BMJ Open

Asymptomatic malaria parasite carriage and anaemia among senior high school students in Tempane District of the Upper East Region of Ghana: a cross-sectional study

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To cite: Awindago JA, Captain-Esoah M, Motey GA, *et al*. Asymptomatic malaria parasite carriage and anaemia among senior high school students in Tempane District of the Upper East Region of Ghana: a cross-sectional study. *BMJ Open* 2026;**16**:e113799. doi:10.1136/bmjopen-2025-113799

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (https://doi.org/10.1136/bmjopen-2025-113799).

Received 12 November 2025
Accepted 16 April 2026

Check for updates

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ABSTRACT

Objectives To determine the prevalence of malaria parasite carriage and anaemia among senior high school students and to identify the demographic, behavioural and residential factors associated with these outcomes.

Design Cross-sectional study.

Setting Participants were enrolled from Tempane Senior High School students in the Tempane District of the Upper East Region of Ghana.

Participants 290 senior high school students aged 15–22 years.

Primary and secondary outcome measures Demographic characteristics, residential status and insecticide-treated bed net (ITN) use were collected using a structured questionnaire. Venous blood samples were obtained for malaria parasite detection by microscopy and haemoglobin measurement. Association analysis was performed using logistic regression models.

Results The prevalence of malaria parasite carriage was 23.1%, while 49.0% of participants were anaemic. Day students had a significantly higher prevalence of malaria (59.2%) than boarding students (15.8%) ($p<0.001$). Malaria parasite infection was also more common among students who did not use ITNs (39.7%) compared with users (5.0%) ($p<0.001$). In multivariate analysis, not using ITN (adjusted OR (aOR)=15.97; 95% CI 6.33 to 40.32; $p<0.001$) and being a day student (aOR=5.65; 95% CI 2.58 to 12.36; $p<0.001$) were significant predictors of malaria parasite infection. Students infected with malaria parasites had significantly lower mean haemoglobin (11.50±1.43 g/dL) than uninfected students (12.56±1.35 g/dL) ($p<0.001$). Malaria parasite infection (aOR=9.36; 95% CI 3.91 to 22.42; $p<0.001$) and male students (aOR=2.26; 95% CI 1.09 to 4.65; $p=0.028$) were associated with higher odds of anaemia. Whereas age groups 18–20 years (aOR=0.41; 95% CI 0.17 to 0.97; $p=0.043$) and those above 20 years (aOR=0.07; 95% CI 0.02 to 0.27; $p<0.001$) were associated with lower odds of anaemia.

Conclusion Malaria and anaemia remain prevalent among senior high school students in the Upper East Region of Ghana, with asymptomatic malaria strongly linked to anaemia. Not using ITN and being a day student significantly increased the odds of malaria parasite infection. These findings underscore the need to extend malaria prevention interventions to adolescents through school-based programmes, including routine screening, treatment and promotion of consistent ITN use, especially among day students.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The study used stratified random sampling across academic levels, which improved the representativeness and diversity of the participants included in the analysis.
⇒ Collection of demographic, behavioural and residential information using a structured questionnaire allowed for adjustment for multiple potential confounders in multivariable regression models.
⇒ The cross-sectional design and reliance on asymptomatic participants limit temporal or causal inference between malaria parasite carriage and anaemia.
⇒ Reliance on microscopy and self-reported behavioural factors such as insecticide-treated bed net use may have underestimated low-density infections and introduced reporting bias.

INTRODUCTION

Malaria remains a major public health challenge in sub-Saharan Africa, despite decades of intensive control efforts.[1] In 2023, the WHO estimated that the African region accounted for 94% of global malaria cases and deaths, with *Plasmodium falciparum* responsible for nearly all infections.[1] Ghana continues to experience endemic transmission, with an estimated prevalence of 8.6% among the general population and higher rates in some regions of the north where transmission is perennial.[2 3] While malaria control interventions have traditionally focused on children under 5 years and pregnant women, school-aged children and adolescents are increasingly recognised as an important reservoir of infection and contributor to ongoing transmission.[4–7] School-age populations often harbour asymptomatic infections that sustain local transmission and are less frequently targeted by routine control measures. Understanding these relationships is important because older students may differ from younger children in exposure, behaviour, immunity and schooling context.[4 8–10]

Anaemia is likewise common among adolescents in many low- and middle-income countries[11–14] and is multifactorial in origin, with contributions from iron and other micronutrient deficiencies, infections (including malaria, schistosomiasis and helminths), menstruation and haemoglobinopathies.[13 15–17] A recent study of Ghanaian adolescents found that malaria infection was strongly associated with lower haemoglobin concentration and higher anaemia prevalence: adolescents with malaria had nearly 52% higher prevalence of anaemia and 0.42 g/dL lower haemoglobin concentration than their uninfected peers.[18] In malaria endemic areas, *Plasmodium* infection is noted as an important and preventable contributor to reduced haemoglobin concentration through red-cell haemolysis and suppressed erythropoiesis.[19–21] The combined burden of malaria and anaemia in adolescents has serious implications on physical growth, cognitive performance and educational attainment, highlighting the need for adolescent-focused surveillance and interventions.[22–25]

Within school settings, multiple interrelated factors influence malaria risk and haemoglobin status. Individual and contextual factors such as living arrangement (eg, boarding vs day students), ownership and use of insecticide-treated bed nets (ITNs) and behavioural or environmental exposures and local transmission intensity all play roles.[26–31] Evidence from multiple African studies shows that inconsistent ITN use and living outside controlled school environments are associated with higher malaria prevalence among school children, while school-based screening or preventive strategies can reduce infection and improve haemoglobin in the short term.[32 33] These findings suggest that combining school-level prevention (eg, ITN distribution and health education) with screening and treatment could reduce both malaria parasite carriage and anaemia among adolescents.

Despite these observations, few studies have focused on senior high school (SHS) students (particularly in the Upper East Region of Ghana), and very few simultaneously examine malaria parasite carriage, haemoglobin concentration, anaemia prevalence and associated factors (residential status, ITN use and academic level) in this adolescent age bracket.[34 35] In a typical Ghanaian high school context, boarding students reside within a structured school setting characterised by communal dormitories, shared sanitation facilities, regulated meal plans and supervised routines. Day students, on the other hand, return to home environments that vary widely in socioeconomic conditions, parental supervision, commuting demands and access to food and utilities. Contextual factors in the Upper East Region in particular, including seasonal transmission patterns, household ITN use coverage and school residential arrangements, may shape adolescents' risk differently from that of younger children and from other regions of the country. Local evidence is therefore needed to inform school-based health strategies that reach both boarding and day students; two categories of students in the Ghanaian SHS. Therefore, the aim of this study was twofold: (1) to determine the prevalence of malaria parasite carriage and anaemia among SHS students in the Tempane District of the Upper East Region of Ghana; and (2) to identify the demographic, behavioural and residential factors associated with these outcomes. By focusing on adolescent students in an SHS setting, this study aims to fill a gap in evidence and to inform school-based malaria and anaemia control interventions in Ghanaian secondary schools and similar settings.

MATERIALS AND METHODS

Study settings

The study site, Tempane Senior High School, is a public SHS in the Tempane District of the Upper East Region of Ghana, which serves students from both rural and peri-urban communities. The district lies within the Guinea savannah ecological zone and shares borders with the Garu district to the west and Burkina Faso to the north (figure 1). It covers an estimated land area of about 1200 km^2 and has an estimated population of approximately 86 993 people, the majority of whom are subsistence farmers.[36] The area experiences a unimodal rainy season from May to October and a prolonged dry season from November to April. Malaria transmission is intense and seasonal, peaking during and shortly after the rainy season when mosquito breeding sites are common. The study period, May to July 2024, coincided with the early rainy season, a period characterised by increasing mosquito breeding and rising malaria transmission intensity. Conducting the study during this window allowed for a realistic estimation of parasite carriage and anaemia prevalence before the seasonal transmission peak. The predominant malaria parasite species is *P. falciparum*, transmitted mainly by vectors *Anopheles gambiae sensu lato* and *Anopheles funestus*.[37 38] The Upper East Region remains one of Ghana's malaria-endemic areas, recording some of the highest annual parasite incidence rates nationwide (12.2%).[3] Despite the scale-up of vector control interventions, including ITN distribution, indoor residual spraying and case management, malaria remains a leading cause of morbidity among school-age children and adolescents in the region.[39]

The Tempane Senior High School, where the study was conducted, admits both boarding and day students, offering an ideal setting for examining how residential

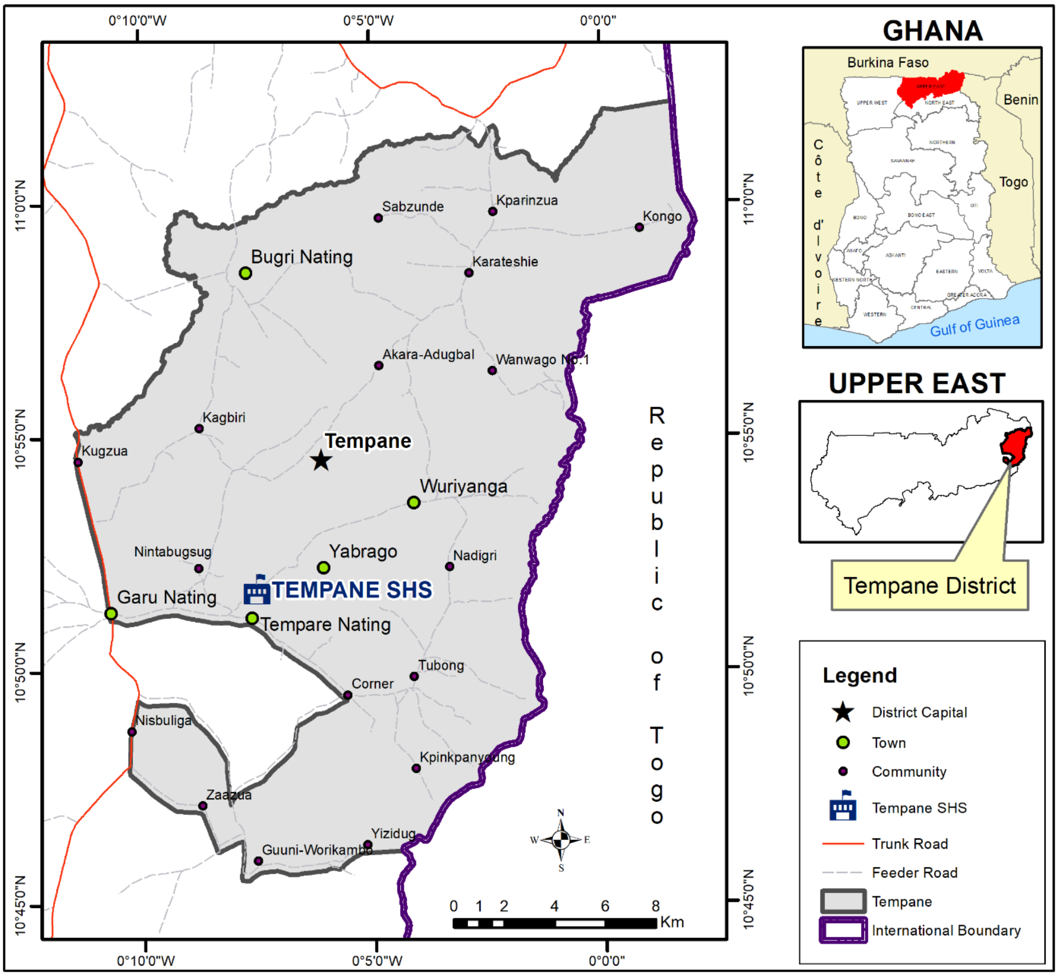

Figure 1 Map of Tempane District showing the location of the study site, the Tempane Senior High School source: Author's original design. SHS, senior high school.

status may influence malaria and anaemia risk. Boarding students typically sleep in dormitories where ITN use may be monitored or encouraged, whereas day students return to their homes daily and may be exposed to differing environmental conditions, housing types and proximity to mosquito breeding sites. These contrasting residential arrangements create a natural framework for comparing exposure risk. Furthermore, SHS students represent a critical but understudied demographic in malaria control. They are old enough to engage in preventive behaviours such as bed net use but may exhibit inconsistent practices due to lifestyle or perceived reduced susceptibility.[40 41] Understanding malaria and anaemia dynamics in this group provides evidence to support school-based malaria control programmes, which are gaining attention across sub-Saharan Africa for their feasibility and public health impact.

Study design, population, recruitment strategy and sampling

An SHS-based cross-sectional study was conducted between May and July 2024 at Tempane Senior High School in the Tempane District of the Upper East Region of Ghana. This approach allows for the simultaneous measurement of the burden of malaria and anaemia and the examination of associated factors while ensuring standard data collection and minimising recall bias. The study population consisted of high school students asymptomatic of malaria. In this study, asymptomatic malaria was defined as the presence of *Plasmodium* parasitaemia detected by microscopy in individuals who did not report malaria-related symptoms at the time of recruitment. Students were eligible if they were present at the school during data collection, provided informed consent (or parental consent and assent where applicable) and had not taken anti-malaria medication within 2 weeks prior to recruitment. Students were excluded if they had chronic health conditions (eg, HIV/AIDS), known haemoglobinopathies, were pregnant, had treatment for malaria within the previous 2 weeks prior to sample collection, or did not consent to participate. Approximately 3 mL of venous blood was collected aseptically from each participant into EDTA tubes following standard phlebotomy procedures. Each sample was used for malaria microscopy and haemoglobin determination.

A total of 290 students were recruited using stratified random sampling. Stratification was based on class level (SHS 1–3). Within each stratum, participants were selected proportionally using simple random sampling from class registers. Invitations were sent to the sampled potential participants who visited the school infirmary for study procedures on informed consent. The sample size was estimated using Cochran's formula for cross-sectional studies, assuming a malaria prevalence of 25% from a pooled adolescent study,[42] a 5% margin of error and a 95% confidence level.

Data collection and questionnaire administration

A structured questionnaire was used to collect demographic data (ie, age, sex, academic level and residence type), information on ITN use and recent history of fever or malaria. The questionnaire was specifically developed for the purpose of this research. The items were designed based on the study objectives and relevant literature to ensure content validity. Data collection was carried out by trained research assistants under supervision. No personal identifiers were included during data collection.

Haemoglobin concentration estimation and anaemia classification

Haemoglobin concentration was measured using a calibrated portable Urit-12 analyser (URIT Medical Electronic, Shenzhen, China). Anaemia was defined as haemoglobin <12.0 g/dL or <13.0 g/dL for adolescent females and men, respectively, according to WHO age-specific and sex-specific haemoglobin thresholds.[43]

Malaria parasite detection

Thick and thin blood films were prepared for each sample, air-dried and stained with 10% Giemsa for 10 min following WHO guidelines.[44] Slides were examined under oil immersion (× 100 objective) by two independent microscopists. A slide was considered negative after examination of 200 high-power fields without detection of asexual parasites. Discrepancies between microscopists were resolved by a third reader.

ETHICAL CONSIDERATION

Permission to conduct the study was obtained from the Ghana Education Service and the school management. Written informed consent was obtained from participants aged 18 years and above, while assent was obtained from those under 18 years, with parental or guardian consent. Participants who had low haemoglobin were referred to the school infirmary for assessment and management. All malaria-positive students were advised to visit the school infirmary if they subsequently develop a fever for assessment and treatment. As per the Ghana Health Service standard treatment guidelines, which align with the WHO guidelines for malaria control in high-transmission areas, asymptomatic malaria infections are not eligible for treatment.[45] Confidentiality and anonymity were maintained throughout the study and in conformity with the Declaration of Helsinki. No incentive was offered to participants.

Patient and public involvement statement

Students and school authorities were not involved in the design of the study. However, school administrators and teachers were consulted to ensure that the study procedures were appropriate for the school setting and student population. Participation was voluntary, and students received information about the study before providing consent. The results will be shared with the relevant stakeholders, including the participating school, to inform future adolescent health and education interventions.

DATA ANALYSIS

Data were entered into Microsoft Excel and analysed using the Stata (V.17.0) package (Stata Corporation, Texas, USA). Continuous variables were expressed as means and SDs, and categorical variables as frequencies and percentages.

Differences between categorical variables were assessed using Pearson's χ^2. Independent t-tests and one-way analysis of variance were used to compare mean haemoglobin levels across groups. Bivariate and multivariable binary logistic regression models were used to estimate crude and adjusted ORs (cOR and aOR) with 95% CIs. The multivariate model included all the variables under consideration to account for any potential confounding effect of each variable, as well as all theoretical factors. Statistical significance was considered at p<0.05.

RESULTS

Demographic characteristics of participants

A total of 290 SHS students participated in the study. Of these, 191 (65.9%) were female and 99 (34.1%) were male (table 1). The majority (52.1%) were aged 18–20 years, while 37.6% were 15–17 years and 10.3% were above 20 years. Participants were evenly distributed across the three academic levels, with SHS 1 and SHS 3 each accounting for 33.5% and SHS 2 representing 33.1%. Most students (83.1%) resided in boarding facilities, and 16.9% were day students. About half of the participants (52.1%) reported not using ITNs.

Prevalence of malaria parasite carriage

The overall prevalence of malaria parasitaemia among the participants was 23.1% (67/290). As shown in table 2, malaria parasite carriage prevalence was higher among males (26.3%) than females (21.5%), though this difference was not statistically significant (p=0.358). Prevalence varied slightly across age groups, with 27.5% among students aged 15–17 years and 20.5% and 20.0%, respectively, among those aged 18–20 years and those above 20 years (p=0.382).

The academic level of students showed a decreasing trend in malaria parasite carriage prevalence with advancing school level, from 27.8% in SHS 1 to 15.5% in SHS 3 (p=0.087). Residential status and bed net use were significantly associated with malaria infection.

Table 1 Descriptive characteristics of study participants

Demographic characteristics	Frequency	Per cent
Sex		
Female	191	65.9
Male	99	34.1
Age group		
15–17	109	37.6
18–20	151	52.1
>20	30	10.3
Academic level		
SHS 1	97	33.5
SHS 2	96	33.1
SHS 3	97	33.5
Residential status		
Boarding	241	83.1
Day	49	16.9
ITN use		
No	151	52.1
Yes	139	47.9
Total	290	100

ITN, insecticide-treated bed net; SHS, senior high school.

Table 2 Prevalence of malaria among participants

	Malaria parasite		
	No	Yes	
Characteristics	n (%)	n (%)	P value
Sex			
Female	150 (78.5)	41 (21.5)	0.358
Male	73 (73.7)	26 (26.3)	
Age group			
15–17	79 (72.5)	30 (27.52)	0.382
18–20	120 (79.5)	31 (20.5)	
>20	24 (80.0)	6 (20.0)	
Academic level			
SHS 1	70 (72.2)	27 (27.8)	0.087
SHS 2	71 (74.0)	25 (26.0)	
SHS 3	82 (84.5)	15 (15.5)	
Residential status			
Boarding	203 (76.9)	38 (15.8)	<0.001
Day	20 (40.8)	29 (59.2)	
ITN use			
No	91 (60.3)	60 (39.7)	<0.001
Yes	132 (95.0)	7 (5.0)	
Total	223 (76.9)	67 (23.1)	

Number of participants (n), percent (%), SHS, ITN. P values were obtained from Pearson's χ^2 test of differences between categorical variables within each group.
ITN, insecticide-treated bed net; SHS, senior high school.

Day students had a much higher prevalence (59.2%) compared with boarding students (15.8%) (p<0.001). Similarly, students who did not use ITNs were more likely to be infected with the malaria parasite (39.7%) than those who did (5.0%) (p<0.001).

FACTORS ASSOCIATED WITH MALARIA PARASITE CARRIAGE PREVALENCE

Binary logistic regression (table 3) identified significant predictors of malaria parasite infection. After adjusting for potential confounders, day students were nearly six times more likely to have malaria parasites compared with boarding students (aOR=5.65; 95% CI 2.58 to 12.36; p<0.001). Not using ITN was also strongly associated with malaria parasite infection, with non-users having about 16 times higher odds of infection (aOR=15.97; 95% CI 6.33 to 40.32; p<0.001). It was instructive to note male students had approximately 50% reduced odds of malaria parasite infection compared with females (aOR=0.48; 95% CI 0.23 to 0.99; p=0.046).

Haemoglobin concentration and anaemia prevalence

The mean haemoglobin concentration among the participants was 12.31±1.44 g/dL (range: 7.6–15.6 g/dL). Anaemia was present in 49.0% of participants (table 4). Males had a higher mean haemoglobin level (12.73±1.54 g/dL) than females (12.10±1.34 g/dL) (p<0.001) (figure 2A). Anaemia prevalence did not differ significantly by sex (p=0.106) (table 4).

Haemoglobin concentration increased with age (p<0.001), and anaemia was more common among younger students aged 15–17 years (65.1%) than those aged 18–20 years (43.1%) and those above 20 years (20.0%) (p<0.001). Academic level was also significantly associated with haemoglobin concentration (p=0.001) and anaemia (p<0.001), with SHS 1 students showing the highest anaemia prevalence (65.0%).

Students with malaria parasite infection had significantly lower haemoglobin levels (11.50±1.43 g/dL) compared with those without infection (12.56±1.35 g/dL) (p<0.001) (figure 2F). Anaemia was much more prevalent among malaria parasite-positive students (71.6%) than malaria parasite-negative students (42.2%) (p<0.001).

Similar trends were observed when anaemia prevalence was stratified by sex except for academic level, where the difference in anaemia prevalence among females was statistically significant (p<0.001). Details can be reviewed from online supplemental table 1.

Factors associated with anaemia

Multivariate analysis (table 5) identified sex, age group, ITN use and malaria parasite carriage as significant predictors of anaemia. Male students had higher odds of anaemia than female students (aOR=2.26; 95% CI 1.09 to 4.65; p=0.028) after adjusting for potential confounding

Table 3 Factors associated with malaria prevalence

Characteristic	cOR (95% CI)	P value	aOR (95% CI)	P value
Sex				
Female	1		1	
Male	1.30 (0.74 to 2.29)	0.359	0.48 (0.23 to 0.99)	0.046
Age group				
15–17	1		1	
18–20	0.68 (0.38 to 1.21)	0.190	1.07 (0.38 to 2.99)	0.898
>20	0.66 (0.25 to 1.77)	0.407	1.48 (0.33 to 6.64)	0.612
Academic level				
SHS 1	1		1	
SHS 2	0.91 (0.48 to 1.72)	0.779	0.63 (0.21 to 1.86)	0.401
SHS 3	0.47 (0.23 to 0.96)	0.039	0.45 (0.13 to 1.49)	0.188
Residential status				
Boarding	1		1	
Day	7.75 (3.98 to 15.09)	<0.001	5.65 (2.58 to 12.36)	<0.001
ITN use				
Yes	1		1	
No	12.43 (5.44 to 28.43)	<0.001	15.97 (6.33 to 40.32)	<0.001

cOR: Unadjusted logistic regression model that assessed the association of each variable and the incidence of malaria parasite prevalence.
aOR: Adjusted logistic regression model that assessed the independent association of each variable and the incidence of malaria parasite prevalence, accounting for the potential effect of covariates such as sex, age group, academic level, residential status and bed net use. 95% CI, ITN, SHS.
aOR, adjusted OR; cOR, crude OR; ITN, insecticide-treated bed net; SHS, senior high school.

factors. Lower odds of anaemia were observed among age groups 18–20 years (aOR=0.41; 95% CI 0.17 to 0.97; p=0.043) and those above 20 years (aOR=0.07; 95% CI 0.02 to 0.27; p<0.001) compared with their younger (15–17 years) peers. Participants with malaria parasites were more than nine times likely to be anaemic compared with those without malaria parasites (aOR=9.36; 95% CI 3.91 to 22.42; p<0.001). Although ITN use was not statistically significantly associated with the odds of anaemia in unadjusted analysis, this association was significant after adjusting for potential confounding factors (aOR=0.47; 95% CI 0.20 to 0.88; p=0.022).

DISCUSSION

This study assessed the prevalence and determinants of malaria parasite carriage and anaemia among SHS students. The findings show that both malaria parasite carriage and anaemia remain significant health concerns, among SHS students with malaria parasitaemia recorded in nearly one-quarter of participants and anaemia affecting about one in five students. Students' residential status and ITNs use were key predictors of malaria parasite infection, and malaria parasite carriage and male sex were strongly associated with lower haemoglobin concentrations and higher anaemia prevalence.

The observed malaria parasite carriage prevalence of 23.1% among the participants indicates that malaria transmission remains active among adolescents despite ongoing control interventions. This prevalence is higher than the 12.2% reported for under-5s in the Upper East Region by the 2022 Ghana Demographic and Health Survey (DHS).[3] While malaria among younger children has generally declined over the past decade (from approximately 26.7% in 2014 to 8.6% in 2022) from the Ghana DHS, our findings suggest that adolescents may still carry a relatively high burden, highlighting the need for age-targeted interventions. This study prevalence is similar to recent school-based and regional reports in Ghana and elsewhere, where school-age and adolescent prevalence in high-transmission settings has been reported in the high teens to mid-20s range.[46–49] School-age children and adolescents increasingly appear to sustain malaria transmission even as under-5 years prevalence declines. Studies and reviews from Ghana and wider sub-Saharan Africa report substantial asymptomatic infection in school populations, indicating that older children and adolescents continue to serve as a substantial reservoir for transmission and call for school-targeted control measures.[42 50–53]

The analysis identified ITN use and day residential status as the most important predictors of malaria infection. Students who did not use ITNs were nearly 16 times more likely to be infected compared with users. This finding is consistent with national and regional studies showing that consistent ITN use significantly reduces

Table 4 Anaemia prevalence among participants

Characteristic	N	Anaemia prevalence: No anaemia n (%)	Anaemia n (%)	P value
Overall	290	148 (51.0)	142 (49.0)	
Sex				
Female	191	104 (54.5)	87 (45.6)	0.106
Male	99	44 (44.4)	55 (55.6)	
Age group				
15–17	109	38 (34.9)	71 (65.1)	<0.001
18–20	151	86 (57.0)	65 (43.1)	
>20	30	24 (80.0)	6 (20.0)	
Academic level				
SHS 1	97	34 (35.1)	63 (65.0)	<0.001
SHS 2	96	67 (69.8)	29 (30.2)	
SHS 3	97	47 (48.5)	50 (51.6)	
Residential status				
Boarding	241	121 (50.2)	120 (49.8)	0.532
Day	49	27 (55.1)	22 (44.9)	
ITN use				
Yes	139	75 (54.0)	64 (46.0)	0.339
No	151	73 (48.3)	78 (51.7)	
Malaria parasite				
Yes	67	19 (28.4)	48 (71.6)	<0.001
No	223	129 (57.9)	94 (42.2)	

Number of participants (n), percent (%), ITN, SHS. Anaemia prevalence is calculated based on the total number of participants within each group, and the p values were obtained from Pearson's χ^2 test of differences between categorical variables within each group.
ITN, insecticide-treated bed net; SHS, senior high school.

malaria infection risk among older children and adolescents.[25 54 55] The protective role of ITNs underscores the need to sustain and expand school-based distribution and education campaigns targeting older students, who are often overlooked in malaria prevention programmes primarily aimed at children under 5 years and pregnant women.

Day students in the study had markedly higher odds of malaria parasite carriage than boarding students, a pattern that likely reflects differences in sleeping environment, exposure and the consistency of prevention behaviours. Boarding students typically sleep in more controlled settings, where ITN use and other mosquito-control measures may be supervised, whereas day students return to varied household environments with uneven ITN coverage, closer proximity to mosquito breeding sites and less oversight of preventive practices.[31] These underlying socioeconomic and household-level factors could partly explain the higher malaria risk observed among day students. Boarding students could benefit from the localised community-level protection effect offered by their environment. Previous studies show that ITN access and utilisation are influenced by household wealth, housing structure and sleeping arrangements, with children in larger or lower-income households less likely to have consistent protection.[56 57] Day students who sleep at home in these potentially heterogeneous transmission settings may therefore experience reduced or inconsistent ITN protection compared with boarders. School-based and population surveys have documented similar patterns: studies of secondary-school and community samples in West and East Africa report higher infection risk linked to household exposure and lower preventive coverage among children who live outside of school compounds, and school-based interventions that improve protective behaviours reduce both malaria parasite infection carriage and anaemia among pupils.[10 58 59]

Strikingly, male students had a lower adjusted odds of malaria parasite infection than females, contrary to some previous findings. Sex differences in malaria infection are context-dependent.[7] While many facility-based and community-based studies report higher parasite prevalence or longer infection duration in males, often attributed to greater outdoor exposure and delayed care,

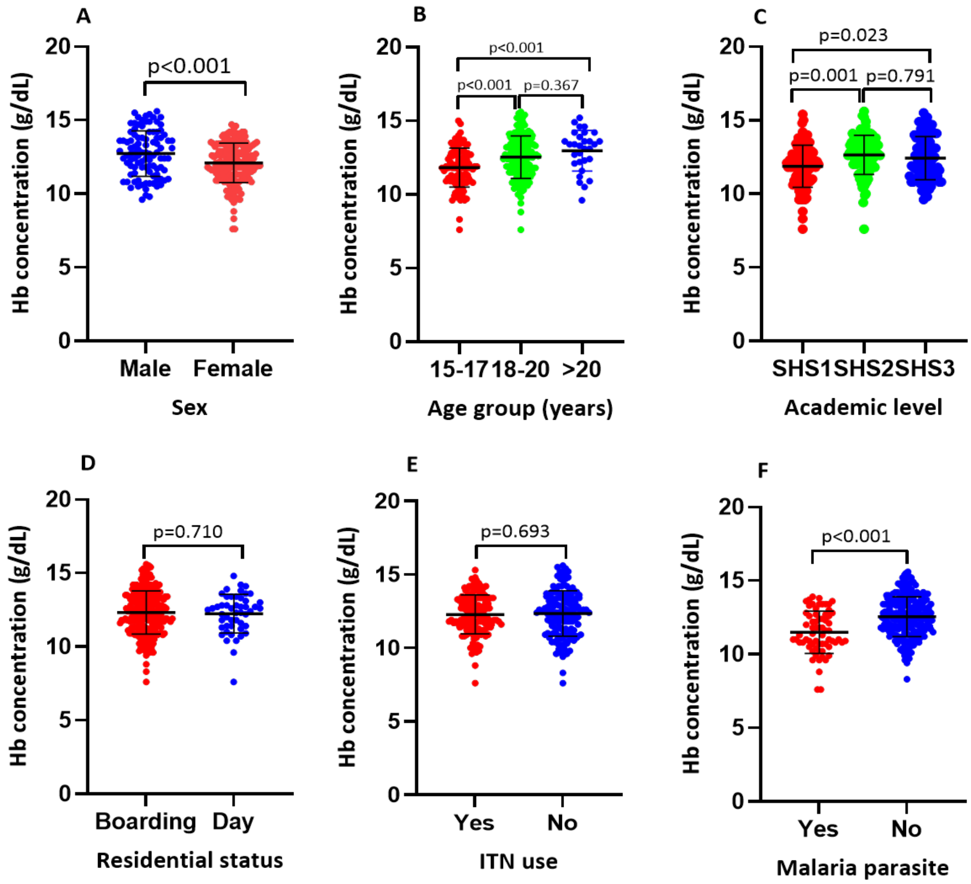

Figure 2 Haemoglobin concentration levels by demographic and malaria parasite carriage. The distribution of haemoglobin levels is stratified by sex (A), age group (B), academic level (C), residential status (D), ITN use (E) and malaria parasite carriage status (F). Mean haemoglobin concentrations (black horizontal lines) are presented with SDs (black vertical lines). The differences in mean haemoglobin concentrations were compared using t-tests and ANOVA where appropriate. ANOVA, analysis of variance; Hb, haemoglobin; ITN, insecticide-treated bed net; SHS, senior high school.

other work highlights situations where females (especially adolescent girls and women of reproductive age) show an equal or higher burden, driven by gendered household roles, pregnancy, differential access to prevention and sex-specific immune responses.[60 61] Biological factors such as hormonal modulation of immunity (eg, effects of oestrogens on immune activation) and gendered behaviours (net use, time outdoors and care-seeking) likely interact to produce setting-specific patterns; therefore, the lower adjusted odds in males observed in our study may reflect local behavioural or household factors rather than an intrinsic biological protection.[62 63] Further qualitative exploration could help clarify these dynamics.

The overall prevalence of anaemia observed in the study was 49% among students. This prevalence is comparable to findings from other studies conducted in northern Ghana. For example, research conducted among school-age children in the Upper East Region reported anaemia prevalence levels ranging approximately from 40% to over 50%, reflecting the persistent burden of anaemia in the region.[17] The persistent high anaemia levels in the region highlight the combined influence of inadequate dietary iron intake and endemicity of infections that may contribute to reduced haemoglobin levels among adolescents. Anaemia in this study was more common among younger students and males. Younger students may be more vulnerable due to growth-related iron demands and less autonomy over diet and preventive practices. During male puberty, the rapid growth and muscle development that occur increase iron requirements for haemoglobin synthesis and expansion of blood volumes.[64 65] If dietary iron intake is inadequate, the risk of anaemia increases. Additionally, higher levels of physical activity among male adolescents may increase iron turnover and loss. Environmental factors such as malaria and other parasitic infections may also contribute to the higher anaemia among males in some settings.[65]

Malaria parasite infection showed a strong association with anaemia in this study. Participants with malaria parasites had significantly lower haemoglobin levels and were over nine times more likely to be anaemic than their uninfected peers. This aligns with findings from national and regional school-based studies. In Ghana, recent adolescent school-based data showed that malaria infection was

Table 5 Factors associated with the prevalence of anaemia

Characteristic	cOR (95% CI)	P value	aOR (95% CI)	P value
Sex				
Female	1		1	
Male	1.49 (0.92 to 2.43)	0.107	2.26 (1.09 to 4.65)	0.028
Age group				
15–17	1		1	
18–20	0.40 (0.24 to 0.67)	<0.001	0.41 (0.17 to 0.97)	0.043
>20	0.13 (0.05 to 0.36)	<0.001	0.07 (0.02 to 0.27)	<0.001
Academic level				
SHS 1	1		1	
SHS 2	0.23 (0.13 to 0.43)	<0.001	0.46 (0.18 to 1.15)	0.079
SHS 3	0.57 (0.32 to 1.02)	0.059	1.83 (0.69 to 4.87)	0.228
Residential status				
Boarding	1		1	
Day	0.82 (0.44 to 1.52)	0.532	0.47 (0.20 to 1.07)	0.071
ITN use				
Yes	1		1	
No	1.25 (0.79 to 1.99)	0.340	0.47 (0.20 to 0.88)	0.022
Malaria parasite				
No	1		1	
Yes	3.47 (1.91 to 6.28)	<0.001	9.36 (3.91 to 22.42)	<0.001

cOR: Unadjusted logistic regression model that assessed the association of each variable and the prevalence of anaemia. aOR: Adjusted logistic regression model that assessed the independent association of each variable and the prevalence of anaemia, accounting for the potential effect of covariates such as sex, age group, academic level, residential status and bed net use. 95% CI, ITN, SHS.
aOR, adjusted OR; cOR, crude OR; ITN, insecticide-treated bed net; SHS, senior high school.

associated with a 52% higher prevalence of anaemia and a mean haemoglobin reduction of 0.42 g/dL.[18] Elsewhere in West Africa, a meta-analysis of adolescent girls found anaemia prevalence of 26.7% in studies published after 2015, although with heterogeneity across countries.[66] In Malawi, a school-based malaria screening and treatment intervention led to a 30.8% reduction in anaemia prevalence, demonstrating the strong link between parasite carriage and haemoglobin status in older children.[25] In Tanzania, similar associations between malaria parasitaemia and reduced haemoglobin concentrations were reported, with children with malaria parasites having over four times the odds of anaemia compared with those without malaria.[67] The mechanism is well established: *Plasmodium* infection causes anaemia through two broad, interacting pathways. First, parasite replication within erythrocytes and immune-mediated processes lead to direct destruction of infected red blood cells and increased removal of uninfected erythrocytes by the spleen and phagocytes, producing acute haemolysis and a rapid fall in circulating red blood cell mass.[68 69] Second, malaria suppresses effective erythropoiesis. Parasite products (notably haemozoin) and the host inflammatory response impair bone-marrow erythroid progenitors, blunt the erythropoietin (EPO) response or induce EPO hyporesponsiveness and promote dyserythropoiesis, resulting in inadequate red-cell replacement (ie, low reticulocytosis) despite anaemia. Together, haemolysis plus ineffective erythropoiesis explains the profound anaemia often seen in infected individuals.[21 70]

Although not using ITNs was associated with a higher risk of malaria, and malaria was in turn associated with increased anaemia risk, the analysis showed that not using ITNs appeared to be protective against anaemia. This unexpected finding may reflect residual confounding, reporting bias or reverse causality, rather than a true protective effect. For instance, individuals who perceive themselves to be at higher risk of malaria may be more likely to use ITNs, which can produce paradoxical associations in cross-sectional studies.[57] Nevertheless, the relationship between malaria and anaemia is well established.

Implications: In the Ghanaian context (and more broadly in sub-Saharan Africa), malaria remains highly prevalent despite decades of control efforts. Recent spatial modelling shows persistent variation in malaria risk at the district level in Ghana from 2016 to 2021.[71] Meanwhile, anaemia among adolescents in East and West Africa has been found to remain high, with a systematic review in 2025 reporting substantial prevalence among adolescent girls.[66]

The findings of this study, therefore, contribute important evidence on these issues in a school environment, reinforcing the need for adolescent-specific health strategies rather than solely under-5 or pregnant-women approaches. Our study underscores the need to integrate malaria prevention more actively into school health strategies, particularly in boarding and day-school settings. For day students, interventions might need to extend beyond the school compound into the home environment. Strategies could include ensuring access to ITNs at home, educating parents/guardians on correct and consistent net use and periodic screening of students for malaria infection.[25 39 54 72–74] Moreover, our results suggest that strengthening ITN distribution and use among adolescents is vital. Although many malaria programmes focus on under-5s and pregnant women, there is growing recognition that school-aged children are a 'neglected' reservoir of infection, contributing to transmission and health burdens.[48]

A recent cluster trial in Ethiopia found that while net ownership increased substantially among school-based children, utilisation and incidence of malaria were still influenced by access, household size to net ratio and prior malaria history.[54] This highlights that simply distributing nets is not enough; consistent use and behavioural reinforcement are key.[75 76] Given the strong link between malaria and anaemia, school-based screening and treatment has appeal not only for reducing malaria infection but also for improving haemoglobin status and supporting overall adolescent health and educational outcomes. Meta-analyses suggest that interventions targeting malaria, when delivered in school settings, can produce cognitive and educational gains (although modest) through health improvements.[50 77] In other words, malaria control in schools may yield multiple benefits beyond just reducing infection rates.

Limitations of the study: The study's cross-sectional design limits causal inference between malaria and anaemia. While malaria infection and anaemia are strongly associated, we cannot definitively assert directionality (though prior literature supports malaria causing anaemia). Additionally, the absence of symptomatic participants limits the study's ability to compare infection-anaemia patterns across clinical presentations. The study also relied on self-reported symptoms of malaria that may introduce some degree of misclassification of asymptomatic carriers as well as on self-reported bed net use, introducing potential recall or social desirability bias. Furthermore, the study did not directly measure home sleeping environment factors (ie, net integrity, number of sleepers per net, night-time exposure to mosquitoes) or seasonal fluctuations in malaria transmission, which could affect results. Malaria parasite detection relied on microscopy alone, which may have underestimated the true prevalence due to its limited sensitivity in detecting low-density and submicroscopic infection. Finally, although several potential confounders were adjusted for, unmeasured factors (such as nutritional deficiencies, helminth infection and socioeconomic status) may influence anaemia independently of malaria.

Future research could take a longitudinal design to track how malaria exposure, bed net use behaviour and haemoglobin levels evolve over time in school populations. Trials of school-based interventions (eg, periodic mass screening/treatment, enhanced net distribution, ITN education programmes targeted to day students and their homes) should measure not only malaria infection but also anaemia, school attendance and academic performance. Given the demonstrated benefits of school-based malaria screening and treatment (such as in Malawi and elsewhere),[25 42 73 78] it would be valuable to replicate and adapt such interventions in Ghanaian secondary schools. It is recommended that future studies incorporate rapid diagnostic tests and/or PCR-based methods to improve sensitivity and provide comprehensive estimates of prevalence.

Conclusion: In summary, the study highlights the substantial burden of malaria and its strong association with anaemia among SHS students. It points to bed net use and residential status (boarding vs day) as important factors. The findings support the view that adolescent school-age populations deserve more focused malaria intervention efforts, both within school and at home. By combining ITN distribution, health education, screening and linkage to care, school health programmes can play a vital role in reducing malaria infection, improving haemoglobin status and ultimately supporting the health and educational success of adolescents. Future studies should employ longitudinal designs to monitor seasonal variations in malaria transmission and evaluate the long-term effects of school-based interventions on malaria parasite infection and anaemia. Research incorporating nutritional status, helminth and schistosomiasis infections and socioeconomic indicators would also provide a more comprehensive understanding of anaemia's multifactorial causes in adolescents.

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Acknowledgements The authors are grateful to the students of Tempane Senior High School who voluntarily participated in this study. We are also grateful to the staff of Presbyterian Hospital, Garu, for their immense support during the participants' recruitment and sample collection processes. Special thanks go to the laboratory technicians; Mr Joshua Adoliba, Mr Fortunate Aruk Akudugu and Emelia Teni Azong, for assisting with laboratory analysis.

Contributors Conceptualised and designed study: JAA, MC-E, EDA and GAM. Data collection: JAA and EDA. Performed experiment: JAA and EDA. Data analysis: SDD, JAA and MC-E. Writing draft manuscript: SDD, JAA and MC-E. Review, editing and approval of final version of manuscript: JAA, MC-E, GAM, EDA, MKA, KKF, MND, MRA and SDD. SDD is the guarantor.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by Navrongo Health Research Centre Institutional Review Board (Approval No.: NHRCIRB714). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. All data relevant to the study are included in the article or uploaded as supplementary information. The dataset used and/or analysed in the study is available from the corresponding author(s) upon reasonable request.

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