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Factors associated with RTS,S vaccination uptake in Northern Ghana, 2021–2022

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Abstract

Background Ghana introduced the RTS,S/AS01$_E$ (RTS,S) four-dosage malaria vaccine on a pilot basis to reduce malaria burden among children. However, achieving high coverages for all four recommended doses remains a challenge. We assessed coverage and factors associated with RTS,S vaccination uptake in a Health and Demographic Surveillance System (HDSS) area in Ghana.

Methods The study used vaccination data collected through biannual cross-sectional surveys of children under-five years of age in the Navrongo HDSS area in 2021 and 2022. Data on RTS,S vaccination dates were transcribed from the maternal and child health record books. Poisson regression models were used to determine factors associated with receiving three or four RTS,S doses.

Results Overall, 95%, 94%, and 89% of children aged 12 to 23 months received the first, second and third doses of RTS,S vaccine respectively. Children aged 12–23 months whose mothers had secondary or tertiary education were more likely to receive three RTS,S doses compared to those whose mothers had basic education (Prevalence ratio (PR): 1.03; 95% CI:(1.01–1.05)). Children delivered at home were less likely to receive three RTS,S doses compared to those delivered in health facilities (PR:0.89; 95% CI (0.85–0.94).

Coverage of the fourth RTS,S dose was 66% among children aged 27–38 months, and 70% among children aged 27–48 months. Children aged 27–38 months delivered at home were less likely to receive four RTS,S doses compared to those delivered in a health facility (PR: 0.87; 95%CI: 0.79–0.96). Among children aged 27–38 months, those whose mothers were Christians were more likely to receive four RTS,S doses compared with those whose mothers were traditionalist (PR:1.08; 95% CI: 1.01–1.16). Residing in rural areas is associated with receiving four RTS,S doses compared to urban areas (PR: 1.24; 95% CI: 1.10–1.39).

Conclusion This study revealed high coverages of the first three RTS,S doses. However, coverage of the fourth dose remains suboptimal. To improve uptake, particularly dose four, targeted interventions should focus on improving health facility delivery, addressing religious and urban-specific barriers to RTS,S vaccination to maximize the public health impact of the RTS,S vaccine.

Background

Malaria is an infectious disease of public health concern that accounts for a high disease burden and deaths among pregnant women and children in sub-Saharan Africa (SSA) [1]. Global estimates by the World Health Organization (WHO) indicate that malaria cases reached 247 million in 2021, of which 619,000 individuals died [2]. The SSA region contributes approximately 95% of worldwide malaria cases and deaths [2]. *Plasmodium falciparum* is responsible for nearly all malaria deaths, the majority of which occur in African children under-five years [3]. In 2022, 95% of all global under-five malaria deaths occurred in the WHO African region [4].

Ghana has significant levels of malaria with an estimated 6,552,000 malaria cases recorded in Ghana in 2023 [5]. Moreover, 41% of outpatient cases in Ghana were due to suspected malaria in 2020. The disease also accounted for 18% of all hospital admissions, especially in pregnant women and children [6]. Even though there have been several interventions with varied successes to control malaria, such as indoor residual spraying, seasonal malaria chemoprevention and use of insecticide-treated bed nets, malaria still remains one of the main causes of under-five mortality in Ghana and many other SSA countries [7]. Several previous attempts to get a malaria vaccine proved futile [8]. The several malaria vaccines failing to provide adequate protection in the field might be due to the complex nature of the malaria parasite's life cycle [8]. Some studies have documented various mechanisms adopted by the parasite to elude the host immune response and cause infection [9]. For instance, a study in Kenya showed that a malaria vaccine induced high antibody titers but was unsuccessful in preventing infection in young children [10].

Recently, the Mosquirix (also referred to as the RTS,S/AS01$_E$ or simply the RTS,S) vaccine has shown some promise, and is the pioneer malaria vaccine demonstrated to provide partial immunity against malaria in children [11]. This remarkable achievement is the product of three decades of the RTS,S vaccine's clinical development [11].

In an attempt to prevent and control malaria, in 2019, approval for the use of the RTS,S/AS01$_E$ malaria vaccine (RTS,S) in Kenya, Ghana and Malawi on a pilot basis was granted by the WHO [3]. The vaccine was subsequently piloted in 42 of Ghana's 261 districts [12] with plans to scale up to the entire country by incorporating the RTS,S vaccine into the routine child immunization programme [12]. The recommended vaccine schedule for RTS,S dose 1, 2 and 3 is 6, 7 and 9 months respectively in Ghana [13]. At 24 months the final dose is then given [13]. However, in Ghana, RTS,S dose 4 schedule was changed to 18 months in 2023 to align with Measles-Rubella dose 2 schedule.

Prior to the pilot introduction of the vaccine, there were widespread skepticism regarding the side effects of the vaccine, leading to fears of vaccine hesitancy among the population [14]. These perceptions have the potential to affect the vaccine's coverage. The Ghana Health Service (GHS) has plans to scale up the RTS,S vaccination nationwide, and it is critical to identify some of the socio-demographic factors that may facilitate or impede RTS,S uptake. This study sought to identify factors associated with RTS,S vaccination uptake using well documented data from a health and demographic surveillance site in Northern Ghana. The findings would contribute to designing strategies to improve RTS,S uptake and consequently reduce malaria cases and deaths among Ghanaian children when the vaccine is rolled out nationwide.

Methods

Study area

The study covers two districts in Ghana's Upper East Region: the Kassena Nankana Municipal (KNM) and Kassena Nankana West district (KNWD). The Navrongo Health and Demographic Surveillance System (HDSS) monitors the population dynamics of these two districts located between latitude 10.30' and 11.10' North and longitude 1.1' West with a land area of about 1,675km^2 [15]. The study area is situated at the northernmost part of Ghana and shares a border with Burkina Faso [16]. The study setting is mainly rural (80%) with an estimated population of 184,871. Majority of people are engaged in subsistence farming [17].

There are two referral hospitals that serve lower-level primary health care facilities. The lower-level facilities include thirteen health centres and ninety-one Community-based Health Planning and Services (CHPS) compounds run by qualified nurses and other health professionals who offer primary health care services. Malaria transmission is seasonal, peaking between June and October [18]. *Plasmodium falciparum* is the main cause of malaria in the area, with its principal vectors being *Anopheles funestus and Anopheles gambiae* [18]. Annual entomological inoculation rate is approximately 418 [18].

Study design

The study used vaccination data collected through biannual cross-sectional surveys of children under-five years by the Navrongo HDSS in 2021 and 2022. In the vaccine's pilot implementation in Ghana, the Kassena Nankana Municipal and West district were part of the implementation districts because of the GlaxoSmithKline (GSK) sponsored safety monitoring vaccine studies in these two districts. The Navrongo HDSS collected data on RTS,S vaccination status and other EPI vaccines during the pilot implementation. The study included children surveyed in 2021 and 2022 who had their vaccination or health cards inspected on the survey day. This study analysed vaccination data of children aged 12–23 months to identify the factors associated with receiving the first three RTS,S doses. We also examined the factors associated with RTS,S dose 4 uptake among children aged 27–38 months. Additionally, to account for children vaccinated with RTS,S dose 4 after 38 months, we analysed children aged 27–48 months separately. In cases where we had multiple records for the same child in the same age group based on the biannual visits, the most recent record of the child was included in the analysis.

Data Collection

Data were collected by the Navrongo HDSS. Trained fieldworkers visited all households every six months to collect data on births, pregnancies, deaths, migrations, childhood vaccinations, etc. Background characteristics of the children and their mothers, as well as their household characteristics were documented as part of the Navrongo HDSS operations. Data on parity, birth order and other maternal characteristics of their mothers are collected when registering new births or pregnancies. All registered members, including children, were given unique identification numbers to prevent multiple enrolments.

Vaccination data collection

The Navrongo HDSS field team documented the routine EPI vaccines as well as the RTS,S vaccine each child received from their health cards during visits to their households every six months. As part of the vaccination data collection, a list of qualified children to be interviewed was generated and given to the fieldworkers. When a child was visited and the child's health or vaccination card was seen, the date each vaccine was received was documented. The vaccination data has records of the vaccines received, the date of the interview as well as other background characteristics of the children such as sex and date of birth.

Study variables and classification

Explanatory variables

Table 1 shows explanatory variables used in the study and their classification and coding.

Table 1 Explanatory variables used in this study

Variable	Classification and Coding
Sex of the Child	Male=1; Female=2
Mother's education	No formal education=1; Primary/JSS=2; Secondary/Tertiary=3
Maternal age	<20=1; 20–34=2; 35–49=3
Marital status	Married=1; Not married=2
Place of birth for the child	Health facility=1; Home/Elsewhere=2
Birth Order of the child	1=1; 2–4=2; 5+=3
Multiple birth status	Singleton=1; Multiple=2
Religion of the mother	Traditional=1; Catholic=2; Other Christians=3; Islam=4
Household Wealth Index	Low=1; Middle=2; High=3
Place of residence of the child	Urban=1; Rural=2

Outcome variable

Three outcome variables were used in our analyses.

- Uptake of the first 3 RTS,S doses among children aged 12–23 months
- Uptake of the fourth RTS,S dose among children aged 27–38 months
- Uptake of the fourth RTS,S dose among children aged 27–48 months

Data Analysis

STATA 18.0 was used for all analyses. The coverage for each of the first three doses: RTS,S1, RTS,S2 and RTS,S3 was calculated using the formula:

$$\frac{\text{Number of children 12–23 months who received a dose}}{\text{Total number of children 12–23 months old}} \times 100$$

The coverage for the fourth dose was calculated using the formula:

$$\frac{\text{Number of children 27–38 months old who received fourth dose}}{\text{Total number of children 27–38 months old}} \times 100$$

In a further analysis to account for children who received the fourth RTS,S dose late, coverage for the fourth dose was calculated using the formula:

$$\frac{\text{Number of children 27–48 months old who received fourth dose}}{\text{Total number of children 27–48 months old}} \times 100$$

Descriptive statistics such as proportions and means were employed to describe the study participants' background characteristics. In bivariate analysis, test of association between the outcome variables and explanatory variables were done using chi-square test. To assess the factors associated with the uptake of the first three RTS,S doses in children aged 12 to 23 months, all children who received all the first three RTS,S doses were categorized as 1 "received all three doses" or 0 "received less than three doses". To investigate the factors associated with the uptake of the fourth RTS,S dose, all children aged 27 to 38 months who received fourth RTS,S dose were categorized as 1 "received all four doses" or 0 "received less than four doses". Similar categorization was done for children aged 27–48 months. All children aged 27 to 48 months who received fourth RTS,S dose were categorized as 1 "received all four doses" or 0 "received less than four doses". These categorizations are based on the RTS,S vaccination schedule of 6 months for dose one, 7 months for dose two, 9 months for dose three and 24 months for dose four as per the schedule before 2023. Unadjusted and adjusted prevalence ratios with 95% confidence intervals were computed to test the relationship between the outcome variables and explanatory variables using Poisson regression with robust variance analysis. Poisson regression was used due to the high RTS,S vaccination coverage. Explanatory variables that were significant in bivariate analysis were included in the adjusted model. Statistical significance was set at $p < 0.05$.

Results

Background characteristics of study participants aged 12 to 23 months

To determine the coverages of the first three RTS,S doses and the factors associated with receiving three RTS,S doses, 4,770 children aged 12 to 23 months were analysed. About half (50.9%) of these children were females and most (92.3%) were born in health facilities. The majority (69.8%) of the mothers were

aged 20–34 years and 28.5% of mothers had secondary/tertiary education. Over 80% of mothers were married, 88.1% resided in rural areas and 73.5% were Christians (Table 2).

RTS,S vaccination coverage among children aged 12 to 23 months

Overall, 95% (95%CI: 94–96%), 94% (95%CI: 93–95%) and 89% (95%CI: 88–90%) of study participants aged 12 to 23 months received RTS,S doses 1, 2, and 3, respectively.

Coverage of the first three RTS,S doses among children aged 12–23 months by background characteristics

In all, 90.7% of children born to mothers with secondary/tertiary education received three RTS,S doses compared to 88.6% of children born to mothers with no formal education. Additionally, 89.2% of children aged 12–23 months delivered in a health facility compared to 79.2% of those delivered at home/elsewhere received all three RTS,S doses. About 90.5% of children in high wealth index households compared to 88% of children in low wealth index households received three RTS,S doses (Table 2).

Table 2 Background characteristics and RTS,S vaccination status of study participants in Northern Ghana, 2021–2022

Variable	Children aged 12–23 months			Children aged 27–38 months		
	Total	Number vaccinated with three RTS,S doses n (%)	P value	Total	Number vaccinated with four RTS,S doses n (%)	P value
Sex of the child						
Male	2342	2069 (88.3)	0.858	1486	968 (65.1)	0.919
Female	2428	2149 (88.5)		1507	979 (65.0)	
Mother's education						
No formal education	376	333 (88.6)	0.006	310	206 (66.5)	0.491
Primary/JSS	3034	2651 (87.4)		1851	1189 (64.2)	
Secondary/Tertiary	1360	1234 (90.7)		832	552 (66.3)	
Maternal age						
<20	520	451 (86.7)	0.132	326	207 (63.5)	0.772
20–34	3329	2964 (89.0)		2062	1349 (65.4)	
35–49	921	803 (87.2)		605	391 (64.6)	
Marital status						
Married	3833	3390 (88.4)	0.948	2402	1579 (65.7)	0.113
Not married	937	828 (88.4)		591	368 (62.3)	
Place of birth for the child						
Health facility	4404	3928 (89.2)	< 0.001	2680	1765 (65.9)	0.007
Home/Elsewhere	366	290 (79.2)		313	182 (58.1)	
Birth Order of the child						
1	1337	1188 (88.9)	0.082	860	574 (66.7)	0.445
2–4	2737	2432 (88.9)		1650	1065 (64.5)	
5+	696	598 (85.9)		483	308 (63.8)	
Multiple births						
Singleton	4566	4037 (88.4)	0.892	2877	1863 (64.8)	0.090
Multiple	204	181 (88.7)		116	84 (72.4)	

Religion of the mother						
Traditional	953	838 (87.9)	0.239	602	379 (63.0)	0.001
Catholic	1287	1147 (89.1)		754	501 (66.4)	
Other Christians	2220	1969 (88.7)		1433	958 (66.9)	
Islam	310	264 (85.2)		204	109 (53.4)	
Household Wealth Index						
Low	1634	1438 (88)	0.013	1010	676 (66.9)	0.001
Middle	1758	1533 (87.2)		1145	769 (67.2)	
High	1378	1247 (90.5)		838	502 (59.9)	
Place of residence of the child						
Urban	570	503 (88.2)	0.885	366	189 (51.6)	< 0.001
Rural	4200	3715 (88.5)		2627	1758 (66.9)	

*NS: Not Significant

Factors associated with receiving all three RTS,S vaccine doses among children aged 12 to 23 months in Northern Ghana

Table 3 shows the factors associated with receiving all three RTS,S vaccine doses among 12 to 23 months old children in the study. In the bivariate analysis, children in wealthy households were more likely to be vaccinated with three RTS,S doses compared to those in poor households (PR:1.03; 95% CI: 1.00–1.05). In multivariable analysis, children born at home or elsewhere were less likely to receive three RTS,S vaccine doses compared to those born in a health facility (aPR:0.89; 95% CI: 0.85–0.94). Additionally, children of mothers with secondary or tertiary education were more likely to receive three RTS,S doses compared to those whose mothers had primary or JSS education (aPR:1.03; 95% CI: 1.01–1.05).

Table 3 Factors associated with receiving all three or four RTS,S vaccine doses among study participants in Northern Ghana, 2021–2022

Variable	Children 12 – 23 Months 3 doses		Children 27 – 38 Months 4 doses	
	Unadjusted Prevalence Ratio (95% CI)	Adjusted Prevalence Ratio (95% CI)	Unadjusted Prevalence Ratio (95% CI)	Adjusted Prevalence Ratio (95% CI)
Sex of the child		NS		NS
Male	1.00		1.00	
Female	1.00 (0.98–1.02)		1.00 (0.95–1.05)	
Mother's education				NS
No formal education	1.01 (0.98–1.05)	1.02 (0.98–1.06)	1.00	
Primary/JSS	1.00	1.00	0.97 (0.89–1.05)	
Secondary/Tertiary	1.04 (1.02–1.06)	1.03 (1.01–1.05)	1.00 (0.91–1.10)	
Maternal age		NS		NS
<20	1.00		1.00	
20–34	1.03 (0.99–1.06)		1.03 (0.94–1.13)	
35–49	1.01 (0.96–1.05)		1.02 (0.92–1.13)	
Marital status		NS		NS
Married	1.00		1.00	
Not married	1.00 (0.97–1.03)		0.95 (0.88–1.01)	
Place of birth for the child				
Health facility	1.00	1.00	1.00	1.00
Home/Elsewhere	0.89 (0.84–0.94)	0.89 (0.85–0.94)	0.88 (0.80–0.97)	0.87 (0.79–0.96)
Birth Order of the child		NS		NS
1	1.00		1.00	

2–4	1.00 (0.98–1.02)		0.97 (0.91–1.03)	
5+	0.97 (0.93–1.00)		0.96 (0.88–1.04)	
Multiple births		NS		NS
Singleton	1.00		1.00	
Multiple	1.00 (0.95–1.06)		1.12 (1.00–1.26)	
Religion of the mother		NS		
Traditional	1.00		1.00	1.00
Catholic	1.01 (0.98–1.04)		1.06 (0.97–1.14)	1.10 (1.01–1.19)
Other Christians	1.01 (0.98–1.04)		1.06 (0.99–1.14)	1.08 (1.01–1.16)
Islam	0.97 (0.92–1.02)		0.85 (0.74–0.98)	0.96 (0.83–1.11)
Household Wealth Index		NS		NS
Low	1.00		1.00	
Middle	0.99 (0.97–1.02)		1.00 (0.95–1.06)	
High	1.03 (1.00–1.05)		0.90 (0.83–0.96)	
Place of residence of the child		NS		
Urban	1.00		1.00	1.00
Rural	1.00 (0.97–1.03)		1.30 (1.17–1.44)	1.24 (1.10–1.39)

*NS: Not Significant

Background characteristics of children 27–38 months old included in the analysis

To determine the coverage of the fourth RTS,S dose and the factors associated with receiving the fourth RTS,S dose, 2993 children aged 27–38 months were included in the analyses. More than half (50.4%) of the children aged 27–38 months were females. Most children (89.5%) were born in a health facility and 10% of the mothers had no formal education. Table 2 describes the background characteristics of the children aged 27–38 months included in the analyses.

RTS,S vaccination coverage among children aged 27 to 38 months

Overall, 66% (95% CI 64–67%) of children aged 27–38 months in the study received the fourth RTS,S vaccine dose. When the age group was expanded to include children aged 27–48 months to account for children vaccinated after 38 months, coverage of the fourth dose of RTS,S was 69.5%.

Coverage of the fourth dose of RTS,S by background characteristics of children aged 27–38 months

In all, 65.9% of children aged 27–38 months delivered in a health facility were vaccinated with the fourth RTS,S dose compared to 58.1% delivered at home or elsewhere. About 67% of children resident in rural compared to almost 52% of children in urban areas received four RTS,S doses (Table 2).

Factors associated with receiving four RTS,S vaccine doses among children 27 to 38 months old in Northern Ghana

Table 3 shows the factors associated with receiving four RTS,S vaccine doses among children aged 27 to 38 months in Northern Ghana. In bivariate analysis, multiple births were more likely to receive four RTS,S doses compared to singleton births (PR: 1.12; 95% CI: 1.00–1.26). Additionally, in bivariate analysis, children in wealthy households were more likely to receive four RTS,S doses compared with those in poor households (PR:0.90; 95% CI: 0.83–0.96). In multivariable analysis, children aged 27–38 months and delivered at home or elsewhere were less likely to receive four RTS,S vaccine doses compared with those born in a health facility (aPR: 0.87; 95% CI: 0.79–0.96). Similar observations were made when the analysis was extended to include children aged 27–48 months to account for those who received RTS,S four after 38 months. Children born at home or elsewhere had a prevalence ratio of 0.85; 95%CI: (0.79–0.92), compared to those born in a health facility (Supplementary Table 1). Being a Catholic (aPR:1.10; 95% CI: 1.01–1.19) or other Christian denomination (aPR: 1.08; 95% CI: 1.01–1.16) was associated with an increased likelihood of receiving four RTS,S vaccine doses compared to those who practiced African Traditional Religion. The results were similar when the analysis included children aged 27–48 months (Supplementary Table 1). In addition, children residing in rural areas were more likely to receive four RTS,S doses compared to those residing in urban areas (aPR: 1.24; 95% CI: 1.10–1.39). Furthermore, including children aged 27–48 months, those residing in rural areas were more likely to receive four RTS,S doses compared to those residing in urban areas (aPR:1.28; 95%CI: 1.17–1.39) (Supplementary Table 1).

Discussion

RTS,S vaccination coverage for the first three doses

The RTS,S vaccination coverage of 95% for the first and 94% for the second dose suggest strong uptake and access to the malaria vaccine in the study area despite reported scepticism and vaccine hesitancy. The vaccine coverages for RTS,S dose one and RTS,S dose two have met the WHO's target of 90% for vaccine coverage [19], demonstrating strong immunization performance. Coverage of the third RTS,S

dose was 89%. The results of this study are similar with the findings of another study in Ghana which reported uptake of 94.1%, 90.6%, and 78.1% for RTS,S1, RTS,S2 and RTS,S3 respectively [20]. Another study from Malawi reported relatively lower RTS,S vaccination coverages for the first three doses than our study findings [21]. In Kenya, Moturi et al. reported RTS,S coverage of 96%, 87%, and 78% for doses 1, 2, and 3, respectively [22].

Although the RTS,S vaccination coverages from this study appear higher than several other studies, the coverage of 89% for the third dose suggest a 6% dropout from dose 1 coverage, which indicates some possible challenges in caregiver compliance or health system factors. Even though the third RTS,S dose and the measles-rubella vaccine first dose are both given at 9 months in Ghana, coverage for measles-rubella 1 was 95% compared to 89% for RTS,S3. This is an indication of missed opportunities for more children to receive RTS,S3 dose. It is possible some mothers presented their children to receive measles-rubella 1 vaccine but refused the RTS,S vaccine resulting in missed opportunities for RTS,S malaria vaccination [22]. Similar observations were found in Kenya where measles-rubella 1 coverage was higher than RTS,S3 even though both were given at the same time [22]. It is crucial for health workers to provide the appropriate education during antenatal and child welfare clinics to reduce dropout rates. Improving vaccine stockout and attitude of health worker towards caregivers will contribute towards improving coverage.

Coverage of the fourth RTS,S dose

Additionally, the coverage of RTS,S4 among children aged 27–38 months was 66%, indicating a remarkable decline of 23% from the third and 29% from the first dose. Other studies reported coverage of RTS,S dose four of 39% [22] and 41.2% [21]. The dose 4 coverage reported in this study is concerning but appears higher than coverages reported in several other studies. Furthermore, this study's results showed a decreasing trend in the vaccine's coverage from RTS,S1 to RTS,S4 and is in congruence with earlier studies conducted in Ghana, Malawi, and Kenya where coverages in later doses tend to be lower [12, 20–22]. Children must receive all four RTS,S vaccine doses in order to have full vaccine protection [23]. The low RTS,S dose 4 coverage reported in this study and several other studies has implications for malaria control as incomplete vaccination may limit optimal protection of the RTS,S vaccine against malaria. This must be addressed if the full benefits of the vaccine are to be realized [21, 23].

In Ghana, children are expected to receive all EPI vaccines by the age of eighteen months per the vaccination schedule. Thus, the low uptake of RTS,S4 could be a result of longer interval between the third and fourth RTS,S dose [24], and a lack of adequate information on the RTS,S vaccination schedule [20]. The dose 4 coverage reported in this study was based on a delivery time of 24 months. The low coverage could also be due to a mother or caregiver unwillingness or failure to attend child welfare clinics after 18 months since the child would have received all the routine EPI vaccines. Some studies observed that mothers/caregivers lacked adequate knowledge on the RTS,S vaccination schedule and the number of doses required to achieve full vaccination [21]. In Ghana, RTS,S dose 4 was initially given at 24 months, and since 2023 has been changed to 18 months. Reducing the RTS,S dose 4 schedule to

18 months is commendable as this has helped to address the challenges that confronted dose 4 uptake at 24 months and affords children the opportunity to receive both the RTS,S vaccine's final dose and measles-rubella 2 at 18 months. To improve coverage, health workers should educate or provide mothers with more detailed information on the EPI and RTS,S vaccination schedules.

Factors associated with RTS,S vaccination uptake

Our study showed that children delivered at health facilities are more likely to receive the first three RTS,S vaccine doses as well as the fourth dose compared to children delivered at home. This observation demonstrates the importance of health facility delivery as a critical entry point to improve uptake and completion of RTS,S vaccination. Our finding is consistent with previous studies that found health facility delivery to be associated with improved immunization coverage compared to home delivery [25–28]. Mothers who deliver in a health facility are more likely to have early engagement with the health system, and possibly be counselled on infant care and the routine childhood immunization and its benefits as well as receiving some education on the EPI schedule [27]. They are also more likely to be encouraged to present their children for subsequent vaccinations even as they utilize other medical services. The fourth RTS,S dose is administered later in the second year of life and often characterised by low uptake. Our observation is particularly important as receiving this dose requires sustained interaction with the health system over time. Mothers who deliver at health facilities may be more likely to maintain contact with the health delivery system and comply with follow-up schedules leading to improved vaccination uptake. In contrast to our finding, a study in Malawi found no association between place of birth and full RTS,S vaccine uptake [21].

Additionally, we found that children of mothers with secondary or tertiary education were more likely to receive three RTS,S doses relative to those whose mothers had primary or junior secondary school education. This study is in congruence with an earlier study in Ghana where higher parental education was found to increase the likelihood of complete RTS,S vaccine uptake [20]. This could possibly be a result of mothers with secondary or tertiary education being exposed to information about the RTS,S vaccine and also being able to fully understand the benefits of childhood vaccinations [20]. Previous studies have demonstrated that women with higher education were more likely to understand the EPI vaccination schedule better and comply with it to the end [20]. Additionally, this finding is consistent with similar observations by Simbeye et al. [21] who found that mothers/caregivers with secondary or higher education ensured their children were fully vaccinated with the RTS,S vaccine. Generally, a mother's educational status could influence a child's chances of being vaccinated, as previous studies suggested that children of mothers with secondary or higher education were more inclined to receive full childhood immunization [25, 26].

Being a Christian (either Catholic or other Christians) was associated with an increased likelihood of receiving four RTS,S vaccine doses in children aged 27–38 months. Children whose mothers were Christians were more likely to receive four RTS,S doses compared with those whose mothers were traditionalist. Similarly, among children aged 27–48 months, children whose mothers were Christians

were more likely to receive four RTS,S doses compared to those whose mothers were traditionalist. Immurana et al. [29] found that mothers who belonged to other Christian faiths (Pentecost/Charismatic, Methodist) were less willing to have their children vaccinated with RTS,S. Also, research by Simbeye et al. [21] found no statistically significant association between religion and full RTS,S vaccine uptake. To improve uptake, religious platforms should be used to educate members on the importance of vaccinating their children with RTS,S.

We found that children residing in rural areas were more likely to receive four RTS,S vaccine doses compared with those in urban areas. This may seem unexpected given the typically better access to health services in urban than rural areas. In this study setting, and nationally, the prevalence of malaria is higher in rural than urban areas [30]. The high risk of malaria infection in rural areas could likely be one of the reasons why children get vaccinated more with RTS,S four in rural than urban settings. Additionally, in rural areas, the strong presence of the community-based health services, coupled with targeted outreach and defaulting tracing mechanisms could contribute to better retention in immunization schedules in rural areas.

Strengths and limitations of the study

This study used well documented large vaccination data from the Navrongo HDSS to estimate RTS,S vaccination coverage and investigate factors associated with the RTS,S vaccination uptake in Northern Ghana. However, this study has some limitations. The study did not have data on all the variables that could potentially influence RTS,S vaccination uptake, especially the health system factors. For instance, the study did not have data on distance to health facilities, the quality of vaccination services and the attitude of health staff that could potentially influence RTS,S vaccination uptake. Secondly, this study is unable to establish causality from the cross-sectional data, as is typical with many observational studies. However, this study has identified important factors, if addressed, could improve RTS,S vaccination uptake and reduce the burden of malaria in children in Northern Ghana.

Conclusion

This study revealed high coverages of the first three RTS,S vaccine doses despite reported vaccine hesitancy in some studies in Ghana. However, coverage of RTS,S dose 4 of 66% is suboptimal. Health facility delivery is associated with complete RTS,S vaccination in this study. Children aged 12–23 months whose mothers had secondary or tertiary education was significantly associated with receiving three RTS,S vaccine doses. Among children aged 27–38 months, residing in a rural area, and being a Christian were associated with receiving four RTS,S vaccine doses. To improve uptake, particularly RTS,S dose four, targeted interventions should focus on improving health facility delivery, increasing female enrolment in secondary and tertiary institutions, addressing religious and urban-specific barriers to RTS,S vaccination to maximize the public health impact of the RTS,S vaccine.

Abbreviations

SSA	Sub-Saharan Africa
WHO	World Health Organization
HDSS	Health and Demographic Surveillance System
KNM	Kassena Nankana Municipal
KNWD	Kassena Nankana West District
NHRC	Navrongo Health Research Centre
CHPS	Community-based Health Planning and Services
JSS	Junior Secondary School
SSS	Senior Secondary School
EPI	Expanded Programme on Immunization
GHS	Ghana Health Service
GSK	GlaxoSmithKline

Declarations

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Author contributions

MBK, PW and TC conceived and designed the study. MBK, PW and POA supervised the data collection. MBK, PW and TC performed data analysis. MBK wrote the initial draft of the manuscript. MBK, PW, TC and POA made substantial revisions and approved the final manuscript.

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Availability of data and materials

The relevant datasets used for this study are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Ethical clearance for the data collection and operations of the Navrongo HDSS was approved by the NHRC Institutional Review Board (NHRCIRB). Permission to use the data was granted by the NHRC. In addition, the University of the Witwatersrand's Human Research Ethics Committee (Medical) provided ethics clearance for the conduct of this study (M240430).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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