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Incomplete vaccination and associated factors among children aged 12–23 months in South Africa: an analysis of the South African demographic and health survey 2016

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ABSTRACT

Background: Socioeconomic and health inequalities remain a huge problem in post-apartheid South Africa. Despite substantial efforts at ensuring universal access to vaccines, many children remain under-vaccinated in the country. This study aimed to assess the prevalence and factors associated with incomplete vaccination in the first year of life, among children aged 12–23 months in South Africa.

Methods: The study is a secondary analysis of the 2016 South African Demographic and Health Survey. A multivariable logistic regression model was applied to the data on 708 children aged 12–23 months. The study outcome, vaccination completeness, was assessed using a composite assessment of nine doses of four vaccines; Bacillus Calmette–Guérin (BCG) (one dose), Polio (four doses), diphtheria-tetanus-pertussis containing vaccines (DTP) (three doses) and measles-containing vaccines (MCV) (one dose). Children who received all the nine doses were categorized as completely vaccinated. Independent variables included child, maternal, and demographic characteristics. Variables were included in the model based on literature findings. Bivariate analyses were used to examine the crude association between each independent variable and incomplete vaccination, while the multivariable logistic regression model was used to examine the adjusted association after controlling for other variables. Measures of association were presented as odds ratios (OR) with their 95% confidence intervals (CI).

Results: About two-fifths (40.8%) of the children were incompletely vaccinated. The prevalence of incomplete vaccination was significantly high among children whose mothers did not receive antenatal care (ANC) during pregnancy (57.5%), and children living in Gauteng Province (52.2%). From the bivariate analyses, the odds of being incompletely vaccinated were three times higher in children whose mothers did not attend ANC compared with children whose mothers attended ANC (crude OR = 2.93; 95% CI 1.42–6.03). The odds were about three times higher in children living in Mpumalanga province (OR = 2.58; 95% CI 1.27–5.25) and in those living in Gauteng province (OR = 2.76; 95% CI 1.30–5.91), compared with those living in Free State province. Conversely, the odds were 32% lower in children from rich households, compared with those from poor households (OR = 0.68; 95% CI 0.47–0.98). In the adjusted model, the higher odds of incomplete vaccination in children whose mothers did not attend ANC were maintained in both magnitude and direction (adjusted OR [aOR] = 2.87; 95% CI 1.31–6.25). Similarly, compared with children living in Free State province, the higher odds of a child being incompletely vaccinated in Mpumalanga (aOR = 2.30; 95% CI 1.03–5.14) and in Gauteng (aOR = 3.10; 95% CI 1.35–7.15) provinces were maintained in both magnitude and direction.

Conclusions: There is a substantial burden of incomplete childhood vaccination in South Africa. Maternal ANC attendance during pregnancy and area of residence significantly influences this burden. Interventions that promote broader health service utilization, such as ANC attendance, can help improve the awareness and uptake of routine childhood vaccination. It is also imperative to take into consideration the provincial disparities in childhood vaccination completeness, in planning and implementing interventions to improve vaccination coverage in the country.



KEYWORDS

Children; incomplete vaccination; coverage; factors; determinants

Introduction

According to a report by the World Health Organization (WHO), global immunization coverage has stagnated far below the 90% target for more than a decade, meaning that a significant proportion of the global annual birth cohort remains incompletely vaccinated or unvaccinated.¹ South Africa in particular, has been in the spotlight concerning its immunization coverage data.² WHO and the

United Nations Children’s Fund (UNICEF) estimates of immunization coverage for 2018 showed that about one-third of children in South Africa are not fully vaccinated.³ Socioeconomic and health inequalities remain a huge problem in post-apartheid South Africa.⁴ This is evident in the uneven access to health-care services such as routine childhood vaccination, despite substantial efforts at ensuring universal access to vaccines.⁵

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In May 2012, South Africa joined other WHO member states to endorse the Global Vaccine Action Plan (GVAP).¹ Launched in 2011, the GVAP sets out goals and objectives for vaccination for the decade. Its vision was of a world in which all individuals and communities enjoy lives free from vaccine-preventable diseases, with a global target for countries to reach 90% national coverage of all their primary series vaccines by 2020. However, immunization coverage through the Expanded Programme on Immunization of South Africa (EPI-SA) during the first year of life, shows that South Africa is not on track in terms of reaching the GVAP targets by the year 2020.² Evidence from studies done outside of South Africa attributes incomplete childhood vaccination to a host of factors such as socioeconomic status, residential areas, mother's level of education, number of children in a family and the mother's age and media exposure.^{6–10} In South Africa, limited evidence attributes incomplete vaccination among children to factors like vaccine stock-outs, lack of awareness of the vaccination schedule by the mothers or caregivers, and nonattendance of antenatal care during pregnancy.¹¹

The National Department of Health (DOH) in South Africa formulates policies, procedures, and guidelines to support routine vaccination services implementation across the country through the EPI-SA.^{2,12} In line with evolving disease burden priorities, the routine childhood immunization schedule had been revised at various times, the most recent revision being in 2015; with the changes in measles vaccine schedules from 9 and 18 months to 6 and 12 months for first and second doses, respectively.^{13,14} Table 1 shows South Africa's current childhood immunization schedule:

Vaccines can prevent diseases only if they reach the target population in need. Adequate and equitable access to vaccines is important for the attainment of not only the GVAP targets but also the Universal Health Coverage agenda and Goal 3 of Sustainable Development Goals (SDGs) by 2030.^{15,16} Data on the prevalence and risk factors for incomplete vaccination specific to the South African context are sparse. To the best of our knowledge, this will be the first study to estimate the national and subnational burden of incomplete childhood vaccination in South Africa using a multi-dose vaccination outcome. Additionally, estimating

the factors associated with incomplete childhood vaccination in South Africa has not previously been done using a nationally representative sample. Understanding the burden and associated factors of incomplete vaccination have policy and practice implications. It will inform contextually appropriate and locally responsive vaccination strategies and interventions, that can redress persistent inequities in vaccination access. Therefore, the study aimed to assess the prevalence and factors associated with incomplete vaccination in the first year of life, among children aged 12–23 months in South Africa.

Methods

Study design

This is a cross-sectional analysis of nationally representative data from the South African Demographic and Health Survey (SADHS) 2016. The main purpose of the DHS was to provide up-to-date estimates of basic demographic and health indicators which include fertility levels, maternal and childhood mortality, immunization coverage, HIV testing and counseling, and physical and sexual violence against women. Another objective was to provide estimates of health and behavior indicators in adults aged 15 y and older.

SADHS 2016 sampling technique and data collection

Administratively, South Africa is divided into nine provinces. The provinces are in turn divided into 52 districts: 8 metropolitan and 44 district municipalities. The district municipalities are further subdivided into 205 local municipalities.¹⁷

The SADHS is a composition of household surveys conducted in South Africa across provinces and districts using a multi-stage, stratified sampling design with households as the sampling unit.¹⁷ The sampling frame used for the SADHS 2016 is the Statistics South Africa Master Sample Frame (MSF), which was created using Census 2011 enumeration areas (EAs). In the MSF, EAs of manageable size were treated as primary sampling units (PSUs). Small neighboring EAs were pooled together to form new PSUs, while large EAs were split into conceptual PSUs.¹⁷ The MSF contained information about location (province, district, municipality), type of residence (urban or non-urban), and number of households for each PSU.

The SADHS 2016 followed a stratified two-stage sampling design with a probability proportional to size sampling of PSUs at the first stage, and systematic sampling of residential dwelling units (DUs) at the second stage. One or more households may be located in any given DU; recent surveys have found 1.03 households per DU on average. The Census 2011 DU count was used as the PSU measure of size. The sampling was designed to provide estimates of key indicators for the country as a whole, for urban and non-urban areas separately, and for each of the nine provinces in South Africa. To ensure that the survey precision was comparable across provinces, PSUs were allocated by a probability proportional to size. Each province was stratified into urban, farm, and traditional areas, yielding 26 sampling strata, from which 750 PSUs were

Table 1. Current childhood vaccination schedule in South Africa (since 2015).

Age	Vaccine offered
Birth	BCG, OPV (0)
6 Weeks	OPV (1), RV (1), DTaP-IPV-Hib-HepB (1), PCV (1)
10 Weeks	DTaP-IPV-HIB-HepB (2)
14 Weeks	RV (2), DTaP-IPV-Hib-HepB (3), PCV (2)
6 Months	Measles (1)
9 Months	PCV (3)
12 Months	Measles (2)
18 Months	DTaP-IPV-Hib-HepB (4)
6 Years	Td (1)
9 Years	HPV (1), HPV (2) (2 doses, 6 months apart)*
12 Years	Td (2)

BCG = Bacillus Calmette-Guerin, DTaP-IPV-Hib-HepB = Hexavalent vaccine (containing diphtheria, tetanus, pertussis, inactivated polio, Haemophilus influenzae b and Hepatitis B antigens), HPV = human papilloma virus vaccine, OPV = oral polio vaccine, PCV = pneumococcal conjugate vaccine, RV = rotavirus vaccine, Td = tetanus and reduced dose diphtheria vaccine.

*The HPV vaccine is given as part of the school health program rather than the EPI-SA.

selected. DUs within each PSU were listed and this list served as a frame for sampling DUs.

Data collection for the SADHS 2016 took place from 27 June 2016 to 4 November 2016. Data were collected using questionnaires administered by conducting face-to-face interviews. Information obtained from the women's or caregiver's questionnaires included vaccination status and maternal, child, and demographic characteristics. Information on vaccination was collected through the Road to Health booklet (RtHB) and mothers' verbal reports. The RtHB contains children's health records and is issued to all caregivers. It also contains checklists of appropriate child growth monitoring and developmental assessments that should be performed during each visit to the hospital by a child, including vaccination status assessment.¹⁸ Interviewers asked mothers to present the vaccination cards to obtain vaccination dates. In the absence of vaccination cards, such mothers were asked to recall the vaccination received by their children. Details of the questionnaires and data collection procedure have been published elsewhere.¹⁹ A dataset was created from information obtained from these questionnaires.

Study sample selection and data collection

From the dataset, we included all children aged 12–23 months, excluding those younger than 12 months and those older than 23 months. A total of 708 children aged 12–23 months, living in 416 communities, within 9 provinces were included in the study. To address our objective, we extracted data on vaccination status; child characteristics: sex, birth order, and birth weight; maternal characteristics: age, education, employment status, marital status, media exposure, antenatal care attendance, and household wealth index; and demographic characteristics: district and province of residence.

Outcome variable

We limited our study to children aged 12–23 months as children at this age are expected to have received all the basic doses of vaccines. This age group represents the birth cohort of the previous year and should have received all scheduled vaccines by 1 y of age. Vaccination completeness was assessed using a composite outcome of nine doses of four vaccines for which SADHS data were collected. The vaccines include; bacillus Calmette–Guérin (BCG) (one dose), polio vaccine (four doses; including two doses of oral polio vaccine (OPV) and two doses of inactivated polio vaccine (IPV)), diphtheria-tetanus-pertussis-containing vaccines (DTP) (three doses) and measles-containing vaccines (MCV) (one dose). The DTP-containing vaccine currently used in South Africa is a hexavalent vaccine that also includes IPV, *Haemophilus influenzae* type b and *Hepatitis B* virus antigens (See Table 1).¹⁴ According to the WHO Guidelines, complete vaccination is defined as receipt of one dose of BCG, three doses of DTP-containing vaccine, at least three doses of vaccine against polio and one dose of measles vaccine within the first year of life.²⁰ Although there are now newer vaccines like the pneumococcal conjugate vaccine (PCV) and rotavirus vaccine (RV) in the country's child vaccination schedule (See Table 1), this study's definition of complete vaccination was limited to the so-called

'traditional vaccines' with which complete vaccination is defined by WHO.²⁰ Children who received all the nine vaccine doses were categorized as completely vaccinated and those who received less than nine doses were defined as incompletely vaccinated.

Independent variables

The following determinant variables were considered in the study; child characteristics: sex, birth order, and birth size; maternal characteristics: age, education, household wealth index, marital status, occupation, media exposure, and antenatal care attendance; demographic characteristics: area and province of residence. Sex of child was defined as male and female. Birth order of children was grouped into 1st – 3rd order and 4th+ order. The weight of the child at birth was grouped into three categories of size; large, average, and small. The mother's age was grouped into 15–24, 25–34, and 35+ y. Educational levels were defined as less than secondary and secondary or higher. Wealth index was originally presented in five quintiles by the SADHS 2016 which were derived from the measurements of ownership of household items such as car, radio, television, and dwelling features like toilet facilities, water source, and type of roofing/floor. This mode of measurement has been used by the World Bank to categorize households into poverty levels based on principal components analysis.²¹ For easy interpretation, we reclassified the wealth index into three categories (poor, middle, and rich). Marital status was grouped into unmarried and married. Maternal occupation was classified as not working and working. Media exposure refers to the frequency of exposure to a newspaper, radio, and television. Those who were exposed to any of the three outlets (for any number of times in a week) were defined as having media exposure and others were considered as not having media exposure. Antenatal care attendance was defined as making at least one antenatal clinic visit during the pregnancy of the index child and categorized as attended and never attended.

Data analysis

Descriptive statistics were used to summarize the data, by presenting the distributions of independent variables by the outcome variable. The distributions were expressed as frequencies and percentages. Bivariate analyses and a multivariable logistic regression model were used to examine the association between various independent variables and incomplete childhood vaccination. Bivariate analyses were used to examine the crude association between each independent variable and incomplete vaccination, while the multivariable logistic regression was used to examine the adjusted association between each independent variable and incomplete childhood vaccination. We have applied binary logistic regression because of the dichotomous nature of the outcome variable. Variables used to build the model were based on previous literature. Measures of association were presented as odds ratios (OR) with their corresponding 95% confidence intervals (CI), with statistical significance considered at p -value <0.05. We used the Bayesian Information Criterion (BIC) to assess the goodness of fit of the model. Variance Inflation Factor (VIF) was applied to test for multicollinearity.

To ensure the representativeness of the sample, sampling weight was assigned at various levels of analysis to account for over and under-sampling within sampling units. This was done by taking into account the probabilities of selection at the various strata in the weighted sample. Given the stratified nature of the data, a multilevel analysis would have been an ideal analytical approach. However, due to a small sample size and insufficient effective sample size of children per PSU, we resorted to a multilevel logistic regression approach. To account for the clustering effect, we used a mixed effect logistic regression approach in fitting the model. Data analysis was done using Stata statistical software (Version 14).²²

Results

Prevalence of incomplete vaccination

Table 2 presents the prevalence of incomplete childhood vaccination by child, maternal, and provincial characteristics. About two-fifths (40.8%; 95% CI = 37.7–44.5%) of all the children were incompletely vaccinated. The prevalence of incomplete vaccination was substantially high among children whose mothers did not receive antenatal care (ANC) during pregnancy (57.5%) and those living in Gauteng province (52.2%).

Measures of association

Table 2 illustrates the estimates from the unadjusted (bivariate) analyses and the adjusted (multivariable) logistic regression model. From the bivariate analyses, the odds of being incompletely vaccinated were three times higher in children whose mothers did not attend ANC during pregnancy compared with children whose mothers attended ANC (crude OR = 2.93; 95% CI 1.42–6.03). The odds were also about three times higher in children living in Mpumalanga province (OR = 2.58; 95% CI 1.27–5.25) and in those living in Gauteng province (OR = 2.76; 95% CI 1.30–5.91), compared with those living in Free State province. Conversely, the odds of being incompletely vaccinated were 32% lower in children from rich households, compared with those from poor households (OR = 0.68; 95% CI 0.47–0.98).

In the adjusted model, the higher odds of incomplete vaccination among children whose mothers attended antenatal care, compared with those whose mothers did not attend ANC, were maintained in both magnitude and direction (adjusted odds ratio [aOR] = 2.87; 95% CI 1.31–6.25). Similarly, compared with children living in Free State province, the higher odds of a child being incompletely vaccinated in Mpumalanga province (aOR = 2.30; 95% CI 1.03–5.14) and in Gauteng province (aOR = 3.10; 95% CI 1.35–7.15) were maintained in both magnitude and direction. Conversely, the lower odds of incomplete vaccination among children from rich households, compared with those from poor households, lost statistical significance.

Discussion

We found a substantially high prevalence (40.8%) of incomplete vaccination among children in South Africa. This fairly mirrors the latest (2018) WHO and United Nations Children's

Fund (UNICEF) estimates of immunization coverage,³ which showed that about 30% of children in South Africa did not receive the third dose of the diphtheria-tetanus-pertussis containing vaccines (DTP3), which is often used as a surrogate indicator of vaccination completeness.¹ We also found that maternal and geographical factors like the province of residence are important determinants of vaccination status of children in South Africa. Our study also shows that the utilization of health services such as antenatal care (ANC) by pregnant mothers can be an important factor for completeness of children's vaccination status. This is consistent with the findings of earlier studies that have demonstrated the benefits of ANC on uptake of child vaccination.^{6,8,23–25} This positive relationship between ANC attendance and vaccination status can be attributed to the fact that women who attend ANC are exposed to the health facilities and useful information about routine childhood vaccination. Regular ANC visits also establish good relationships between women and health-care providers, creating opportunities for health personnel to encourage women to seek subsequent health services for themselves and their children. Furthermore, ANC attendance can increase the likelihood of giving birth at health-care facility, which has been shown to be significantly associated with improved child vaccination.^{6,24,25} Health-care facility delivery allows mothers to have their children vaccinated at birth and also obtain information on subsequent vaccination schedule for their children.⁶

Another finding of this study is the differential odds of incomplete vaccination across provinces. Previous findings of the subnational and between-province disparities in social determinants of health in South Africa lend support to this.^{26–28} South Africa is one of the countries in the world where a substantial proportion of children are missing out on vaccination, despite the huge investments in immunization program by governmental and non-governmental organizations.² It has also been described as one of the 'most unequal countries' in the world.²⁶ Our findings highlight the remarkably higher odds of incomplete childhood vaccination in provinces such as Gauteng and Mpumalanga, which may reflect major gaps in the immunization programs in those places. These gaps may be attributed to supply-side issues such as vaccine stock-outs, long waiting time, and improper vaccination scheduling.^{11,12,29} They may also be due to misconceptions about vaccination, including vaccine hesitancy and other social barriers to vaccination uptake.^{30,31}

Previous studies have shown that factors such as child's birth size, birth order, maternal education, maternal employment status, household poverty, and rural residence have a profound influence on mother's health-seeking behavior, including their attitude toward childhood vaccination.^{6,32–36} However, the present study did not find a significant association between these factors and incomplete vaccination. This may reflect a true lack of association between these variables and child vaccination completeness in South Africa or maybe due to insufficient statistical power by the study to detect such associations.

This study is not without its limitations. First, its findings depend on the quality of DHS data. Although the DHS program is generally considered as one of the most reliable sources

Table 2. Prevalence and factors associated with incomplete childhood vaccination among children aged 12–23 months in South Africa (2016).

Variables	Vaccination status		Measures of association	
	Total: Number	Incompletely vaccinated: Number (%)	Crude odds ratio (95% CI)	Adjusted Odds ratio (95% CI)
All children	708	289 (40.82)		
Sex of child				
Female	325	138 (42.46)	Reference	Reference
Male	383	151 (39.43)	0.88 (0.65–1.19)	0.84 (0.60–1.17)
Birth order				
1st – 3rd order	604	241 (39.90)	Reference	Reference
4th + order	104	48 (46.15)	1.29 (0.85–1.96)	1.08 (0.63–1.82)
Birth size				
Large	183	69 (37.70)	Reference	Reference
Average	413	170 (41.16)*	1.16 (0.81–1.65)	1.00 (0.68–1.45)
Small	104	42 (40.38)	1.12 (0.68–1.83)	1.17 (0.68–2.00)
Maternal age				
15–24	258	107 (41.47)	Reference	Reference
25–34	336	135 (40.18)	0.95 (0.68–1.31)	0.79 (0.53–1.16)
35+	114	47 (41.23)	0.99 (0.63–1.55)	0.72 (0.41–1.28)
Maternal education				
Less than secondary	70	33 (47.14)	Reference	Reference
Secondary or higher	638	256 (40.13)	0.75 (0.46–1.23)	0.83 (0.47–1.47)
Wealth index				
Poor	384	168 (43.75)	Reference	Reference
Middle	145	59 (40.69)	0.88 (0.60–1.30)	0.85 (0.54–1.33)
Rich	179	62 (34.64)	0.68 (0.47–0.98)*	0.66 (0.40–1.08)
Marital status				
Not Married	551	225 (40.83)	Reference	Reference
Married	157	64 (40.76)	1.00 (0.70–1.43)	1.29 (0.84–1.97)
Antenatal care				
Attended	634	244 (38.49)	Reference	Reference
Never attended	40	23 (57.50)*	2.93 (1.42–6.03)*	2.87 (1.31–6.25)*
Maternal occupation				
Working	194	83 (42.78)	Reference	Reference
Not working	514	206 (40.08)	0.89 (0.64–1.25)	0.68 (0.46–1.00)
Media access				
No access	622	248 (39.87)	Reference	Reference
Has access	86	41 (47.67)	0.73 (0.46–1.14)	0.97 (0.57–1.65)
Residence				
Urban	358	140 (39.11)	Reference	Reference
Rural	350	149 (42.57)	1.15 (0.86–1.56)	1.06 (0.69–1.58)
Province				
Eastern Cape	95	33 (34.74)	1.35 (0.65–2.80)	1.34 (0.62–4.51)
Free State	53	15 (28.30)	Reference	Reference
Gauteng	69	36 (52.17)*	2.76 (1.30–5.91)*	3.10 (1.35–7.15)*
KwaZulu-Natal	120	47 (39.17)	1.63 (0.81–3.29)	1.73 (0.78–3.82)
Limpopo	99	40 (40.40)	1.72 (0.84–3.53)	1.54 (0.66–3.58)
Mpumalanga	105	53 (50.48)	2.58 (1.27–5.25)*	2.30 (1.03–5.15)*
Northern Cape	54	17 (31.48)	1.16 (0.51–2.67)	1.02 (0.40–2.61)
North West	77	35 (45.45)	2.11 (1.00–4.46)	2.37 (1.04–5.40)*
Western Cape	36	13 (36.11)	1.43 (0.58–3.54)	1.68 (0.62–4.51)

**P*-value less than 0.05 (*P*-values presented are based on Chi-squared (χ^2) tests of proportions and association, with statistical significance considered at *p*-value <0.05). CI = confidence intervals.

of quantitative data, particularly maternal and child health data, it may be that the responses were affected by recall and social desirability biases because the survey data were self-reported. Another limitation of our study is that it did not assess health facility-level determinants of incomplete childhood vaccination, such as poor vaccination scheduling, vaccine stock-outs, and long waiting periods, which are important enablers of incomplete vaccination of children.³⁷

The quantitative design of the study and its statistical methods are consistent with the methodological conventions for observational, cross-sectional studies of this nature. However, because population survey data often have a hierarchical structure, there is the potential of clustering of both individual-level and contextual characteristics. And because traditional multivariable regression models, such as in this study, treat the units of analysis as independent observations, the models are unable

to unmask such hierarchical structure and clustering. One possible consequence of this limitation is the underestimation of standard errors of regression coefficients, leading to an overestimation of observed effect sizes. In an attempt to address this fundamental issue, we had earlier planned a multilevel regression. However, that was not analytically feasible due to the insufficient sample size of the dataset (with an effective sample size of 1.7 children per neighborhood cluster) and the non-detection of significant neighborhood- and provincial-level variances from the null/empty model. Hence, we had to proceed with fitting a multivariable logistic regression model.

While we acknowledge these limitations and limitations inherent in national demographic surveys of this nature, the surveys represent the best available population-based data covering all the provinces and regions in the country. This, therefore, allows the results from this study to be fairly

generalizable within the reference South African context. It is important to stress that our study's aim was not to establish causality between the identified factors and incomplete vaccination. Rather, it was to provide an empirical evidence base for informing future vaccination policy and program implementation decision-making, for optimizing vaccine access and coverage among children in South Africa, regardless of where they are born, who they are, or where they live.

Given these findings, our study recommends some policy and practice measures for addressing the situation. Fulfilling the vision of the Expanded Programme on Immunization (EPI) requires sustained investments in routine vaccination, health systems responsiveness, and efficient service delivery.³⁸ Although a substantial proportion of women attend ANC during pregnancy in South Africa, there remain worrying gaps in access to ANC services and coverage.^{12,39–40} Women have cited many reasons for not attending ANC, such as long waiting times and attitude of health-care personnel. Addressing these barriers through policies and frontline healthcare quality improvement measures can improve the appeal of ANC to expectant mothers.^{39–41} It is imperative to embed such strategies in the current efforts toward the implementation of South Africa's national health insurance (NHI) scheme.⁴² While the promotion of improved access to ANC is a goal of the country's primary health care (PHC) re-engineering strategy,^{39,42} efforts at optimizing PHC service delivery access and coverage need to be reinvigorated to address lingering unmet ANC needs. These can help nurture greater interaction between the mother and the health system during ANC visits, building their trust and confidence in the health system, while gaining better awareness about the importance of childhood vaccination.

It is also important to address geographical inequities in vaccination access, as revealed by the higher odds of incomplete childhood vaccination in provinces like Gauteng and Mpumalanga. These call for integrated policies and strategies tailored to address geographical and contextual barriers to vaccination. Such strategies should be aimed at educating communities on the benefits of vaccination while addressing any misperception about those benefits. Besides, issues relating to misconception about vaccine safety and unwillingness of mothers to present children for vaccination should be adequately addressed. While the national and provincial governments address the problem of over-centralization of the vaccination program management, governments at municipal, local, and district levels need to address facility-level inefficiencies that may lead to poor vaccination scheduling, vaccine stock-outs, and long waiting periods, which are important enablers of missed opportunities for vaccinating children.^{38,43} These could contribute to ensuring equitable and improved immunization coverage toward the attainment of the Global Vaccine Action Plan (GVAP) targets, Universal Health Coverage agenda, and Goal 3 of Sustainable Development Goals (SDGs) by 2030.

Our findings have implications for future research on the topic. First, it highlights the need for future SADHS to have larger samples to make it more nationally representative and allow for adequate statistical power for secondary analyses such as this. The ongoing national vaccination survey, the first of its

kind since 1994, provides an opportunity for collecting more accurate and nationally representative data.⁴⁴ Secondly, the findings of the present study underscore the need to conduct research aimed at unraveling the contextual determinants of poor childhood vaccination uptake at multiple levels and perspectives. This is important to unmask the contextual enablers of geographical disparities in vaccination access, as highlighted by our study. Such research endeavors will require the integration of quantitative and qualitative methods to assess the burden, as well as temporal and spatial trends of incomplete vaccination among children – empirical evidence of which is currently sparse in South Africa.

Conclusions

There is a substantial burden of incomplete childhood vaccination in South Africa. Individual-level factors such as maternal attendance of antenatal care during pregnancy, and geographical factors such as province of residence significantly influenced this burden. Interventions that promote broader health service utilization, such as antenatal care attendance, can help improve the awareness and uptake of routine childhood vaccination. It is also imperative to take into consideration the geographical disparities in incomplete childhood vaccination, in planning and implementing interventions to improve childhood vaccination coverage.

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Disclosure of potential conflicts of interest

The authors declare that they have no competing interests.

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Ethical considerations

This study was based on analyses of secondary data set from the DHS program which gave us the permission for its use. The survey was approved by the Institutional Review Board (IRB) of ICF Macro International in the United States and the National Ethics Committee in the Federal Ministry of Health of South Africa. All participants in the survey gave their consent to participate.

Authors' contributions

The study was conceived by DN and CSW. Methods of analysis were designed by DN and CAN with contributions from OAU, CSW, and TM. CAN and DN wrote the first manuscript. CAN, DN, TM, OAU, and CSW contributed to reviewing in writing the final draft of the manuscript. All the authors read and approved the final manuscript.

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