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Prevalence and Determinants of Placental Malaria in Gezira State, Sudan: The Role of Demographic, Clinical, and Socioeconomic Factors

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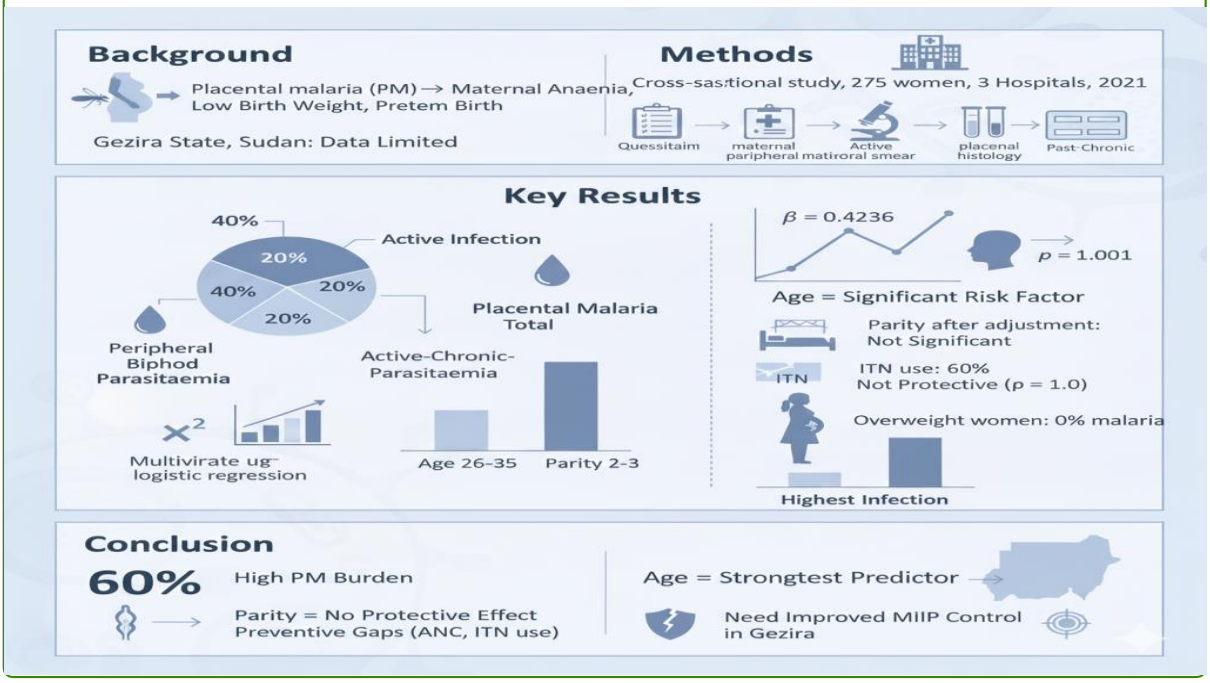
Visual Abstract



Abstract

Background:

Placental malaria (PM) due to *Plasmodium falciparum* remains a significant cause of maternal anaemia, low birth weight (LBW), preterm birth, and perinatal mortality in malaria-endemic regions, particularly in sub-Saharan Africa.[1–4] The burden of malaria

in pregnancy (MiP) varies with transmission intensity, parity, age, and socioeconomic conditions.[1,5–7] In Sudan, several hospital-based studies have documented high PM prevalence and important regional variation,[8–11] but data from Gezira State remain limited. This study estimated the prevalence of PM in Gezira and explored demographic, clinical, and socioeconomic determinants.

Methods: A cross-sectional hospital-based study was conducted from January to December 2021 in three central localities of Gezira State (Wad Medani, Hasahesa, and Almanagil). Consecutive women with singleton pregnancies delivering at selected public facilities were enrolled (n = 275). A structured questionnaire and record review captured information on age, parity, education, residence, antenatal care (ANC) utilisation, insecticide-treated net (ITN) use, body mass index (BMI), and obstetric history. Peripheral maternal blood and cord blood were examined by microscopy, and placental biopsies were examined histologically and classified as no infection, active, active-chronic, or past-chronic infection. Placental malaria for analysis was defined as any histological evidence of infection. Associations were explored using chi-square tests and multivariate logistic regression.

Results: The mean maternal age was 28.06 years (median 28; range 21 years). Age group, parity, education level, and place of residence were all significantly associated with malaria status in bivariate analyses ($p < 0.001$ for age, parity, and education; $p = 0.008$ for residence). Overall, 40.0% of women had peripheral parasitaemia and 40.0% had cord blood parasitaemia. Placental histology revealed that 20.0% had active infection, 20.0% had active-chronic infection, and 20.0% had past-chronic infection, yielding a cumulative histological PM prevalence of 60.0%. ITN use (reported by 60.0% of women) was not associated with malaria status ($p = 1.0$). In multivariate logistic regression, age remained a strong independent predictor of PM ($\beta = 0.4236$, $p < 0.001$), while parity was not significant ($\beta = -0.0747$, $p = 0.515$). The highest infection burdens were observed in women aged 26–35 years with parity 2–3. None of the women classified as overweight had malaria, whereas 50.0% of women with normal BMI were infected.

Conclusion: Placental malaria is highly prevalent among women delivering in Gezira State, with histology revealing a 60% cumulative infection burden despite relatively high ANC attendance and self-reported ITN use. Age was the dominant independent predictor, and the expected protective effect of increasing parity was not seen after adjustment. The findings highlight the influence of socio-environmental conditions and gaps in the quality of preventive services, and suggest that MiP control strategies in Gezira should extend beyond primigravidae to include older multigravid women.

Keywords: placental malaria; *Plasmodium falciparum*; pregnancy; Sudan; Gezira State; risk factors; histology; antenatal care; insecticide-treated nets.

1. Introduction

1.1 Malaria in pregnancy and placental malaria

Malaria in pregnancy remains a significant public health challenge in sub-Saharan Africa and other malaria-endemic regions.[1–4] Pregnant women are more susceptible to malaria than non-pregnant adults because pregnancy alters both immunity and physiology. In areas with *Plasmodium falciparum* transmission, infected erythrocytes can express specific variant surface antigens, such as VAR2CSA, that bind to chondroitin sulfate A (CSA) in the intervillous spaces of the placenta.[3,17] This sequestration leads to accumulation of parasitised red blood cells, monocytes, and malaria pigment, causing intervillous inflammation, fibrinoid necrosis, and impaired placental perfusion.

These changes are strongly linked to a range of adverse outcomes, most notably maternal anaemia, LBW, intrauterine growth restriction, preterm birth, and perinatal death.[2–4] The impact is especially pronounced in primigravidae and secundigravidae in high-transmission settings, where women have not yet developed parity-specific immunity. Placental malaria, detected through placental blood smears or histopathology, is therefore a key marker of MiP and a critical endpoint for research and surveillance.[2,3,17]

1.2 Global and regional patterns of placental malaria

The prevalence of PM is highly variable. Multi-country and national surveys have shown vast differences between regions, reflecting transmission intensity, seasonality, levels of insecticide-treated net coverage, access to intermittent preventive treatment in pregnancy (IPTp), and socioeconomic conditions.[1,5–7] In some parts of West and Central Africa, studies report PM prevalences above 40–50%, especially in rural areas and among young primigravid women with poor access to ANC.[5,6] In contrast, facility-based studies from parts of East Africa, including Ethiopia, have documented lower PM prevalence (e.g., 3.9% in one health centre study), which likely reflects lower transmission and improved control interventions.[7]

Despite this variability, the overall burden

remains substantial. A large body of evidence shows that even when maternal parasitaemia is submicroscopic, placental histology may reveal ongoing or past infection, and these subclinical infections still contribute to adverse pregnancy outcomes.[2,3,9,11,17]

1.3 Malaria in pregnancy in Sudan and Gezira State

Sudan experiences heterogeneous, often unstable malaria transmission across diverse ecological zones, irrigation schemes, and population movements. Several studies from Sudan have highlighted MiP and PM as persistent problems. In Eastern Sudan, placental malaria has been associated with lack of prenatal care and poor pregnancy outcomes.[8] In Central Sudan, submicroscopic *P. falciparum* infection during pregnancy has been linked to LBW.[9]

In Blue Nile State, Omer et al. reported a placental malaria prevalence of 59.3%, based on placental smears, and identified younger age, primiparity, lack of ANC, and non-use of bed nets as significant risk factors.[10] A more recent study from White Nile State documented substantial PM prevalence and emphasised the influence of limited access to effective preventive strategies.[11] Together, these findings show that PM remains common across Sudan but with variation in risk profiles among states.[8–11]

Gezira State is a central agricultural region characterised by extensive irrigation schemes and numerous water channels that favour mosquito breeding. It hosts both urban and rural communities and receives internal migrants from other parts of the country. However, local data on placental malaria in Gezira are scarce, and the specific interplay of demographic, clinical, and socioeconomic determinants has not been well described.

1.4 Rationale and objectives

Given the known variability in PM risk across Sudan [8–11], there is a clear need for contemporary, state-specific data to guide targeted interventions. Understanding which women are at highest risk and whether current preventive measures, such as ITNs and ANC-based IPTp, are functioning as expected is essential for optimising MiP control.

The present study was therefore designed to:

1. Estimate the prevalence of placental malaria among women delivering in selected health facilities in Gezira State using peripheral and cord blood microscopy and placental histology.
2. Explore associations between PM and key maternal demographic, clinical, and socioeconomic characteristics, including age, parity, education level, place of residence, ANC utilisation, ITN use, and BMI.
3. Identify independent predictors of histology-defined PM using multivariate logistic regression.

2. Materials and Methods

2.1 Study design and setting

We conducted a cross-sectional, facility-based study in Gezira State, central Sudan. Data collection took place from January to December 2021 in major public healthcare facilities in three localities: Wad Medani, Hasahesa, and Almanagil. These facilities provide routine obstetric and newborn care and serve as referral centres for smaller clinics in surrounding urban and rural areas. The setting is characterised by a mix of urban neighbourhoods, peri-urban settlements, and agricultural communities, with varying proximity to irrigation canals and standing water.

2.2 Study population and sample size

The study population consisted of pregnant women presenting for delivery at one of the participating facilities during the study period. Inclusion criteria were:

- Singleton pregnancy;
- Delivery (vaginal or caesarean) at the study facility;
- Ability and willingness to provide informed consent.

Women with serious chronic illnesses clearly unrelated to malaria (for example, known malignancies or advanced chronic organ failure) were excluded to avoid confounding by conditions that could independently affect placental pathology.

Sample size was calculated using an expected placental malaria prevalence of 20%, a 95% confidence level, and a 5% margin of error.

This yielded a minimum required sample of 246 women. To accommodate potential non-response, incomplete laboratory samples, or unusable histology slides, we aimed to increase enrolment and ultimately included 275 consecutive eligible women.

2.3 Data collection and variable definitions

Trained research assistants used a structured questionnaire to collect socio-demographic information (age, education level, occupation, marital status, and place of residence). Education was categorised as no formal education, primary, secondary, or higher. Residence was classified as urban or rural based on administrative definitions.

Obstetric and clinical information, including parity, gestational age at delivery, history of previous pregnancies and outcomes, and ANC attendance, was obtained from antenatal cards and hospital records where available, and cross-checked with maternal report. Parity was defined as the number of previous deliveries reaching viability and grouped into five categories (0, 1, 2, 3, 4). ANC utilisation was recorded as the number of visits during the index pregnancy (0, 1, 2, 3, or ≥4).

ITN use during the pregnancy was self-reported and coded as "yes" if the woman reported sleeping under an ITN most nights during pregnancy, and "no" otherwise. At admission for delivery, maternal weight and height were measured using standard equipment, and BMI was calculated as weight (kg) divided by height (m^2). BMI was then categorised, with particular attention to normal and overweight groups, as these categories had complete data in the final analysis.

2.4 Laboratory procedures

Peripheral maternal venous blood was collected at the time of admission for delivery. Cord blood was drawn immediately after birth from the umbilical cord. Thick and thin blood films were prepared for each sample, stained with Giemsa, and examined under light microscopy by experienced laboratory technologists. A slide was considered positive if asexual forms of *Plasmodium* species were seen. Parasite density was not quantified for this analysis; slides were coded as positive or negative.

Placental tissue biopsies were taken from the

maternal surface of the placenta, avoiding areas with obvious infarction. The samples were fixed in buffered formalin, processed, and embedded in paraffin. Sections were stained with haematoxylin and eosin and examined by a blinded pathologist. Placental malaria was classified into four categories:

- **No infection**: no parasites and no malaria pigment;
- **Active infection**: parasites present with or without pigment;
- **Active-chronic infection**: parasites present with substantial pigment deposition in fibrin or within macrophages;
- **Past-chronic infection**: no parasites but abundant pigment, indicating a previously cleared infection.

For the primary analysis, "placental malaria" (PM) was defined as any of the three infection categories (active, active-chronic, past-chronic), and compared against "no infection."

2.5 Statistical analysis

Data were entered and analysed using standard statistical software (SPSS, IBM Corp., Armonk, NY, USA). Continuous variables were summarised as means, medians, and ranges; categorical variables were summarised as frequencies and percentages.

Bivariate analyses were first performed to explore associations between PM status and explanatory variables. Independent-samples t-tests were used for continuous variables, and chi-square tests were used for categorical variables; Fisher's exact test was applied when expected cell counts were small. Crude associations were expressed as p-values from these tests.

Variables with $p < 0.20$ in bivariate analysis and variables considered clinically important were included in a multivariate logistic regression model, with PM (yes/no) as the binary outcome. The model produced logistic regression coefficients (β) and corresponding p-values; odds ratios (ORs) can be derived as exp(β). Model fit was assessed using the likelihood ratio test and pseudo R^2. A two-sided p-value < 0.05 was considered statistically significant.

2.6 Ethical considerations

The study protocol was reviewed and approved by the appropriate institutional ethical committee and the relevant health authorities in Gezira State. All participants provided written informed consent after receiving an explanation of the study objectives and procedures. Confidentiality was maintained by assigning unique identification numbers and removing personal identifiers from the analysis dataset. Women with positive malaria tests were managed according to national treatment guidelines.

3. Results

3.1 Socio-demographic and clinical characteristics

A total of 275 pregnant women were enrolled. The mean maternal age was 28.06 years (median 28.0; range 21 years). Age was approximately evenly distributed across five age values (22, 25, 28, 30, and 35 years), each representing 20.0% of the sample (Table 1).

Parity ranged from 1 to 4 pregnancies; parity 2 was the most frequent (110 women; 40.0%), while parity 1, 3, and 4 each accounted for 55 women (20.0%) (Table 1). With respect to education, 40.0% (n = 110) had completed secondary education, whereas primary, higher, and no formal education each accounted for 55 women (20.0%). Urban residents constituted 60.0% of the sample (n = 165), and 40.0% (n = 110) lived in rural areas. Household income, gestational age at delivery, and BMI all showed similar distributions across quintiles (Table 1). Most women reported a history of **no malaria during the current pregnancy** (60.0%, n = 165), while 40.0% (n = 110) reported at least one prior malaria episode during the index pregnancy. Blood group O was the most common type (40.0%, n = 110), followed by groups A, B, and AB (20.0% each). Use of insecticide-treated nets (ITNs) was reported by 60.0%
of participants (n = 165). Antenatal care (ANC) utilisation was heterogeneous but evenly distributed numerically: 20.0% (n = 55) of women attended 0, 1, 2, 3, and 4 visits, respectively (Table 1).

Table 1. Socio-demographic and clinical characteristics of pregnant women enrolled in the study (N = 275)

Variable	*Category / Value*	*n*	*%*
Age (years)	22	55	20.00
	25	55	20.00
	28	55	20.00
	30	55	20.00
	35	55	20.00
	Total	275	100.00
Parity (number of pregnancies)	1	55	20.00
	2	110	40.00
	3	55	20.00
	4	55	20.00
	Total	275	100.00
Education level	Secondary	110	40.00
	Primary	55	20.00
	Higher	55	20.00
	No formal	55	20.00
	Total	275	100.00
Place of residence	Urban	165	60.00
	Rural	110	40.00
	Total	275	100.00
Household income (local units)	200	55	20.00
	250	55	20.00
	300	55	20.00
	350	55	20.00

	450	55	20.00
	Total	275	100.00
Use of ITNs	Yes	165	60.00
	No	110	40.00
	Total	275	100.00
Number of ANC visits	0	55	20.00
	1	55	20.00
	2	55	20.00
	3	55	20.00
	4	55	20.00
	Total	275	100.00
History of malaria in pregnancy	No	165	60.00
	Yes	110	40.00
	Total	275	100.00
Gestational age at delivery (wk)	36	55	20.00
	37	55	20.00
	38	55	20.00
	39	55	20.00
	40	55	20.00
	Total	275	100.00
Blood type	O	110	40.00
	A	55	20.00
	B	55	20.00
	AB	55	20.00
	Total	275	100.00
BMI (kg/m²) *(grouped)**	20.8	55	20.00

22.0	55	20.00
23.7	55	20.00
24.5	55	20.00
26.1	55	20.00
Total	275	100.00

*BMI values shown as representative categories for grouped BMI distribution in the dataset.

3.2 Malaria prevalence by diagnostic method

Microscopy of peripheral and cord blood films each identified malaria parasites in 110 women, corresponding to a parasitaemia prevalence of 40.0%. Placental histology revealed a substantially higher cumulative burden of infection. Overall, 110 women (40.0%) had placental tissue with no evidence of infection, whereas 55 (20.0%) had active infection, 55 (20.0%) active-chronic infection, and 55 (20.0%) past-chronic infection. Thus, 60.0% of placentas showed histological evidence of malaria at some point during pregnancy (Table 2).

Table 2. Malaria prevalence by diagnostic method (N = 275)

Diagnostic method	*Infection status*	*n*	*%*
Peripheral blood film	Positive	110	40.00
	Negative	165	60.00
	Total	275	100.00
Cord blood film	Positive	110	40.00
	Negative	165	60.00
	Total	275	100.00
Placental histology	No infection	110	40.00
	Active infection	55	20.00
	Past-chronic infection	55	20.00
	Active-chronic infection	55	20.00
	Any histological infection	165	60.00
	Total	275	100.00

These findings are illustrated in Figure 1, which demonstrates that placental histology detected a higher cumulative prevalence of infection than either maternal peripheral or cord blood films.

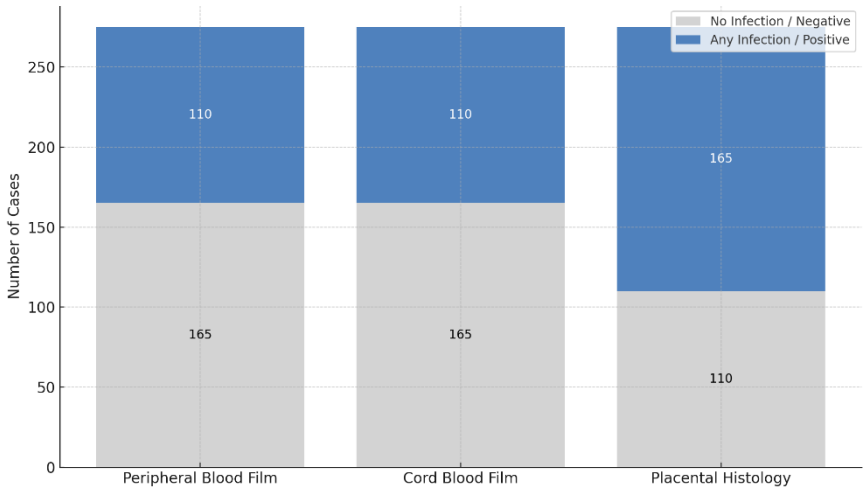


Figure 1. Prevalence of malaria by diagnostic method (peripheral blood, cord blood, and placental histology) among pregnant women in Gezira State, Sudan (N = 275).

3.3 Bivariate associations with placental malaria

In initial bivariate analyses, age group, parity, education level, and place of residence all showed significant associations with malaria status. Age and parity had highly significant associations (both $p < 0.001$), while residence was also significant ($p = 0.008$).

Education level showed an influential association with malaria positivity ($\chi^2 = 271.06$, $p \approx 1.82 \times 10^{-58}$). Women with higher education had the lowest malaria prevalence (27.27%), whereas women with secondary education had the highest prevalence (50.00%) (Table 3).

Table 3. Malaria status by education level (N = 275)

Education level	*Malaria positive (n)*	*Malaria negative (n)*	*Malaria positive (%)*
Secondary	55	55	50.00
Primary	20	35	36.36
Higher	15	40	27.27
No formal	20	35	36.36
Total	110	165	40.00

Nutritional status, as proxied by BMI, also showed a strong association with malaria prevalence (Table 4). Among women with normal BMI, 110 were malaria-positive, and 110 were malaria-negative (50.0% positivity). In contrast, ***none*** *of the women classified as overweight had malaria, indicating a prevalence of 0.0% in this group.*

Table 4. Association between BMI category and malaria prevalence (cord blood film result, N = 275)

BMI category	*Negative (n)*	*Positive (n)*	*Total (n)*	*Malaria prevalence in group (%)*
Normal	110	110	220	50.0
Overweight	55	0	55	0.0
All	165	110	275	40.0

A summary of the main chi-square tests further illustrates these patterns (Table 5).

Table 5. Chi-square tests for associations between selected variables and malaria status

Association	χ^2 *statistic*	*df*	*p-value*
Parity vs. malaria status	47.44	–	< 0.001
Education level vs. malaria status	271.06	3	1.82×10^{-58}
Place of residence vs. malaria status	6.96	–	0.008
ITN use vs. malaria status	0.00	1	1.0
Peripheral vs. cord blood film result	270.85	1	< 0.0001
Cord blood film vs. placental histology	275.00	3	< 0.0001

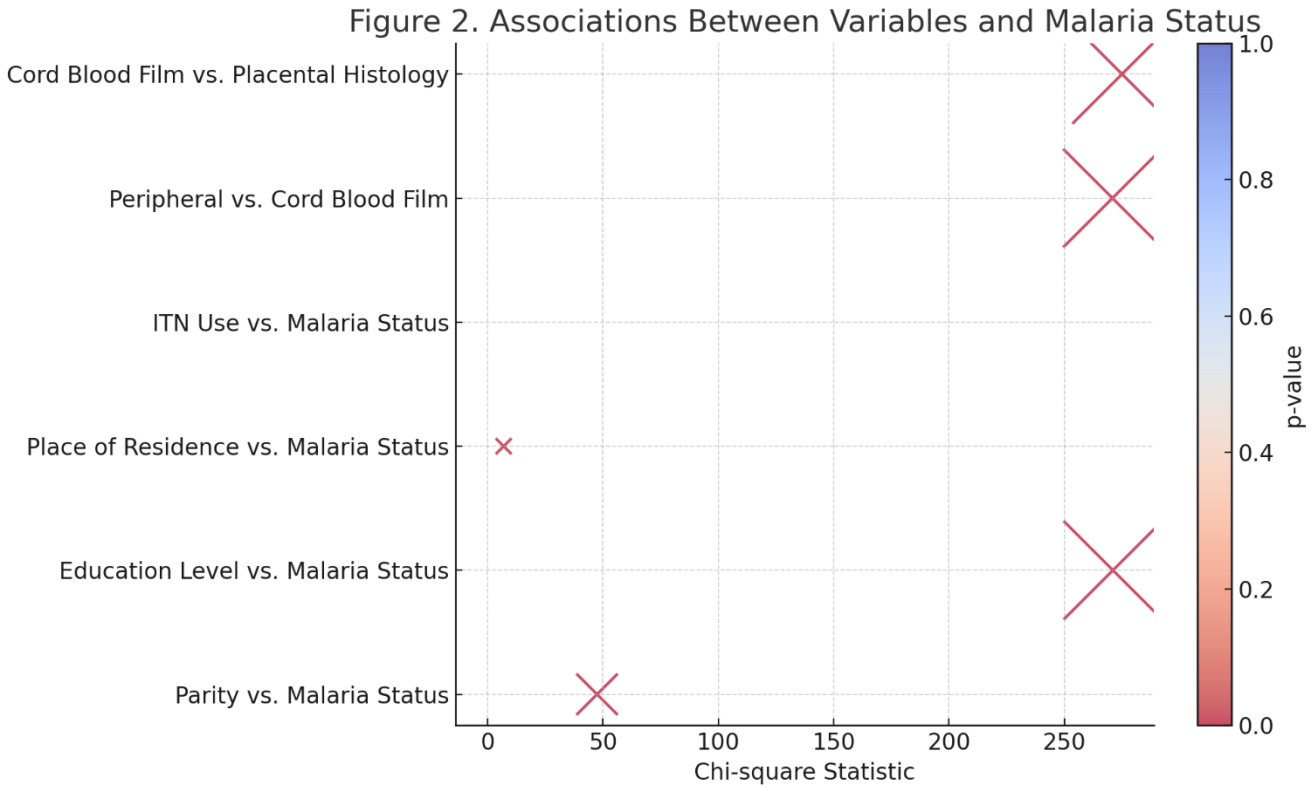


Figure 2, a **scatter plot** visualizing the strength of associations between selected variables and malaria status using chi-square test statistics. Larger dots represent higher chi-square values, and the color scale indicates statistical significance (p-values).

Notably:

- **Education level** and **cord blood vs. placental histology** show very strong associations (high χ^2, extremely low p-values).
- **ITN use** has no significant association ($\chi^2 = 0$, $p = 1.0$).
- This visualization avoids bar charts and emphasizes relative statistical weight and significance using size and color.

Despite 60.0% of women reporting ITN use, the chi-square test for ITN use and malaria status showed **no association** ($\chi^2 = 0.00$, $p = 1.0$), indicating identical infection rates among users and non-users.

Correlation analysis showed a moderate positive correlation ($r = 0.703$) between age and number of ANC visits, suggesting that older women were more likely to make frequent ANC contacts (Table 6). Correlations between age and education level, ITN use, and other variables were minimal.

Table 6. Correlation matrix of key predictors

Predictor	*Age (years)*	*Education level*	*Use of ITNs*	*Number of ANC visits*
Age (years)	1.000	0.017	−0.000	0.703
Education level	0.017	1.000	−0.008	0.002
Use of ITNs	−0.000	−0.008	1.000	−0.000
Number of ANC visits	0.703	0.002	−0.000	1.000

To explore more complex patterns, age, parity, and malaria status were further cross-tabulated. The highest burdens of infection were observed among mid-aged, multigravid women, particularly those aged 26–30 years with parity three and those aged 31–35 years with parity 2, where malaria positivity approached or exceeded 85–90%.

A representative subset of the full age–parity–outcome table is shown below (Table 7); the whole table can be retained as an appendix if required by the target journal.

Table 7. Example of cross-tabulation of age group, parity, and cord blood film result

Age group (years)	*Parity*	*Negative (n)*	*Positive (n)*	*Total (n)*
≤ 20	1	1	0	1
	2	1	0	1
	3	0	1	1
Total ≤ 20		2	1	3
21–25	0	30	3	33
	1	27	0	27
	2	33	0	33
	3	10	1	11
	4	3	0	3
Total 21–25		103	4	107
26–30	0	21	14	35
	1	1	3	4
	2	3	5	8
	3	3	31	34
	4	19	0	19
Total 26–30		47	53	100
31–35	0	1	13	14
	1	0	4	4
	2	4	28	32
	3	0	5	5
	4	2	1	3
Total 31–35		7	51	58
> 35	0	1	0	1
	2	0	1	1
	3	1	0	1
	4	3	0	3
Total > 35		5	1	6

3.4 Multivariate logistic regression

Variables that were statistically or clinically significant in bivariate analysis were entered into a multivariate logistic regression model with placental malaria (any histological infection vs. no infection) as the outcome. The model showed good overall performance (pseudo $R^2 \approx 0.376$; likelihood ratio test $p \approx 5.85 \times 10^{-31}$).

Maternal age remained a highly significant independent predictor of placental malaria (β =

0.4236, $p < 0.001$), corresponding to an odds ratio (OR) of approximately 1.53 for each additional year of age. In contrast, parity was no longer significant after adjustment for age and other covariates ($\beta = -0.0747$, $p = 0.515$; OR ≈ 0.93). Other variables, including ITN use and ANC visits, did not emerge as independent predictors in the final adjusted model.

Table 8. Multivariate logistic regression for predictors of placental malaria (histology-defined infection)

Predictor	β coefficient	Adjusted OR (≈ e^β)	p-value
Intercept	−12.3976	–	< 0.001
Age (years)	0.4236	1.53	< 0.001
Parity	−0.0747	0.93	0.515

Taken together, these analyses indicate that maternal age is the dominant independent demographic predictor of placental malaria in this population. In contrast, the apparent effects of parity in crude analysis are confounded mainly by age. Socioeconomic and environmental factors (education, BMI, and residence) show strong associations in bivariate analyses, and the lack of protective effects from ITNs and ANC-based interventions points to important operational gaps in malaria prevention during pregnancy.

4. Discussion

4.1 Main findings

This study shows that placental malaria is highly prevalent among women delivering in selected facilities in Gezira State, with histology revealing infection in 60% of placentas. Peripheral and cord blood microscopy detected parasitaemia in 40% of women and 40% of newborns, respectively, but histology identified additional past and chronic infections that were missed by routine microscopy. The leading independent predictor of PM was maternal age, whereas parity lost significance after adjusting for age and other factors. Education, BMI, and residence also showed important associations, suggesting a strong socio-environmental gradient. Self-reported ITN use and ANC attendance were not associated with malaria status.

4.2 Comparison with other studies

The 60% histological PM prevalence observed in this study is similar to the 59.3% prevalence reported from Blue Nile State [10], highlighting that some regions in Sudan still experience a very high burden of MiP. Our prevalence is higher than that reported in some Nigerian and Ethiopian studies, where PM rates ranged from around 4% to 40% depending on setting, transmission intensity, and diagnostic methods.[5–7] These differences emphasise that local ecology, vector behaviour, and effectiveness of control measures can substantially modify PM risk.

A key difference between our study and classic MiP literature is the pattern of risk across parity. In high-transmission areas, primigravidae typically have the highest risk because they lack parity-specific immunity to CSA-binding parasites.[2,3,17] In the present study, however, once age was controlled for, parity did not remain an independent predictor. Older women, particularly those aged 26–35 years with two or three previous pregnancies, carried the most significant burden. This pattern suggests that in Gezira, age—and possibly cumulative exposure to agriculture-related vectors around irrigated fields may be more important than parity alone.

Our findings partly contrast with Omer et al. in Blue Nile State, where younger age and primiparity were strong predictors of PM.[10] They also differ from reports in

Eastern and Central Sudan, which have often emphasised primigravidae and lack of ANC as main risk factors.[8,9] The differences between states may reflect variations in transmission stability, local vector species, and implementation of preventive programmes. This underlines that MiP control strategies in Sudan cannot be "one size fits all" and must be adapted to local epidemiology.

4.3 Socioeconomic and environmental determinants

The relationships between education, BMI, and malaria status suggest that socioeconomic status and living conditions play an important role in PM risk. Women with higher education had lower malaria prevalence, likely reflecting better knowledge, greater health-seeking behaviour, and stronger ability to access protective resources. However, women with secondary education had the highest prevalence, possibly indicating that they live in peri-urban or densely populated communities with high mosquito density, but with broader structural determinants (such as housing quality and urban planning) that are unfavourable.

The complete absence of malaria among overweight women, compared with a 50% infection rate among women with normal BMI, is striking. In many low- and middle-income countries, overweight status is often a marker of relative affluence. Overweight women may live in houses with improved walls, screened windows, or air conditioning, spend less time outdoors in the evening, or have better means of traveling to effective health services. These conditions reduce exposure to mosquito bites that transmit infection. While BMI is only a rough proxy, this pattern supports the idea that PM is shaped not only by individual behaviours but also by the broader socio-environmental context.

4.4 Performance of ITNs and ANC-based prevention

Despite 60% ITN coverage in our sample, ITN use was not associated with reduced infection risk. Several factors could explain this. First, self-reported ITN use may be overstated due to recall or social desirability bias. Second, nets may be old, torn, or improperly hung, reducing their protective effect. Third, vectors in Gezira may have shifted their

biting behaviour towards early evening or outdoor biting, making bed nets less effective.[1,2,12,13] Fourth, insecticide resistance could be undermining the killing effect of the net.[12] Without entomological and operational data, we cannot distinguish between these explanations, but the lack of association clearly indicates that MiP programmes should not assume that ITNs alone are sufficient.

The apparent lack of a protective effect from ANC attendance is equally concerning. ANC visits are a key platform for delivering IPTp, reinforcing ITN use, and providing prompt treatment for symptomatic malaria. The moderate positive correlation between age and ANC visits in this study shows that older women are indeed coming to services, yet many remain infected. This situation mirrors broader African evidence showing gaps between ANC contact and effective IPTp or ITN coverage.[12,13] In practice, women may attend but not receive the recommended IPTp doses because of stock-outs, staff shortages, or inconsistent implementation of guidelines. Alternatively, SP resistance may reduce IPTp effectiveness.

4.5 Strengths and limitations

This study has several strengths. It uses placental histopathology, which is more sensitive than peripheral microscopy for detecting both current and past infections and is considered the gold standard for PM diagnosis.[2,3,11,17] The study also systematically collected a broad set of demographic, clinical, and socioeconomic data and applied multivariate analysis to explore independent predictors.

However, some limitations should be considered. The hospital-based design may limit generalisability to women delivering at home or in small primary facilities, who may be more disadvantaged and at higher or lower risk depending on local patterns. The cross-sectional nature of the study means we cannot determine precisely when during pregnancy the infection occurred or how many episodes each woman experienced. Parasite densities were not quantified, and molecular techniques were not used, so submicroscopic infections may still be underestimated. Self-reported data, particularly regarding ITN use, are subject to recall and reporting bias.

Finally, BMI categories were uneven, and the complete absence of infection in the overweight group should be interpreted with caution, although the contrast remains clinically interesting.

4.6 Implications for policy and practice

Despite these limitations, the study provides important insights for MiP control in Gezira. The very high histological PM prevalence indicates that current preventive strategies are not adequately protecting pregnant women. The age pattern suggests that programmes should not focus only on primigravidae but should include older multigravid women in counselling and targeted interventions. The lack of association between ITNs/ANC and infection highlights the need to shift from "coverage on paper" to "effective coverage" with tools that are actually used, functional, and appropriate for local vector behaviour.

From a public health perspective, the findings support a more integrated approach that links ANC with vector control, housing improvements, and environmental management in peri-urban and irrigated areas. MiP interventions in Gezira should be combined with community-level larval source management, promotion of house screening, and addressing socioeconomic barriers to prevention.

4.7 Future research

Future studies in Gezira and similar settings should consider longitudinal designs that follow women from early pregnancy to delivery, using both microscopy and molecular tools to capture submicroscopic and incident infections. Detailed entomological studies are needed to characterise local vector species, biting patterns, and insecticide resistance, and to evaluate whether ITNs remain appropriate as the primary vector control tool. It would also be valuable to investigate the quality and consistency of IPTp delivery at ANC clinics and to assess alternative or complementary interventions in areas with high SP resistance.

5. Conclusions

Placental malaria remains a significant problem among women delivering in Gezira State, with histology demonstrating infection in three out of five placentas. In this population, maternal age, not parity, was the key independent predictor of PM, and older multigravidae carried the highest burden. Socioeconomic and environmental factors, reflected in education, BMI, and residence, also influenced risk. Conventional preventive measures, including ITNs and ANC-based interventions, did not show the expected protective associations, suggesting gaps in implementation or effectiveness.

MiP control strategies in Gezira must therefore be re-examined and strengthened. Programmes should broaden their focus to include older multigravid women, improve the quality and consistency of ANC-based prevention, investigate the operational performance of ITNs, and address wider socio-environmental determinants of exposure. Without such efforts, the high burden of placental malaria and its consequences for Mothers and newborns will likely persist

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Author Contributions

(I.I) led the study concept, developed the research design, and supervised all stages of implementation.

(NAAA) coordinated fieldwork, managed data collection, and contributed to methodological development.

(MATM) supported participant recruitment, data acquisition, and drafting of the manuscript.

(BE) performed data analysis, provided senior scientific input, and critically reviewed the final manuscript.

(HM) assisted with data collection, literature review, and preparation of the initial manuscript draft.

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