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RESEARCH

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High parasitaemia correlates with malaria episodes and the socioeconomic impact of recurrent malaria infection in high-transmission zone of Nigeria

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Abstract

Background: Recurrent malaria infection is a major phenomenon in a hightransmission zone with deplorable health and socioeconomic consequences on individuals and the public. However, the association between parasitaemia, repeated episodes of the infection, and its socioeconomic impact is less studied. Therefore, this study aimed at bridging this research gap by conducting an epidemiological survey in selected malaria-endemic settings of Kwara state, Nigeria.

Results: High prevalence and intensity of infection were observed, 56.6% of 572 study participants were infected with average parasitaemia of 3022.25 ± 1001.51 per µl of blood and the majority of heavy infection was due to *Plasmodium falciparum*. The heavily asymptomatic infected participants were among the younger age group particularly ≤ 20 years, and infection decreases with increasing age. Parasitaemia and the number of episodes of malaria attacks were positively correlated ($R^2 = 0.2388$, $p < 0.0001$). Highrecurrent malaria was associated with male ($p = 0.001$), younger age ($p = 0.0012$), low-income status ($p = 0.0004$), bush around habitation (0.0014), and unavoidability of preventive strategies and treatment ($p < 0.0001$) of malaria. Our study further revealed socioeconomic factors as cause and/or consequence of recurrent malaria infection. Low income individuals (aOR 1.948 95%CI 0.945–2.512) and illiterates (aOR 1.920 95%CI 1.470–2.149), those living close to bush (aOR 2.501 95%CI 2.033–3.714) and dumpsite (aOR 2.718 95%CI 1.661–3.118) are at least twice likely to have recurrent infection. The socioeconomic consequence of recurrent malaria episodes includes reduced economic activities, personal savings, and change of lifestyle in adults, while infected children suffered declined academic performance and sports activities.

Conclusions: This study underscores high malaria intensity as a prevalent health problem in our study location and demonstrates a positive correlation between malaria episodes and parasitaemia which can be explored in the clinic for the screening of suitable antimalarial drugs that cure beyond a single infection. Our finding also advocates for mass distribution of insecticide-treated nets, provision of socio-infrastructural amenities such as medical centers, good drainage system and highly subsidized malaria treatment in endemic endemic rural communities

Keywords: Recurrent malaria, Malaria episodes, Parasitaemia, Kwara state, Lifestyle

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Background

Malaria is a mosquito-borne infectious disease that affects humans and other animals (Perkins 2018; Guggisberg et al. 2018). Human malaria infection causes severe morbidity and mortality worldwide particularly in sub-Saharan Africa, 94% of global malaria cases (229 million) are shared within the WHO African region and children under 5 years accounted for 67% (274,000) malaria-associated death worldwide (WHO 2020). Of the five prominent etiologic agents of human malaria; *P. falciparum* followed by *P. vivax* poses the greatest threat and both share significant overlapping endemicity in many parts of the world (Menkin-Smith and Winders 2019). Many reports have shown that infection due to *P. falciparum* is one of the leading causes of anemia, thrombocytopenia and its severe case often results in excessive immune cell death such as pyroptosis, NETosis, apoptosis, ferroptosis, and autophagy to drive immunosuppressive-mediating sepsis in most infected individuals particularly children (Viriyavejakul et al. 2014; Babamale et al. 2017; Aitken et al. 2018; Pereira et al. 2020; Sena-dos-Santos et al. 2021).

The severity of the attack depends on the species of *Plasmodium*, as well as host-associated factors such as the age, genetic constitution, malaria-specific immunity, nutritional status of the individual, and previous exposure to antimalarial drugs (Ehrhardt et al. 2006; Crutcher and Hoffman 1996). In the world today, *P. falciparum* is responsible for the vast majority of death and morbidity due to its innate capacity to progress to life-threatening disease in many infected individuals. Severe infection is symptomized by hypoglycemia, acute respiratory distress syndrome (ARDS), shock, jaundice, hemoglobinuria, acidosis, and death (Moxon et al. 2020; Milner 2018). Transmissions in endemic areas are environmentally related; human activities, agriculture, and road construction have created more favorable habitats and thus contribute to the spread of malaria into several areas where it was not previously observed (Pinchoff et al. 2016; Kanyangarara et al. 2016; Essendi et al. 2019; Babamale et al. 2020). Repeated symptomatic infections accompanied by serious life-threatening outcomes are common before the attainment of substantive immunity against the disease. This often results in recurrent malaria episodes which may be caused by reinfection from a new mosquito bite, recrudescence due to treatment failure of blood-stage parasites or relapse mediated by reactivation of dormant hypnozoites in the liver (Maneerattanasak et al. 2017; Pasini et al. 2021).

In Nigeria, 76% of the population lives in high-transmission areas (World Health Organization 2019), and several malaria control strategies such as the use of Artemisinin combined therapy (ACT), and insecticide-treated bed nets (ITNs) as well as indoor residual spraying of insecticide have been exploited. Despite these efforts, the overall prevalence of infection has been on increase, and it is having a colossal effect on the health sectors of the nation. The emergence and spread of drug resistance, high transmission rates, and poor socioeconomic level have impeded the successful outcome of most malaria control strategies. This has imposed severe burdens on both individuals and governments. Individual bears the cost of treatment, lost days of work and absence from school while the cost of insecticide spraying or distribution of insecticide-treated bed nets; loss of income, and opportunities for joint economic ventures and tourism are borne by government (CDC 2015). This current study, conducted in a high-malaria-transmission zone in Northcentral Nigeria, examined the current impact of recurrent malaria infection on socioeconomic activities and the possible correlation between infection episodes and parasitaemia level which may be beneficial in the treatment of resistant malaria parasites.

Methods

The study area characteristics

This study was conducted in selected towns (Ogele, Patigi, Gaa-imam) across three Local governments (LGAs) of Kwara state with Ilorin as a state capital (Fig. 1). Ogele-8°23′0″ N (Asa LGA), Pategi-8°44′N 5°45′E (Patigi LGA), and Gaa-Imam (Ilorin South LGA) are about 15 km, 164.1 km, and 6 km from Ilorin, respectively. Ogele and Gaa-Imam are both peri-urban areas with similar climate and topographical conditions. The climate is tropical with well-defined wet (April–October) and dry (November–March) seasons; mean annual precipitation of over 1133.4 mm, mean annual temperature of 24 °C, and relative humidity of 85%. Meanwhile, Patigi is one of the agro-area surrounded by River Niger and shares a boundary with Kogi State. With the exception of some features, population characteristics in the three locations are similar. Inhabitants are majorly peasant farmers (though aquatic farmers are prevalent in Patigi), with poor homing facilities. Sanitation is poor; wastes are indiscriminately littered, dumpsites and unkempt drainages are located close to human habitations. The communities are inadequately provided with essential amenities such as electricity and a potable water supply. Yoruba is the major language in Gaa-Imam and Ogele, while Nupe and a few Hausa-speaking people dominate the Patigi area.

Sample collection and laboratory procedures

Before the study, we visited the community leaders and opinion groups for their consent and cooperation. Thereafter, the estimated population density

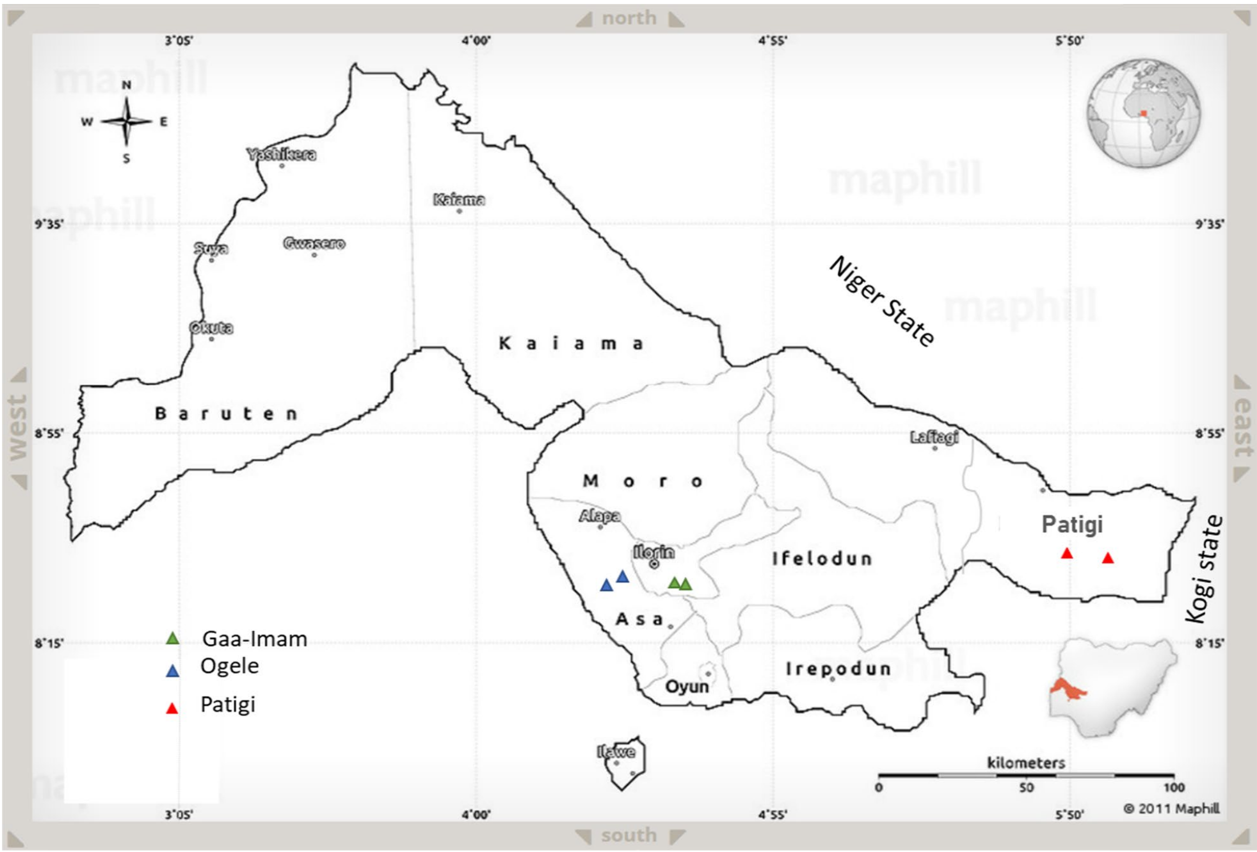


Fig. 1 Global map showing our study locations in Kwara state, Nigeria

of each community under our investigation was sought and obtained from the Kwara State Bureau of statistics and population census. All consented individuals were enlisted; 570 individuals were validated for the study with a confidence level of 95% using Creative Research Systems survey software. Participants who did not provide a blood sample or failed to return the questionnaire sheet or both were excluded from the study.

Samples were collected from house to house, and blood smears were prepared from capillary blood obtained by finger prick using a sterile lancet. Each blood smear was stained immediately with Giemsa and examined under the oil immersion microscope. Simultaneously, pretested questionnaires were administered to all volunteers to obtain information about the number of times each volunteered participant had malaria infection in six months. The individual demographic information and socio-economic and environmental factors were also obtained with a questionnaire before sample collection. The collection of blood and administration of questionnaires were conducted face-to-face by postgraduate students of Parasitology with the assistance of three medical officials. The questionnaire transcript was revised twice by each participant to ensure the accuracy of the information.

Quantification of Parasitaemia of infected participants

The number of parasites per microliter of blood was calculated using Greenwood and Armstrong's theory (Greenwood and Armstrong 1991; Adu-Gyasi et al. 2012). Identification of species and estimates of parasite density was based solely on parasite asexual blood form. *Plasmodium* parasites were counted against 200 WBC on the thick film, and parasitaemia per microliter of blood was calculated as the ratio of parasite count to counted WBC multiplied by the WBC count/µl of the participant. WBCs were counted by use of a Coulter automated cell counter. Infection is categorized as light, moderate, and heavy infection when the parasite count is less than 9, 9–10, and greater than 10 after counting 200 WBCs. Species categorization was done using the key of Cheesbrough (Cheesbrough 2005). All the slides were examined by two investigators who were blinded to the results and slides were counter-read randomly by a third experienced malariologist (BOA). Individuals with high parasitaemia were advised to go for medical treatment, and they were also enlightened on how to keep their immediate environment free of malaria transmission.

Ethical consideration

Ethical clearance was sought and obtained from the State Ministry of Health, Local Government Areas, the University of Ilorin Ethical Review Committee, village authorities, and community leaders. Informed written consent for the study was received before data collection, from each individual/parent in the case of children.

Statistical analysis

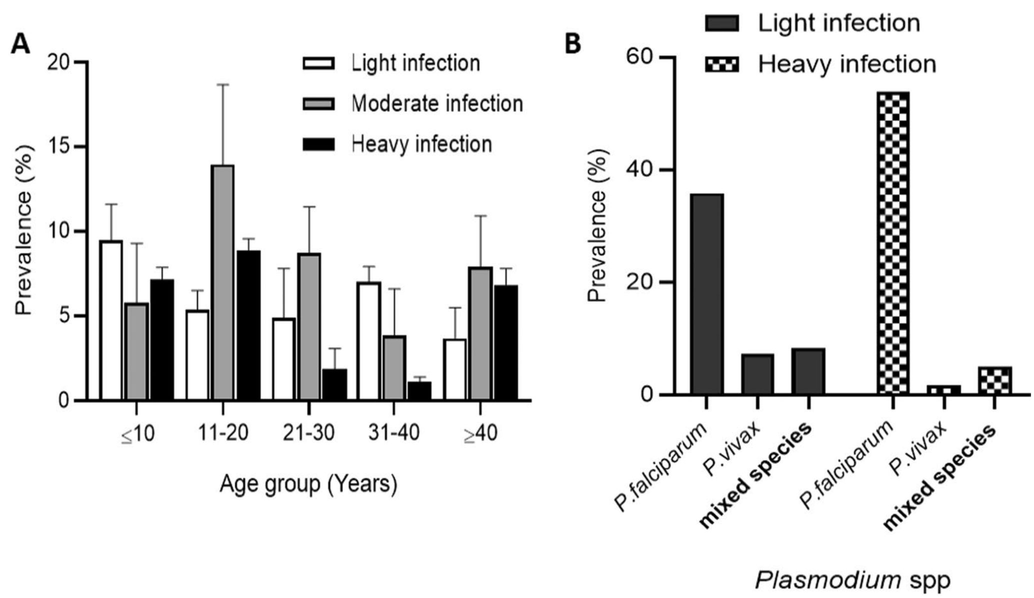
Data analysis was conducted using SPSS software version 16 and GraphPad Prism 8.0.1. SPSS was used to conduct a descriptive comparison of the mean which was subjected to ANOVA with Duncan post hoc analysis to investigate the variation of parasite counts within the group. Distributions of categorical variables were compared with the Chi-square (X^2) test, presented as absolute count and percentage. A two-tailed probability value of $p < 0.05$ was considered statistically significant. The confidence interval was calculated at the level of 95%. Univariate analysis was done for risk analysis. Linear correlation and Mann–Whitney tests were conducted on GraphPad Prism to investigate the correlation and significance of malaria episodes in relation to infection intensity and socioeconomic status of the study participants.

Results

Prevalence and intensity of infection in this study were high, 56.6% of 572 study participants were infected with average parasite counts of 3022.25 ± 1001.51per µl of blood (Table 1) and the majority of heavy infection was due to *Plasmodium falciparum* (Fig. 2B). The heavily infected participants were among the younger age group particularly ≤ 20 years and transmission of infection decreases with increasing age. Although males have a significantly higher intensity of 3148.32 (95%CI 2930.64–3691.39) than females, the difference in prevalence with regard to sex is insignificant (Male vs Female: 53.3% vs. 57.8%, respectively) Table 1. The pattern of infection with respect to parasitaemia showed that heavy infection was often found among youngest and adult individuals while participants within the age group of 21–40 years suffered from light/moderate infection (Fig. 2A). Morphological identification of species showed largely that *P. falciparum* is the most prevalent and associated with high intensity. However, we found few cases of mixed infection of *P. falciparum* and *vivax*: 8.3% and 5.01% among lightly and heavily infected participants, respectively, whereas 9.2% of overall prevalence are associated with *P. vivax* alone (Fig. 2B). Our logistic analysis revealed a significant positive correlation between parasitaemia and malaria episodes ($p < 0.0001$) (Fig. 3A), suggesting that individuals with high malaria intensity are prone to several recurrences of malaria infection within six months. Factors such as gender, socioeconomic status, and environmental factors have impact on malaria episodes. Males were found to have high episodes than their female counterparts (Fig. 3B) which is consistent with their high parasitaemia previously reported in Table 1. Remarkably, the younger age group displayed higher malaria reoccurrence particularly ≤ 10 and 11–20 years than the adult age (≥ 30 years) groups ($p < 0.0001$) (Fig. 3B). Individuals with low or no income and those who lived close to bush recorded high malaria episodes (Fig. 3C). The rate of repeated infection is also dependent on preventive and curative strategies employed by the individual. The majority of people that used specific antimalarial drugs

Table 1 Malaria prevalence and intensity stratified by age and sex

Variables	Number examined	Prevalence *N* (%)	Parasitaemia Mean ± SD	95% confidence interval
Age (years)				
≤ 10	109	83 (76.2)	2619.33 ± 164.02	2109.04–2730.55
11–20	128	78 (61.0)	3001.95 ± 172.17	2785.11–3417.19
21–30	163	76 (46.6)	2205.02 ± 431.70	1824.85–2225.99
31–40	49	26 (53.1)	1108.20 ± 111.05	1104.46–1431.02
≥ 41	123	61 (50.0)	2018.45 ± 105.12	1739.03–2099.71
p Value		0.003	0.043	
Gender				
Male	278	154 (53.2)	3148.32 ± 921.30	2930.64–3691.39
Female	294	170 (57.8)	2919.55 ± 353.01	1731.38–2343.81
p Value		0.094	0.040	
Overall	572	324 (56.6)	3022.25 ± 1001.51	2692.07–3496.03



P: *Plasmodium*, spp: species

Fig. 2 Malaria intensity stratified with age and malaria species

such as (chloroquine and Artemisinin-based combination therapy) and the insecticide-treated net had low infection episodes (Fig. 3D) and the worst scenario of malaria episodes was associated with participants that are without any preventive or curative measures.

Occurrence of malaria infection stratified with socioeconomic and environmental factors as presented in Table 2 showed that dearth of socioeconomic amenities such as no or low earned income (unemployment), living in proximity to the bush (62%) and stagnant water (67.9%), inadequate toilet facilities and lack of knowledge about the infection were significantly correlated with the occurrence of infection in the study area. Unemployed individuals were prone to infection twice than wage earners (aOR 1.948, 95% CI 0.945–2.512). Also, 64% of the infected population were without toilet facilities and approximately three times more susceptible to infection than those with toilets (aOR 2.411 95%CI 0.997–3.602), those living in close proximity to stagnant water had infection three folds higher than their counterparts living in area free of stagnant water (aOR 2.718 95%CI 1.661–3.118). Furthermore, analysis of socioeconomic impact assessment of malaria infection among adults and children as investigated by questionnaire approach (Table 3) unveiled a feedforward loop response of how socioeconomic factors mediated malaria occurrence to further worsen the socioeconomic status of the infected population in this study. The effect of infection on economic activities and school attendance of adults and children was relatively high and severe, respectively. About 37.8% (95%CI 29.91–46.28) of the adults expressed that infection portends little effect on their savings due to their declined economic activities while 18.7% (95% CI 13.83–24.70) of children suffered the same impact on their academic performance. Indebtedness and sleepless nights were also reported to be severe among (25.2% and 14.7% respectively) of the adults, while 5.6% and 7.4% of children of the study participants feel ashamed and had sleepless nights, respectively, due to malaria infection. A similar impact of infection was found on the loss of clients, religious devotion and lifestyle of both young and adult participants. (Table 3).

Discussion

This study reiterates the health and socioeconomic implications of malaria infection in Nigeria (Oyibo et al. 2021) and in sub-Saharan Africa as previously documented by Carrasco-Escobar et al. 2021 in almost 13 countries of the region. The prevalence and average intensity of 56.6% and 3022.25 per µl of blood, respectively, in this report is a confirmation that malaria infection remained a major health problem in resources constraint settings. Therefore, more robust and mutually inclusive control strategies should be enhanced to curtail the probable infection recrudescence and relapse, particularly among children and pregnant women in high-transmission zone. This high prevalence may be associated with the pitiable economic downturn and inadequate provision

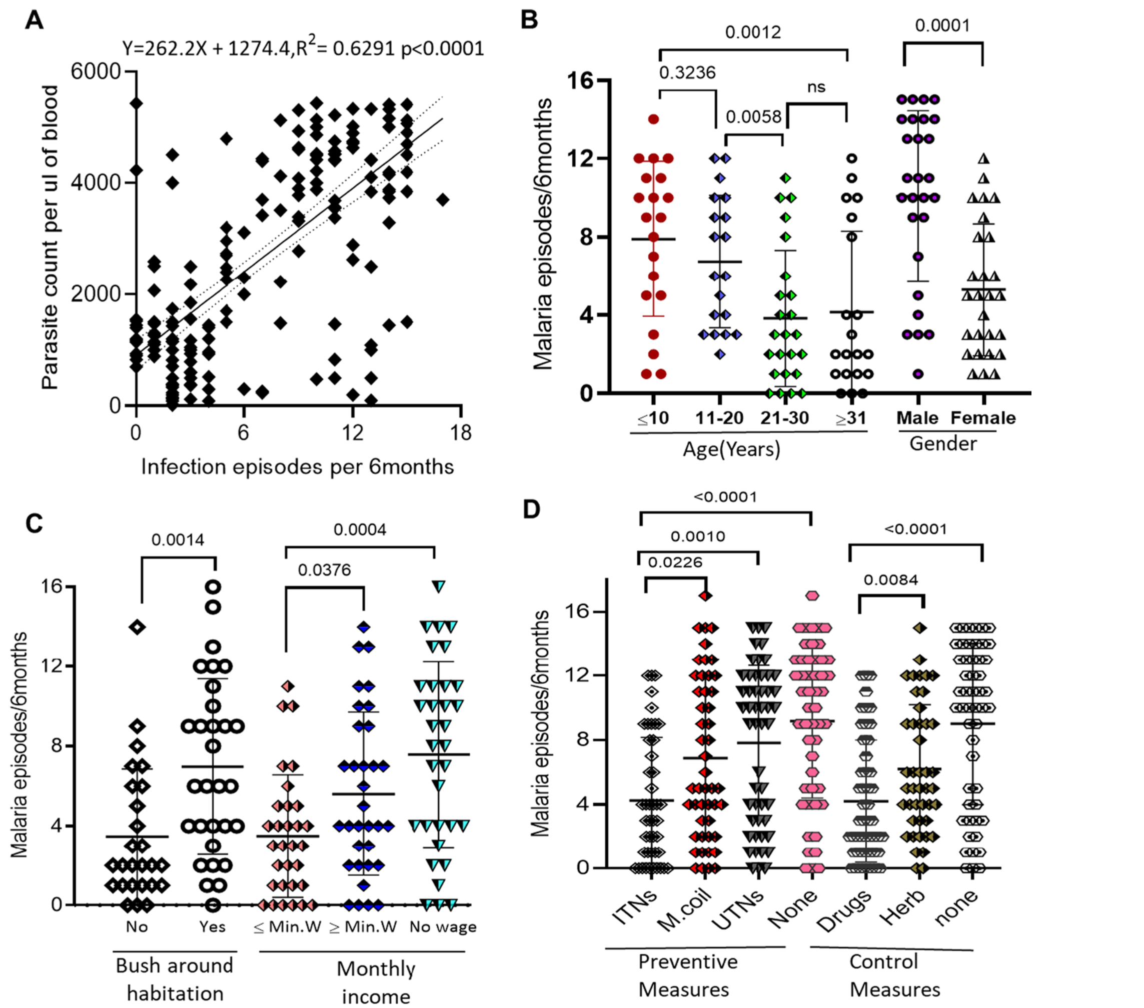


Fig. 3 Correlation of malaria episodes with respect to malaria intensity, age and socioeconomic status. *ITNs* insecticide-treated nets, *M. coil* mosquito coil, *UTNs* non-insecticide-treated nets

of basic socio-infrastructural amenities such as water, hospital, and good settlement layout for human habitation in the remote rural communities where malaria is majorly endemic. Many houses in our study location are surrounded by bushes and stagnant water, and their windows are devoid of mosquito nets. All these features are essential environmental risk factors for malaria infection as previously reported by our research group (Babamale et al. 2020) and others (Rodríguez-Rodríguez et al. 2021; Okwa 2019).

The infection pattern with respect to age and gender is similar to our previous report (Babamale et al. 2018) and several studies both in Nigeria (Dawaki et al. 2016; Awosolu et al. 2021) and other countries in sub-Sahara Africa (Yang et al. 2020; Obasohan et al. 2021). The occurrence of infection decreases with increasing age while intensity significantly rises to the climax at 11–20 age group then declines (Table 1). The age-related illnesses and susceptibility to infectious diseases including malaria are attributable to biological changes in the immune system (Bajaj et al. 2021). Maternally derived antibodies that protect neonates are fast depleting and the development of acquired antibodies and T-cell mediated immunity necessary to subvert parasite multiplication is gradual (Kurup et al. 2019; Barua et al. 2019). Therefore, increased host susceptibility to malaria infection and growing parasitaemia may be imperative during this progressive proliferation of immune cells. The rising of parasitaemia from 2619.33 (≤ 10 years) to 3001 (11–20 years) per μl of blood is hypothetically connected to the transitory phase of immunity and its gradual declination to 1108.20 per μl of blood at 31–40 year when strong immunity must have developed. All together suggest the likely interplay of host protective immunity in the parasite

Table 2 Prevalence of malaria infection and logistic regression analysis of socioeconomic and environmental factors of individuals

Variables	*N*	Infection rate	Adjusted odd ratio (95% CI)	*p* Value
Toilet facilities				
Water system	73	24 (32.8)	1.00	
Cesspit	85	35 (41.2)	1.809 (1.359–1.954)	0.057
No toilet	414	265(64.0)	2.411 (0.997–3.602)	0.031
p Value		0.002		
Bush around habitation				
No	128	48 (37.5)	1.00	
Yes	444	276 (62.2)	2.501 (2.033–3.714)	0.001
p Value		0.001		
Source of drinking water				
Portable water	233	145 (62.2)	1.1021 (1.009–1.610)	0.205
Others (river and well)	339	179 (52.8)	1.00	
p Value		0.103		
Distance of dumpsite to habitation				
≥ 50 m	267	117 (43.8)	1.00	
≤ 50 m	305	207 (67.9)	2.718 (1 .661–3.118)	0.034
p Value		0.021		
Monthly income				
≥ N18000	86	35 (40.7)	1.00	
≤ N18000	168	82 (48.8)	1.081 (1.001–1.104)	0.741
No income	318	207(65.1)	1.948 (0.945–2.512)	0.029
p Value		0.017		
Education status				
Illiterate	234	143(61.1)	1.920 (1.470–2.149)	0.092
Primary school	114	67 (58.8)	1.055 (1.181–2.107)	0.121
Postprimary school	224	114(50.8)	1.00	
p Value		0.113		
Knowledge about infection				
Yes	266	126(47.4)	1.00	
No	306	198 (64.7)	2.133 (1.610–2.611)	0.009
p Value		0.038		

proliferation. The significant gender-dependent parasite counts obtained in this survey may be ascribed to the innate capacity of females to clear their asymptomatic infections more rapidly than males, thus projecting gender-based differences as important in the host response to this globally important pathogen as previously mentioned (Briggs et al. 2020).

The predominant etiology of human malaria infection in Nigeria is *P. falciparum*. Although few cases of *P. vivax* and mixed infection were recorded, the majority of infected individuals in this study were diagnosed with *falciparum* malaria. This underscores the potential health implication of recrudescence, drug resistance, and severe morbidity among our study participants (Mahittikorn et al. 2021). Highrecurrence of malaria infection ranging between 2–16 episodes in 6 months is noteworthy, particularly among individuals with high parasitaemia. The significant linear correlation between parasitaemia and malaria episodes suggests that parasite count can be used to predict repeated episodes of malaria infection, severe infection, treatment failure, and vice versa. This finding revalidates the earliest report that patients with hyperparasitaemia have an increased risk of recrudescence (Luxemburger et al. 1995) as well as a recent case report of a 65-year-old man who returned to France from Chad with high *P. falciparum* counts (240,000 parasites/mL), leading to a diagnosis of severe malaria recrudescence (Landre et al. 2021). During the developmental cycle in the human host, *P.* vivax and *P. falciparum* undergo relapse and recrudescence, respectively, to circumvent host immunity pressure by forming hypnozoites in the liver or persistent reservoir parasites that periodically reactivate to elicit a new symptomatic blood-stage infection without new infection (Schafer

Table 3 Impact assessment of malaria infection on socioeconomic activities of children and Adult

Impact assessment of malaria infection Questions and options	Adult (≥ 19 years) (143) % (95% CI)	Children (≤ 18 years) (152) % (95% CI)
Inability to do daily economic activities/ school		
Quite a lot	18.9 (8.39–20.22)	29.8 (24.84–32.63)
Only a little	69.2 (60.88–76.53)	56.4 (30.07–58.32)
Not at all	11.9 (7.28–18.62)	13.0 (10.25–14.21)
Decline in personal saving/academic performance		
Quite a lot	18.9 (11.25–24.15)	7.0 (3.41–10.40)
Only a little	37.8 (29.91–46.28)	18.7 (13.83–24.70)
Not at all	43.4 (35.18–51.90)	74.3 (67.81–79.90)
Decline in religious commitment		
Quite a lot	8.4 (6.29–11.96)	5.6 (2.39–8.68)
Only a little	7.7 (4.09–13.67)	14.5 (10.20–20.09)
Not at all	83.9 (76.63–89.33)	79.9 (73.78–84.93)
Loss of job or client/ school admission or debate		
Quite a lot	10.5 (2.16–10.21)	7.0 (3.76–10.96)
Only a little	16.8 (11.25–24.15)	15.0 (10.60–20.61)
Not at all	72.7 (64.54–79.67)	78.0 (71.77–83.27)
Change of lifestyle/inability to engage in school sports		
Quite a lot	6.3 (1.72–9.31)	9.3 (4.47–12.08)
Only a little	19.6 (13.61–27.23)	7.5 (4.47–12.08)
Not at all	74.1 (66.01–80.92)	83.2 (77.33–87.80)
Sleepless nights		
Quite a lot	14.7 (8.39–20.22)	7.4 (1.14–6.29)
Only a little	10.5 (6.19–17.00)	10.3 (6.70–15.34)
Not at all	74.8 (66.75–81.53)	82.2 (76.31–86.98)
Indebted/ashamed due to malaria infection		
Quite a lot	25.2 (18.47–33.25)	5.6 (2.73–9.26)
Only a little	14.2 (9.52–21.80)	6.1 (3.41–10.40)
Not at all	60.1 (51.60–68.13)	88.3 (83.06–92.15)

et al. 2018). Stratification of malaria episodes with infection risk factors revealed that recurrence of malaria infection is higher among the youngest age than in adult individuals. Speculatively, these results may be attributed to age-dependent host immunity development in which according to Barua et al. (2019) the antibodies to merozoite and IE variant surface antigens were significantly higher in children who had episodes of malaria than in children who did not. This observation was substantiated by Wang et al. (2021), in their animal study that uncovered the contribution of enhanced cellular and humoral adaptive in the rapid clearance of malaria among adults, likely in a PD-1-dependent manner due to induction of CD4 + T cells exhaustion in *P. yoelii 17XNL* infected mice. Similarly, male individuals exhibit high malaria episodes than their female counterparts partly due to gender-bias immunity as reported by Briggs et al. (2020) and delayed health-seeking behavior of males. Although, the role and mechanism of sex hormones in disease susceptibility in malaria infection is largely elusive, previous animal studies have linked testosterone and estrogen to malaria susceptibility and resistance, respectively (Wunderlich et al. 1991; Cernetich et al. 2006). However, several other factors may warrant high malaria episodes in males including; activities such as alcohol, and tobacco consumption, and staying late outside for long-repeated mosquitos' exposure which may suppress host immunity and elicit reinfection (Pathak et al. 2012; Lefèvre et al. 2010). Summarily, this finding emphasizes that recurrent malaria infection due to relapse and recrudescence is a common phenomenon in our study area and it is speculatively ascribed to age- and sex-dependent host and behavioral factors. Recurrence of high parasitaemia associated with bush around habitation, low-income capacity, and lack of appropriate preventive and curative strategies further reecho the contribution of reinfection to the public health burden of malaria in high-transmission zone. Parasitic infection exhibits no relief effect, thus continuous exposure to new infection via the bites of an infected mosquito aggravates the pathological progression of the previous infection, resulting in the accumulation of danger associated pattern of malaria parasites called hemozoin, thus complicated malaria symptoms such as cerebral malaria, septic shock, and convulsions are ensued. Poor socioeconomic status and amenities of individual and community, respectively, may warrant unavoidability and inaccessibility of health care and insecticide-treated net or inability to complete malaria treatment. All these put together will ultimately increase the rate of recurrent malaria as evidenced in Fig. 3C, D in which reduced malaria episodes were observed among those people who keep their habitation away from the bush, treat their infection with specific antimalarial drugs, and those with above-average minimum wage.

Our findings further showed a positive feedback loop between malaria infection and the prevailing socioeconomic factors. Logistic analysis adjusted by odds ratio revealed that individuals without decent toilet facilities, a bush-free environment, good monthly income, and sufficient infection knowledge are prone to malaria infection twice or thrice in this study location. This underlines socioeconomic infrastructures as another strong risk factors for highrecurrent malaria infection which may further deteriorate the socioeconomic status of the adult and academic performance of the young infected individual. This is consistent with the report that odds of *Plasmodium* infection also increased with a decrease in income as well as drugs and ITNs availability as previously reported in Nigeria (Babamale et al. 2018, 2020) and other countries (Sharma et al. 2021; Tusting et al. 2015; de Castro and Fisher 2012). Impact assessment of recurrent malaria infection on young and adults is investigated to unveil a vicious cycle between malaria disease and wealth index of individual and public, i.e., malaria infection is a consequence of or a cause for low household socioeconomic status as well as school absenteeism in some school-aged children. In this study, a large proportion of our interviewees ascribed their inability to enroll in daily economic and academic activities to recurrent malaria infection and this correspondingly reduced the saving capacity of infected adults andthe academic and extracurricular performance of infected children in school. A significant proportion of adults had to change their lifestyle such as leaving work early to meet up with treatment schedules in the hospital. Also, the prevailing low financial status forced some to borrow for their medical care, and become indebted. This summarily showed enormous impact of recurrent malaria infection on both young and adults, which may integrate to affect the national economic growth and development. The reduced academic performance majorly found among the school children is attributable to the pathological finding that recurrence of malaria induces short-term and long-term neurological impairment in infected individuals (Meremikwu et al. 1997; Boivin 2002; Carter et al. 2005). A corroborative study conducted among 457 Thai children also indicated recurrent malaria attacks affect students' performance in mathematics and the Thai language (Vorasan et al. 2015). Consequently, recurrent malaria infection portends severe public health problems such as pathological progression and resistant malaria parasites, previous reports showed that drug resistance variant of *Plasmodium* species persisted after artesunate monotherapy-treated malaria episodes (Landre et al. 2021) which may evade innate immune responses with probable induction of T cell anergy accompanied by apoptosis, and ultimately allowing pathogen persistence (Rodrigues et al. 2014).

Conclusions

The finding of this study confirmed the recurrence of high parasitaemia as a common phenomenon in high-malaria-transmission areas, particularly among children and resource-poor individuals. The deplorable socioeconomic condition was observed as a critical cause and consequence of recurrent malaria infection, and an essential prognostic biomarker of hyperparasitaemia. Social life and academic performance of adults and young, respectively, are affected by malaria morbidity and repeated attacks. Therefore, assessment of antimalarial drugs should include their ability to cure beyond a single infection safely, and their overall efficacy for the long-term cumulative incidence of disease without jettisoned safety. Importantly, intensive malaria treatment and vaccine administration should be highly subsidized at all levels or completely free, especially for people living in resource-poor communities and malaria-endemic settings.

Abbreviations

ARDS: Acute respiratory distress syndrome; ACT: Artemisinin combined therapy; ITNs: Insecticide-treated bed nets; WHO: World Health Organization; WBC: White blood cells; CDC: Centers for Disease Control.

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Author contributions

BOA conceptualized, designed, and involved in data analysis. He also supervised the work and drafted the manuscript, AOA was involved in the organization of data. OJY, KF, BOO, and OFA were involved in the collection of samples, administration of the questionnaire, and analysis of data, USU supervised the work and read the final manuscript, and BOA and MMU revised the manuscript. All the authors read and approved the final manuscript.

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Not applicable.

Declarations

Ethics approval and consent to participate
The study protocol was reviewed and approved by the University of Ilorin Ethical Review Committee (KWMH/2016/613). Written informed consent was obtained from all volunteers and mothers/caretakers of children who participated in the study.

Consent for publication
All volunteers and mothers/caretakers of children who participated in the study gave consent for the publication of the findings without their details and photograph (s) and video and others that can involve their identities.

Competing interests
The authors declare that they have no competing interests.

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