vaccination with no contraindications visits a health facility but does not receive one or more recommended vaccines [13,14]. The DHS program determined child vaccination status from two sources. Child vaccination record cards provided by mothers/caretakers were used as a primary source, but if these were not available, mothers/caretakers' verbal reports of children's immunization status were recorded. The majority (87%), had vaccination record cards. Of those, 35,027 (64%) cards were seen by the data collectors, 12% had cards but were not seen by the data collectors, and 11% no longer had cards. The remainder (13%) had no cards at all.

2.3. Independent variables

We used the WHO Commission on Social Determinants of Health framework [15] to identify variables that may predict the inequitable coverage of full childhood vaccination. Household wealth index, maternal education levels, and maternal occupational status were used as indicators of mothers' socioeconomic position. The wealth index is a composite measure of a household's cumulative living standard that is calculated using principal components analysis [16]. A household's cumulative living standard was determined based on ownership of selected household assets such as television, radio, refrigerator, and vehicle; materials used for housing construction; and access to sanitation facilities and clean water.

We categorised mothers' education levels as (no education, primary, secondary or higher). For this analysis, we grouped related occupations and formed four categories of women's occupation status (not currently working, skilled and professional, agricultural, and sales and services). We include exposure to media as one of the covariates in this study. We categorised frequency of listening to radio and watching television (TV) as not at all, less than once a week, and once a week or more. We categorised distance to a health facility – as a barrier to accessing health services -- as a big problem or not a big problem). We also included the use of reproductive and maternal health services, including the use of antenatal care that we categorised as fewer than four, or four or more contacts), and place of delivery that we categorised as birth at a health facility or home.

2.4. Statistical analysis

We used the concentration curve and concentration index to quantify socioeconomic inequalities in full vaccination, incomplete vaccination, or zero-dose children. We used the concentration curve to show inequality in vaccine uptake by plotting the cumulative percentage of the population ranked by wealth status (x-axis) against the cumulative percentage of the vaccination coverage on the y-axis. If all children had an equal uptake of vaccine regardless of their wealth status, then the curve would overlap with the 45° line, which indicates the presence of equality in the coverage of vaccination. If the concentration curve falls below the 45° line of equality, it indicates that the uptake of vaccines is pro-rich, but if the curve falls above equality, it indicates pro-poor vaccine uptake.

Concentration indices are used to measure relative inequality by estimating the distribution of one variable (e.g., full vaccination)

over the other (wealth status). Concentration index (CI) is two times the area between the line of equality and the concentration curve. The index takes a value between − 1 and + 1; an index of 0 indicates equality in the uptake of vaccines. The concertation index takes on a positive value if there is an uneven concentration of vaccination coverage among the rich, and a negative value of the concentration index implies pro-poor vaccination coverage [17]. We used ***conindex*** command to estimate concentration indices in Stata [18]. The estimated concentration indices with confidence intervals are presented in Fig. 3. A positive CCI indicates pro-rich full vaccination coverage; if the confidence interval involves zero, inequalities are statistically insignificant, while negative concentration indices suggest a pro-poor full vaccination coverage.

We used a multilevel logistic regression analysis to determine factors driving inequalities in full vaccination among children. We adjusted for sampling design (stratification and clustering) and sampling weights. We specified a 3-level model: at level 1 we adjusted for child, mother, and household factors (46,790 mother–child pairs); at level 2 we adjusted for clustering (12,948 clusters); and at level 3 we adjusted for a country (25 countries). Results are presented with adjusted odds ratios (OR) and statistical significance was declared when the p value was < 0.05. Analyses were conducted using Stata 14.2 and IBM Statistical Package for Social Sciences (SPSS, Chicago, II) version 25.0.

3. Results

Our sample included data from 55,102 children aged 12 to 23 months in 25 sub-Saharan African countries. The number of children per country ranged from 655 in Lesotho to 6143 in Nigeria; these reflect the populations of each country. The majority (68.6%) of children were from rural areas; (22.6%) were from the poorest quantile; and 35.1% of their mothers had no education. The majority, 56% of mothers had four or more antenatal care contacts, and (66.9%) gave birth at a health facility (Table 1).

3.1. Vaccination coverage

Overall, 56.5% (95% CI: 55.7% to 57.3%) of children received full vaccination; 35.1% (34.4% to 35.7%) received incomplete vaccination; while 8.4% (95% CI: 8.0% to 8.8%) of children received zero-dose. Missed opportunities for vaccination across all countries was 43.5% (95% CI: 42.7% to 44.3%); this ranged from 7.3% in Rwanda to 76.1% in Guinea. Fig. 1 shows coverage of all recommended vaccinations that all children should receive by the age of 12 months. The BCG vaccine had the highest coverage at 86.2% (95% CI: 85.6% to 86.8%); whereas three doses of oral polio vaccine had the lowest coverage at 68.2% (95% CI: 67.5% to 68.9%).

There were important differences across the countries in vaccination uptake. For example, in Ghana, Burundi, and Rwanda more than 77% of children received full vaccination; but coverage was <40% in Ethiopia, Nigeria, Angola, Chad, and Guinea (Fig. 2). The highest full vaccination coverage was in Rwanda (93%); while Guinean children received the lowest coverage of full vaccination (24%). The proportion of children who received incomplete vaccination was highest in Chad (56%), while the lowest proportions were registered in Rwanda (7%). In Guinea, 23% of children received zero-dose vaccination, while this was as low as 0.3% in Burundi.

3.2. Socioeconomic inequalities

Fig. 3 shows socioeconomic inequalities in child vaccination in 25 sub-Saharan African countries. With increasing child vaccination coverage, socioeconomic inequalities in vaccination uptake decreased in countries such as Rwanda (CCI: 0.019, 95% CI: 0.01 to 0.029), Burundi (CCI: 0.006, 95 %CI: −0.005 to 0.017), and Ghana (CCI: −0.003, 95% CI: −0.03 to 0.024). On the other hand, as vaccination coverage decreased, socioeconomic disparities in vaccination uptake increased in countries such as Nigeria (CCI: 0.269, 95% CI: 0.241 to 0.297), Angola (CCI: 0.299, 95% CI: 0.254 to 0.344) and Guinea (CCI: 0.153, 95% CI: 0.074 to 0.231). Receipt of full vaccination was pro-rich across most countries, except in Gambia (CCI: −0.138, 95% CI: −0.185 to −0.092) and Namibia (CCI: −0.05, 95% CI: −0.079 to −0.021).

We also found that countries had varied distribution in the coverage of incomplete vaccinations. In most countries, incomplete vaccination was either disproportionately concentrated among disadvantaged subgroups (e.g. in Rwanda, Tanzania, Cameroon, and Nigeria) or showed no statistically significant inequalities (e.g. Burundi, Ghana, Zimbabwe, South Africa, and Benin). On the other hand, zero-dose children were disproportionately concentrated among disadvantaged subgroups in most countries. Inequalities in zero-dose children was highest in Benin (CCI: −0.385, 95% CI:-0.474 to −0.297) followed by Angola (CCI: −0.358, 95% CI: −0.416 to −0.300) and Nigeria (CCI: −0.311, 95% CI: −0.351 to −0.272) (Fig. 3).

We also found variations in full vaccination across different regions of sub-Saharan Africa. The highest inequalities in coverage were registered in the Central African region (CCI: 0.148, 95% CI: 0.127 to 0.169) that include countries such as Cameroon, DR Congo, Angola, and Chad; while the Southern African region showed no inequalities (CCI: −0.009, 95% CI: −0.030 to 0.012) (Fig. 4).

Table 1 shows predictors of full vaccination in the 25 sub-Saharan African countries. We found multiple factors that were associated with higher odds of full vaccination, including: increasing childbirth order, four or more antenatal care contracts, childbirth at a health facility, improved maternal education, higher household wealth, frequently listening to the radio, and residence in rural areas. Children whose mothers attended four or more antenatal care had higher odds (AOR 1.44, 95% CI: 1.24, 1.68) of receiving full vaccination than those who had fewer than four antenatal care contacts. Children who were born at health facilities had higher odds (AOR 1.79, 95% CI: 1.60, 2.01) of receiving full vaccinations than those who were born at home.

The odds of receiving full vaccination increased with the rising level of mother's education: children of women with primary level education (AOR 1.22, 95% CI: 1.06, 1.40) and those with secondary or higher education had higher odds (AOR 1.49 95% CI: 1.24, 1.80) compared to children of women who had no education. The increasing wealth of women's household also increased the odds of children receiving full vaccination. Children from the richest (fifth) quantile had the highest odds of receiving full vaccination (AOR 1.66, 95% CI: 1.27, 2.17), followed by those in the fourth quintile (AOR 1.40 95% CI: 1.20, 1.62) compared to children from the poorest household (Table 1).

4. Discussion

We systematically examined inequalities in child vaccination in 25 sub-Saharan African countries. We found differences in national full vaccination coverage ranging from 24% in Guinea to 93% in Rwanda. We also observed inequalities in the receipt of full vaccination between and within countries.

The COVID-19 pandemic might have worsened the already existing persistent and severe disparities in accessing healthcare services. Routine vaccination disruptions due to Covid-19 maybe even more detrimental for poor households and remote or rural areas in low-income and middle-income countries. Globally, in

Table 1
Factors associated with receiving full vaccinations.

Study variables	Number (%) of study participants		Received full vaccinations (95% CI)	Unadjusted OR (95 CI)	P	Adjusted OR (95 CI)	P
	Frequency	Percent					
Parity					0.002		0.005
First	12,443	22.6	61.2 (60.0 to 62.4)	1.0 (Reference category)		1.0 (Reference category)	
Second	10,598	19.2	59.4 (58.1 to 60.8)	1.01 (0.91, 1.11)		1.13 (1.02, 1.25)	
Third	8846	16.1	58.6 (57.2 to 60.0)	0.98 (0.89, 1.07)		1.14 (1.03, 1.27)	
Fourth	6940	12.6	57.0 (55.5 to 58.6)	0.95 (0.86, 1.06)		1.20 (1.06, 1.34)	
Fifth or more	16,275	29.5	50.0 (48.8 to 51.2)	0.79 (0.70, 0.90)		1.05 (0.93, 1.17)	
Antenatal care contacts					<0.001		<0.001
<4 contacts	23,146	44.0	48.3 (47.2 to 49.4)	1.0 (Reference category)		1.0 (Reference category)	
Four or more contacts	29,490	56.0	63.8 (62.9 to 64.6)	1.78 (1.44, 2.21)		1.44 (1.24, 1.68)	
Place of delivery					<0.001		<0.001
Home	18,247	33.1	36.8 (35.6 to 38.0)	1.0 (Reference category)		1.0 (Reference category)	
Health facility	36,855	66.9	66.4 (65.6 to 67.2)	2.24 (1.90, 2.64)		1.79 (1.60, 2.01)	
Mother's education levels					<0.001		<0.001
No education	19,347	35.1	43.8 (42.5 to 45.1)	1.0 (Reference category)		1.0 (Reference category)	
Primary	19,481	35.4	62.6 (61.5 to 63.6)	1.58 (1.30, 1.91)		1.22 (1.06, 1.40)	
Secondary or higher	16,273	29.5	64.6 (63.5 to 65.7)	2.44 (1.82, 3.26)		1.49 (1.24, 1.80)	
Mother's occupation					0.034		0.022
Not working	14,037	27.4	56.1 (54.7 to 57.5)	1.0 (Reference category)		1.0 (Reference category)	
Skilled and professionals	3760	7.3	61.0 (58.7 to 63.2)	1.31 (1.15, 1.49)		0.99 (0.86, 1.14)	
Sales and services	15,446	30.1	53.8 (52.6 to 55.1)	1.07 (0.94, 1.21)		0.97 (0.88, 1.07)	
Agriculture	18,008	35.1	60.3 (59.0 to 61.6)	0.97 (0.83, 1.14)		1.17 (1.02, 1.34)	
Household wealth index					<0.001		<0.001
Poorest	12,469	22.6	49.6 (48.1 to 51.1)	1.0 (Reference category)		1.0 (Reference category)	
Poorer	11,926	21.6	52.8 (51.4 to 54.2)	1.22 (1.10, 1.36)		1.13 (1.02, 1.26)	
Middle	11,068	20.1	57.3 (56.0 to 58.7)	1.53 (1.31, 1.80)		1.27 (1.12, 1.44)	
Richer	10,230	18.6	60.2 (58.8 to 61.7)	1.86 (1.45, 2.40)		1.40 (1.20, 1.62)	
Richest	9408	17.1	66.1 (64.5 to 67.6)	2.51 (1.64, 3.82)		1.66 (1.27, 2.17)	
Frequency of listening to radio					<0.001		0.005
Not at all	23,904	43.4	48.4 (47.3 to 49.6)	1.0 (Reference category)		1.0 (Reference category)	
Less than once a week	10,602	19.3	61.5 (60.2 to 62.9)	1.44 (1.29, 1.60)		1.18 (1.05, 1.34)	
At least once a week	20,559	37.3	63.6 (62.6 to 64.6)	1.52 (1.41, 1.65)		1.18 (1.06, 1.30)	
Frequency of watching television					<0.001		0.204
Not at all	34,992	63.6	54.0 (53.1 to 55.0)	1.0 (Reference category)		1.0 (Reference category)	
Less than once a week	6746	12.3	59.1 (57.4 to 60.7)	1.24 (1.01, 1.53)		0.91 (0.81, 1.02)	
At least once a week	13,298	24.2	62.6 (61.3 to 64.0)	1.64 (1.30, 2.06)		1.01 (0.89, 1.15)	
Distance to health facility					0.001		0.083
Not a big problem	31,235	61.4	60.3 (59.4 to 61.2)	1.0 (Reference category)		1.0 (Reference category)	
Big problem	19,640	38.6	52.8 (51.6 to 54.0)	0.77 (0.69, 0.87)		0.94 (0.87, 1.01)	
Place of residence					0.008		0.017
Urban	17,288	31.4	59.0 (57.7 to 60.3)	1.0 (Reference category)		1.0 (Reference category)	
Rural	37,813	68.6	55.6 (54.6 to 56.6)	0.70 (0.52, 0.94)		1.19 (1.03, 1.36)	

2020, an estimated 30 million children might have missed doses of DTP3, and 27·2 million might have missed measles-containing vaccine doses. In Pakistan, there was a daily 52.5% vaccinations decline on average during lockdown compared to baseline [19]. In Colombia, an estimated 14.4% reduction was reported in 2020 compared with the same period in 2019 [20]. The most significant declines in coverage were observed among children < 12 months living in rural areas [20]. In Nigeria, WHO confirmed in their preliminary analysis that 362,700 pregnant women missed antenatal care between March and August 2020, and 310 maternal deaths occurred in health facilities in August 2020, nearly twice the number of deaths in August 2019 [21].

The extent of within-country inequality varied by country: most countries showed a substantial pro-rich inequality, except for Gambia and Namibia, where we found pro-poor vaccination coverage. This coverage could partly be explained by the fact that Gambia and Namibia have small populations. As a result, programs may have been able to target and reach vulnerable populations. Further studies are needed to identify what factors contributed to the observed pro-poor vaccination coverage in both Gambia and Namibia.

In Rwanda, Burundi, Ghana, and Zimbabwe, where we found higher vaccination coverage (76% or more), socioeconomic-related inequality was lower. On the other hand, countries such as the Democratic Republic of Congo, Nigeria, Ethiopia, and Guinea had lower child vaccination coverage of 52% or less and higher socioeconomic inequality. The Democratic Republic of Congo, Nigeria, and Ethiopia are also high-priority countries where the proportion of children who remain unvaccinated is the highest in the world [7]. The large population of these countries, especially Nigeria and Ethiopia, could partly explain the low vaccination coverage as the volume of children to vaccinate can place pressure on

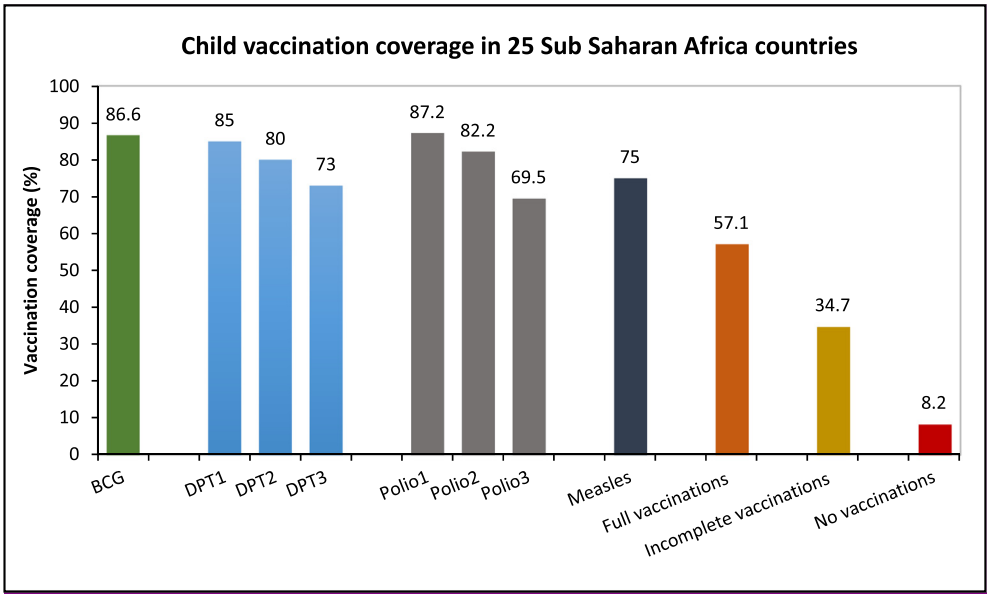

Fig. 1. Coverage of routinely recommended vaccines among children aged 12 to 23 months in 25 sub-Saharan Africa countries (DHS 2013 to 2020).

the health systems [2]. The struggle to ensure equity in vaccination coverage may continue due to fast growing population in sub-Saharan Africa [22]. For example, the population growth rate in Nigeria and Ethiopia has been more than 2% regularly for more than two decades, and in 2018, the population growth rate was 2.6% in Nigeria and Ethiopia [22].

The population size of countries, the rural location of communities and political instability and conflict may have restricted health service activities resulting in low vaccination coverage [23]. For example, in northern Nigeria, if an armed conflict occurs within 10 km from where a child resides, the odds that a child receives any vaccination were 47.2% lower [23].

Missed opportunities for vaccination are a key reason for low vaccination coverage in many countries [13]. The prevalence of missed opportunities for vaccination across the 25 countries covered in our analysis was 42.9%. Low vaccination coverage disproportionately affects disadvantaged subgroups. The prevalence was 50% among the poorest quintile but only 34% among the richest quintile. Reasons for missed opportunities include vaccine stockouts, and provider attitudes and practices that may include a reluctance to opening a multi-dose vaccine vial for fewer children for fear of vaccine wastage [13,14,24]. For example, an opportunity to vaccinate with measles vaccine is more frequently missed as it is provided in ten-dose vials and must be used within six-hours once opened [25].

The lack of vaccination services due to vaccine stockouts is a longstanding and persistent problem across sub-Saharan African health systems that results in missed opportunities [14,25]. In resource-limited settings, a lack of adequately trained personnel to administer vaccines, coupled with non-existent or intermittent access to electricity to manage the cold chain, presents substantial challenges in most African countries [8]. Parents may become discouraged and less likely to return for vaccination if they miss work, have to travel long distances to facilities, experience long waiting times, and fail to receive services [25]. In Kenya [25], people were less likely to seek immunisation services because of frequent vaccine stockouts at health facilities when they presented for vaccination.

The mistreatment of mothers by health workers in an unfriendly, disrespectful, or abusive manner may lower the uptake of vaccination services. Recent systematic reviews of the literature [14,25] reported that health workers chastised mothers who forgot the child's vaccination card, missed a scheduled appointment, or had a dirty or poorly dressed child. This provider mistreatment may result in feelings of humiliation and discourage mothers from vaccinating their children. These attitudes could have negative health consequences for the mothers, as they may contribute to postpartum depression [26]. Providers may also refuse to vaccinate eligible children due to fears and false beliefs such as that a child over 12 months is 'too old' for measles vaccination, or a sick child should not be vaccinated [27].

Vaccine hesitancy/refusal can also occur despite the availability of vaccination services because of negative attitudes, or concerns of real or perceived vaccine adverse events [28,29]. Parents' positive attitudes and their belief that vaccination prevents disease and knowledge of when and where the child needs to receive full vaccinations are important factors for improved vaccine uptake [30].

In many countries, the inability to address both vaccine supply and demand has contributed to disparities in service uptake [14]. Supply-side hurdles include limited access to services, low quality of care, and poor health worker knowledge and attitudes [14,25]. Demand for vaccination can be affected by fear of the vaccine's potential side effects, parents' conflicting priorities, and lack of practical knowledge of vaccination [14,25,31].

Most disadvantaged parents travel longer distances and may wait for long periods for vaccination, despite having work and family responsibilities [32,33]. Other conflicting priorities may include not being able to leave older children while traveling to vaccinate younger children and the need to care for other sick children at home [25]. Although vaccination services are free of charge in many low-income countries, parents often incur additional indirect costs including transportation, which can be challenging [6].

Maternal education contributes to improved child health [30,34,35]; and in this analysis maternal education was associated with immunisation service uptake. Positive perceptions of vaccine safety and importance of vaccination for health are crucial factors in vaccine uptake [30]. Formal education improves critical thinking, communication, problem-solving, and other related skills that are vital to generating income [34]. Educated women are also more likely to attend antenatal care, give birth at a facility, or seek health services for sick children [34,36].

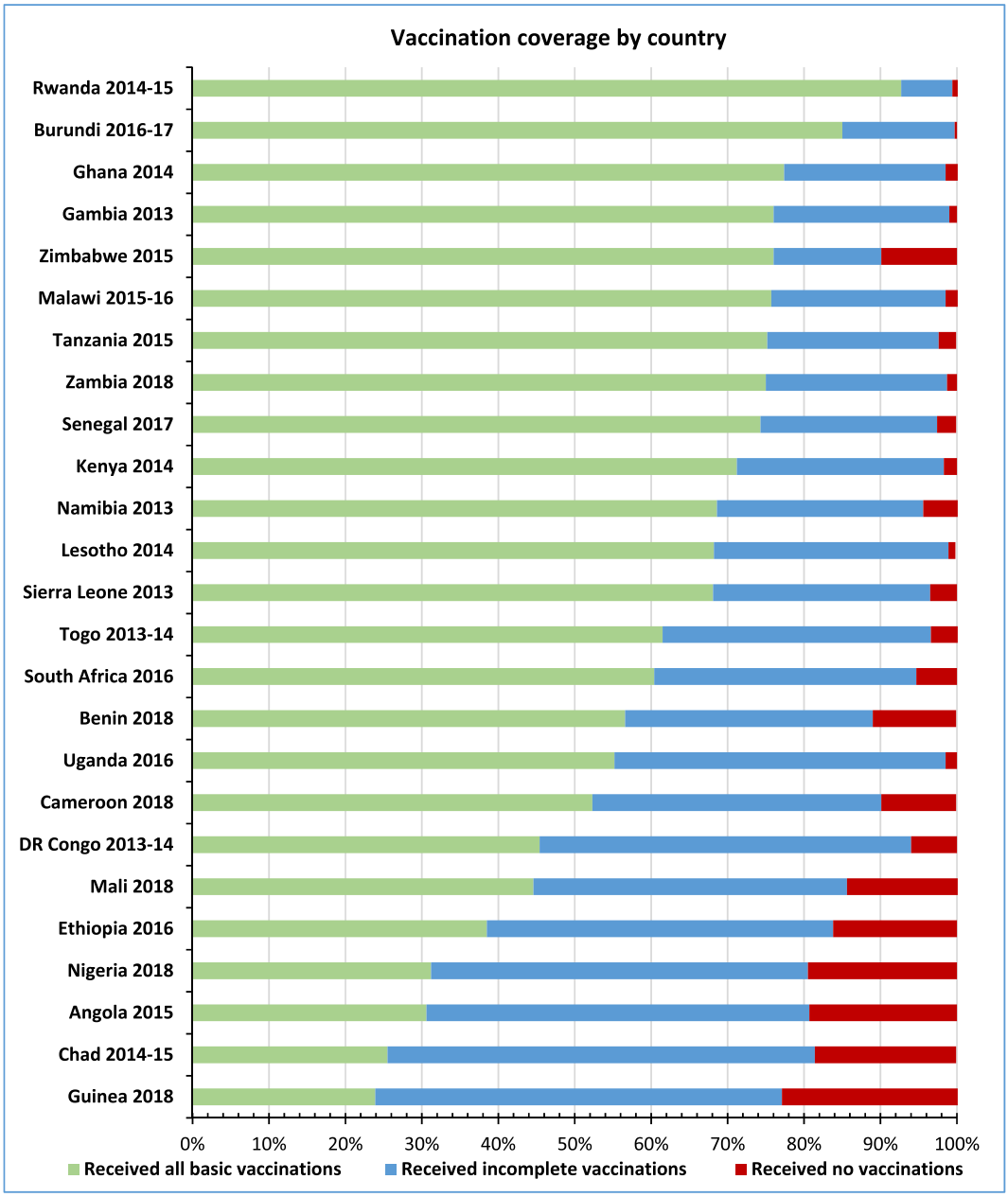

Fig. 2. Vaccination coverage among children aged 12 to 23 months by country (DHS 2013 to 2020).

Mass media is an important tool for creating awareness and promoting positive perceptions towards vaccination and health services [37]. In our analysis, households or women who frequently listened to the radio had improved vaccine uptake. Radio-based health promotion campaigns are an important strategy to raise community awareness and encourage mothers to vaccinate their children [27]. Communication strategies that inform and educate can help address soon-to-be parents and new parents about childhood vaccination, and vaccination sites and schedules [38,39]. Health education can be offered to groups of parents, pregnant women attending antenatal clinics or vaccination services, and during home visits [38,39]. Posters and flyers in clinics and communities can also be used to augment this education. Interventions to remind and recall important health messages can be provided using vaccination cards that serve as reminders for vaccination appointments. Furthermore, local radio announcements and town announcers can effectively work to remind communities about routine immunisation clinic visits in rural settings [38].

The continuum of care has recently become a core principle of programs for maternal, newborn, and child health services to reduce morbidity and mortality [40]. This approach helps to avoid divisions between maternal and child health services or places of service delivery by focusing efforts at reducing dropouts [40]. Our analysis demonstrated the strong connection between maternal and child health services where the use of antenatal care and institutional delivery was associated with increased odds of vaccination service uptake. During antenatal care, childbirth at a facility, or postnatal care visits women receive counselling on newborn and child health, improving their awareness about vaccination benefits and service arrangements [41]. These service points present an opportunity for creating initial awareness of the benefits of vaccines, vaccination schedules, and vaccination service arrangements.

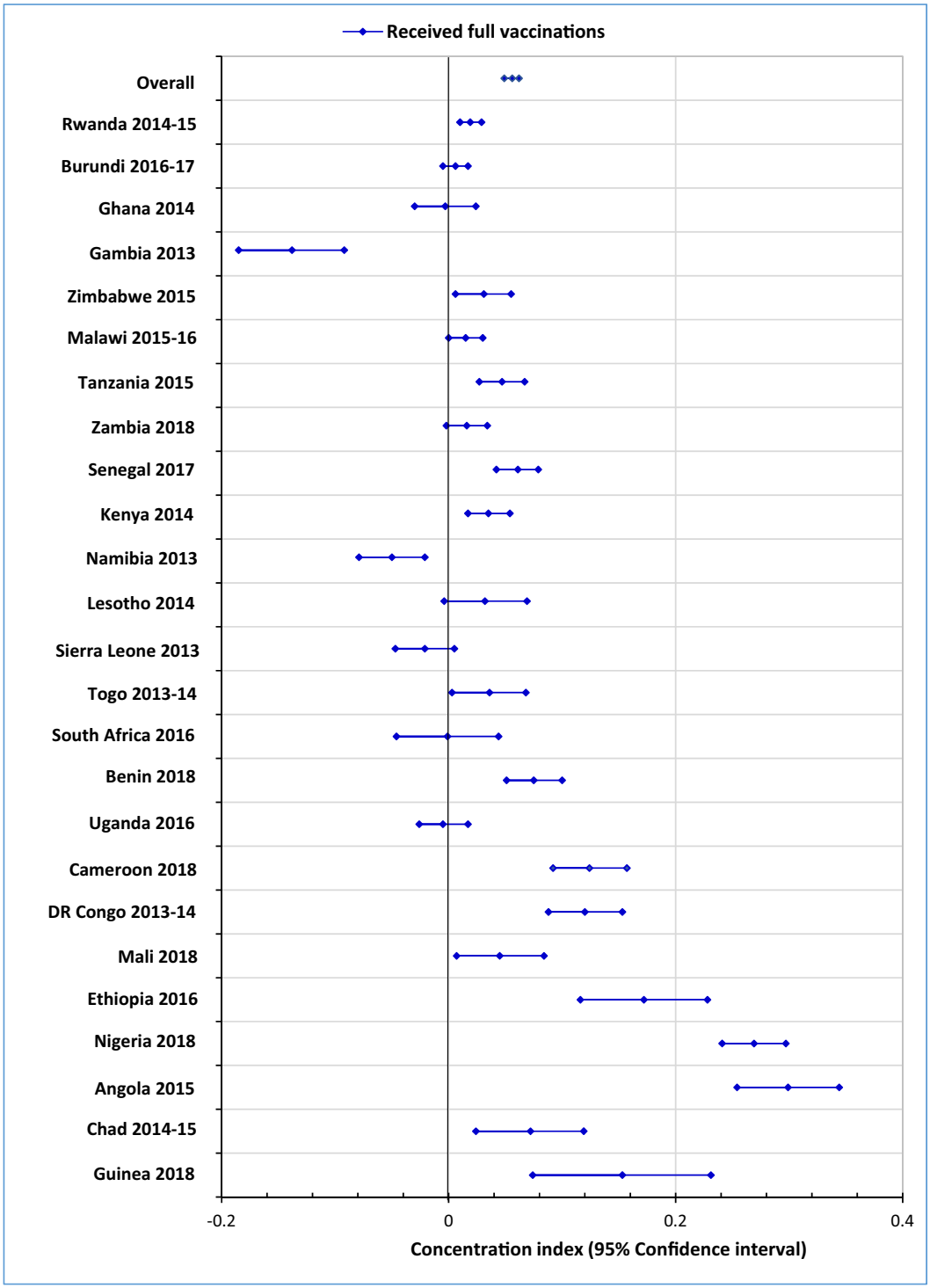

Fig. 3. Concentration indices for child vaccination status across 25 Sub Saharan Africa countries (DHS 2013 to 2020).

To address missed opportunities and reduce inequalities in vaccination coverage, one or a combination of strategies can be used [3,24,27]. Important strategies include enforcing booster vaccinations, screening for vaccination and providing health cards that record immunisation status [24,27]. Studies have demonstrated that screening for all children aged two to five years who are eligible for vaccination during any contact (sick or well) with health services improves immunization coverage while reducing missed opportunities for vaccinations [27,42]. Effective implementation of this approach could increase vaccination coverage by at least 10% [24]. In the United States, a study showed that screening for the vaccination status of children aged 18 months could increase vaccine coverage rates by 27 to 61 percentage points [42]. However, there are significant challenges in implementing screening and vaccination of sick and well children (aged over two years) in low-income countries. These challenges include health workforce shortages and a lack of clear guidelines to implement immunisation screening and protect health workers [27].

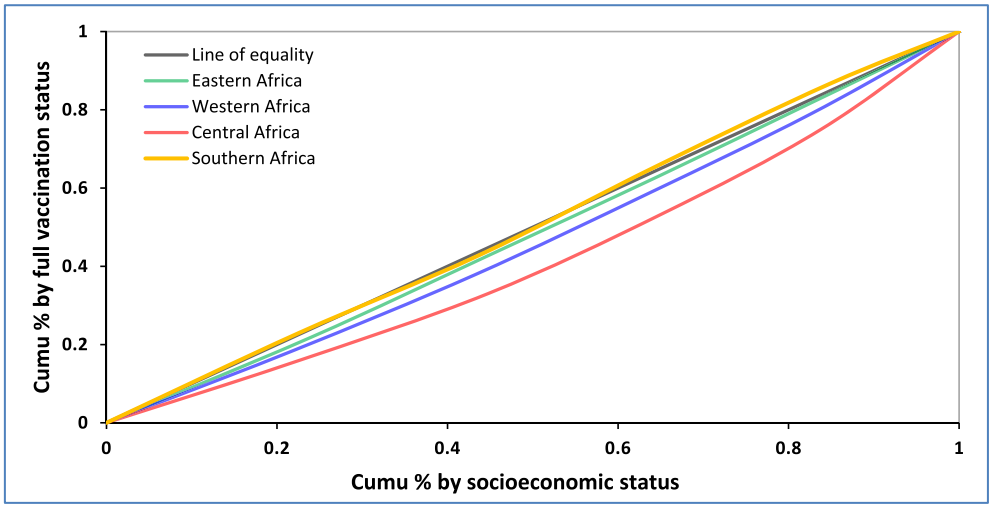

Fig. 4. Concentration curves for full vaccination status across sub-regions in the sub-Saharan Africa region (DHS 2013 to 2020). Note: The black line represents the line of equality (45-degree line). As shown in the figure, all sub-Saharan regions showed pro-rich inequality in the uptake of full vaccination, except for Southern Africa (yellow line), which almost coincides with the line of equality (black line). Central Africa reported the highest pro-rich inequality followed by Western Africa.

Campaigns are another effective strategy to provide immediate and widespread access to vaccination services. Campaigns involve communication followed by the administration of vaccine doses to a large population over a short period of time [7,24]. They can be particularly effective in acute situations such as natural disasters, outbreaks, or conflicts [2,7]. The use of campaigns has contributed to increasing vaccination coverage or even eradicating some diseases; in doing so, campaigns have contributed to making progress towards universal coverage [43]. To get the most out of vaccination campaigns, planning for campaigns should be supported by robust evidence of coverage gaps, and efforts to ensure that those people missed by routine immunisation programs are reached [24,43]. However, campaigns are not part of the regular system of health initiatives and countries might lack the resources to ensure sustainability, as priority is given to routine immunisation [7].

Another strategy to reduce vaccination coverage inequalities is implementing regular immunisation outreach programs [3,7,24]. Outreach activities involve health workers travelling to communities far from health facilities to deliver vaccines. In Ethiopia [44] and Malawi [45], the establishment of routine outreach programs has been effective in reaching remote areas. For communities that move seasonally, this approach ensures better access to health services, including immunisation services [3,24]. However, routine outreach programs are challenging in countries that experience political instability and military conflict as it weakens health systems and puts the safety of health workers in danger.

Our study's strengths include the use of large, nationally representative population-based surveys collected from 25 countries in sub-Saharan Africa. We used two approaches to examine inequality in the uptake of vaccination services. First, we used the concentration curve and index to assess wealth inequalities in full vaccination, incomplete vaccination, and zero-dose children within and across 25 sub-Saharan countries. Second, we used a multilevel logistic regression analysis to determine factors driving inequalities in child full vaccination. However, there were some limitations to the study. If vaccination/health cards were not available, maternal recall was used to identify a child's vaccination status. We used the most recent data available from the Demographic and Health Surveys, dating back to 2013 for some countries. There may be differences from the current rates for some countries as it may not represent recent vaccination coverage. Although we were able to examine wealth-related inequality in child vaccination for each country, we were unable to identify the predictors of inequality in full vaccination specific to each country. A record card is the "gold standard" source of information to estimate child vaccination coverage. However, cards might not always be seen at the time of interview because of loss, storage at health facilities, misplacement or elsewhere, or other survey-related procedures. In such situations where record cards are not available, maternal reports have been used throughout the literature to estimate coverage. Evidence suggests parental/caregiver vaccination reports should be used to improve coverage estimates where cards are not available [46–49].

5. Conclusions

Despite global progress in vaccination coverage, we found that substantial numbers of children fail to receive and benefit from all recommended vaccines. We found pro-rich inequality in the coverage of full vaccination and disproportionate levels of zero-dose and incomplete vaccination among disadvantaged population groups. This inequality within countries should be addressed on a priority basis through equity-oriented and context-appropriate policies and practices.

Continued efforts to improve access to vaccination services are required in sub-Saharan Africa. In addition to addressing the vaccine supply issues, health service delivery systems should also target increasing demand for vaccination services by providing targeted health information and education. Health facilities should also focus on addressing vaccine stockouts by securing adequate vaccine doses and ensuring reliable cold chain management. Improved training of personnel is necessary to strengthen screen and deliver vaccines to all previously unvaccinated eligible children and improve health worker attitudes towards service users.

Vaccination programs and policies should primarily target areas with poor vaccination coverage and directly consider the needs and experiences of poor and vulnerable populations. In addition to education initiatives, areas with critical vaccination coverage gaps can be supported by monetary or material incentives.

CRediT authorship contribution statement

Firew Tekle Bobo: Conceptualization, Methodology, Software, Writing - Original draft preparation, Investigation. **Augustine Asante:** Conceptualization, Supervision, Writing- Reviewing and Editing. **Mirkuzie Woldie:** Conceptualization, Supervision, Writing- Reviewing and Editing. **Angela Dawson:** Conceptualization, Supervision, Writing- Reviewing and Editing. **Andrew Hayen:** Conceptualization, Supervision, Validation, Software, Writing-Reviewing and Editing.

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.

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