Bridging the Knowledge Gap: Associations between malaria infections, personally used prevention measures, and risk factors in Al Gezira State, Sudan

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Abstract

Background: The burden of malaria continues to disproportionately affect Low- and middle-income countries (LMICs), including Sudan, due to various risk factors that influence malaria transmission. This study aimed at investigating the risk factors associated with malaria in three hyper-endemic areas in Al Gezira state, central Sudan. Where malaria transmission extend from January to September and get interrupted by the heavy rains during October-December.

Methods: a descriptive cross-sectional study was implemented between January and September 2022. Febrile patients attending to the healthcare facilities seeking medical care in randomly selected healthcare facilities in the three localities were recruited. In addition to the results of malaria diagnosis, we interviewed the participants using a well-established questionnaire to collect data about potential risk factors for malaria infection. The risk estimates with Odds Ratio of 95% Confidence Interval was used to test the association of risk factors with malaria positive cases. A logistic regression model was used to analyze the association between the risk factors and malaria positive cases. A *p-value* < 0.5 was considered a statistically significant.

Results: A total of 469 patients were enrolled, of them, 334 (71.2%) tested positive for malaria. The analysis of preventive measures and risk factors showed that wearing protective clothing (covering most of the mosquito-biting body-sites) is significantly protective against malaria, with a negative beta coefficient of -0.757 (*p-value* 0.003). The relationship of using insecticides and presence of trees with reduced malaria infection was found statistically significant; *p-values* were 0.040 and 0.035, respectively. Similarly, the presence of stagnant water was a significant risk factor for malaria, with a negative beta coefficient of -0.483 (*p-value*0.022).

Conclusions:

The study's outcomes highlight the importance of advocating towards using preventive measures such as wearing clothes that reduce mosquito bites, and avoid being close to potential breeding sites (bodies of stagnant water) in malaria-endemic regions.

Background

Malaria is caused by a protozoan parasite belongs to the *Plasmodium* genus, with five species known to affect human health: *Plasmodium falciparum*, *P. vivax*, *P. malariae*, *P. ovale*, and *P. knowlesi* [1]. Malaria continues to pose a significant public health threat worldwide, with Africa contributing to approximately 96% of global malaria cases [2]. In 2021, the World Health Organization (WHO) estimated that more than 245 million cases of malaria occurred in over 80 endemic countries, resulting in approximately 619,000 deaths [2]. Malaria remains a significant challenge, particularly in vulnerable populations and resource-limited settings.

Vulnerability to malaria is complex and multifactorial, particularly in low- and middle-income countries like Sudan, which is accounted for about 54% and 58% of malaria cases and related deaths in the Eastern Mediterranean region, respectively, with 64,000 estimated cases in 2021 [1]. There are several endemic and invasive competent vectors of malaria are widely distributed in the country. *Anopheles arabiensis* is the predominant species of malaria vectors in the country, however, other vectors like An. stephensi, An. funestus, An. pharoensis, and *An. rufipes* are increasingly spreading throughout the country [2–6]. Also, the country's health system is under-resourced and the public health operation is severely inadequate. Additionally, a wide range of other risk factors, including suboptimal housing, insufficient personal protective measures, limited access to effective and affordable healthcare services, and low awareness about the risk factors and prevention measures are present in the country [7, 8]. Furthermore, changes in climate, living environment, and land use as well as the growing armed conflicts and living in humanitarian crisis are driving the transmission of vector-borne diseases and their vectors [3, 9, 10]. Moreover, this situation is intensified by the rapid development and spread of drugs and insecticide resistance among parasites and diseases vectors respectively, in lack of alternative disease control measure such as vaccination in the country [8, 11]. The driving role of these factors is not exclusive to malaria only but it has been highlighted by the recently growing reports about the emergence and rapid spread of several infectious diseases outbreaks including Chikungunya [12], Dengue [13, 14], Hepatitis E virus [15, 16], Leishmaniasis [17], and Rift Valley fever [18, 19]. A substantial increase in malaria cases and death has been observed in different region of the country, this might be due to this combination of risk factors in Sudan [9, 20–22].

Therefore, examining, understanding, and addressing these underlying drivers and risk factors are necessary to inform and guide the decision making, strategic planning, proper implementation of effective disease control measures in LMICs including Sudan [20, 23, 24].

Despite existing research on malaria transmission in Sudan, there is still a significant lack of knowledge regarding the local risk factors and their influence on the disease transmission. As such, this study aims to address this gap by identifying the risk factors associated with malaria transmission in Al Gezira state, Sudan. The findings of this study will inform the design and implementation of preventive and control measures, in order to improve outcomes for those impacted by malaria in central Sudan.

Methods

Study design and study area

A descriptive cross-sectional study was implemented in Al Gezira state between January and September 2022. Al Gezira state is one of the 18 states of Sudan, which lies in central Sudan between the Blue Nile and the White Nile. It contributes 24% and 6.9% of the total malaria cases and related deaths, respectively in 2021 (http://www.fmoh.gov.sd). Al Gezira state is hosting the largest naturally irrigated agriculture project in the world. The state is composed of 8 localities including Al Hasaheisa, Wad Madani, South Al Gezira, East Al Gezira, Um Al Qura, Al Kamleen, Al Managel, and Al Qurashi-24, covering an area of 27,549 km^2. Healthcare facilities in three peri-urban localities including Al Hasaheisa, Al Kamleen, and Al Managel, were included in this study. Participants were recruited for sample collection and questionnaire data gathering (Fig. 1).

Study population

Febrile patients attending outpatient clinics in Al Hasaheisa locality (Al Hasaheisa hospital, and Medical Insurance hospital), East Al Gezira locality (Rofaa hospital), and Al Managel locality (Al Managel hospital) were recruited to participate in the study.

Individuals who presented with fever or abdominal disturbances and sought medical attention were enrolled in the study after being informed of the study objectives, criteria, purpose, and potential risks. They were provided with up to 30 minutes to consider their participation before being included in the research.

After voluntarily consenting to participate in our study, individuals either signed an informed consent form for themselves or signed on behalf of a minor for whom they were responsible. The participants were interviewed using a questionnaire about factors that might be associated with malaria infection including their socio-demographic information, medical and travel history, and their knowledge about signs, symptoms, as well as prevention and control measures of malaria. As well, behavioral and practices to protect themselves from malaria. Furthermore, we collected their clinical signs and diagnostic outcomes.

Confirming malaria infection

Malaria infection or lack of infection was confirmed by the attending laboratory technologist who microscopically examined Giemsa-stained blood films that obtained from the healthcare seeking individuals [25].

Data analysis

The data was collected anonymously without personal identifiers. The data were then analysed using the Statistical Package for Social Sciences (SPSS version 20, IBM, USA). The participants ages were grouped according to the model established previously by Khagayi et al., 2019 [26]. Chi-Square test was performed to analyse the categorical data and test for significant differences between the variables. The risk estimates with Odds Ratio of 95% Confidence Intervals (95% CI) was used to test the association of risk factors with positive and negative microscopic tests of malaria. Spearman Correlation coefficient was used to test the association between malaria and related risk factors. A logistic regression model was developed to estimate the association between the risk factors and malaria cases. The Hosmer-Lemeshow goodness-of-fit test was used to assess that the model fits the data. A *p-value* < 0.5 was considered a statistically significant.

Results

Patients' demographics

The study enrolled 469 patients who visited outpatient clinics seeking healthcare for febrile illness. Of them, 334 (71.2%) tested positive for malaria, while 135 (28.8%) tested negative. Based on gender the study population included 233 (49.7%) males and 236 (50.3%) females, with age range of 4 months to 87 years. The mean age of the study population was 24.75 ± 19.81 years [95% CI (22.95–26.55)], and the median age was 24 years. The analysis revealed that the highest proportion of malaria cases was among patients aged 5–14 years, while the lowest proportion was among patients aged over 59 years; 35 (7.5%). However, the differences between the age groups were not statistically significant (*p-value* = 0.214). Meanwhile, based on gender, a slightly higher proportion of females tested positive for malaria compared to males, but again, the difference was not statistically significant (*p-value* = 0.065). Whereas, a statistically significant difference in malaria diagnosis between the different locations was found; *p-value* = 0.024. The highest proportion of positive malaria cases was observed in Al Hasahisa; 77 (77.0%), while the lowest proportion was observed in East Al Gazira; 103 (76.9%) (Table 1).

Table 1
distribution of the study patients according to their age group, gender, and location

	Malaria diagnosis		Total	p-value
	Positive	**Negative**		
Patient age group				
Less than 1 year	26 (60.5%)	17 (39.5%)	43 (9.2%)	0.214
1–4 years	30 (65.2%)	16 (34.8%)	46 (9.8%)	
5–14 years	58 (67.4%)	28 (32.6%)	86 (18.3%)	
15–59 years	193 (74.5%)	66 (25.5%)	259 (55.2%)	
More than 59 years	27 (77.1%)	8 (22.9%)	35 (7.5%)	
Patient gender				
Male	158 (67.8%)	75 (32.2%)	233 (49.7%)	0.065
Female	176 (74.6%)	60 (25.4%)	236 (50.3%)	
Patient location				
Al Hasahisa	77 (77.0%)	23 (23.0%)	100 (21.3%)	0.024
Al Managel	154 (65.5%)	81 (34.5%)	235 (50.1%)	
East Al Gazira	103 (76.9%)	31 (23.1%)	134 (28.6%)	
Total	**334 (71.2%)**	**135 (28.8%)**	**469 (100%)**	

Clinical characteristics of the participants and its associations with malaria infection

Concerning the malaria symptoms observed in this study, 246 (73.7%) of the confirmed malaria cases reported fever, while 88 (65.2%) of those who tested negative for malaria have reported fever (*p-value* = 0.044). However, the odds ratio was 1.130 (95% CI: 0.983–1.298), indicating a positive but not statistically significant association between fever and malaria diagnosis (Spearman Correlation Coefficient − 0.085, *p-value* 0.067.)

Among the participants who reported not having diarrhea, 245 (73.4%) were positive for malaria while 114 (84.4%) were tested negative (*p-value* = 0.006). The odds ratio was 0.601 (95% CI: 0.398–0.909), indicating a negatively statistically significant association between the absence of diarrhea and malaria diagnosis (Spearman Correlation Coefficient − 0.119, *p-value* = 0.010).

Overall, the results show that several symptoms were negatively associated with malaria diagnosis, including headache (Spearman Correlation Coefficient – 0.120, *p-value* 0.009), vomiting (-0.093, *p-value* 0.044), abdominal pain (-0.099, *p-value* 0.032), shivers, (-0.153, *p-value* < 0.001) anxiety (-0.159, *p-value* < 0.001), and fatigue (-0.166, *p-value* < 0.001). However, the associations were not statistically significant for joint pain (-0.046, *p-value* 0.323) (Table 2).

Table 2
Patients signs and symptoms and their relation with malaria diagnosis

	Malaria diagnosis		Total	OR	95% Confidence Interval		p-value	Spearman Correlation Coefficient	
	Negative	Positive			Lower	Upper		value	p-value
Fever									
Yes	88 (65.2%)	246 (73.7%)	334 (71.2%)	0.670	0.436	1.029	0.044	-0.085	0.067
No	47 (34.8%)	88 (26.3%)	135 (28.8%)						
Headache									
Yes	61 (45.2%)	195 (58.4%)	256 (54.6%)	0.588	0.393	0.879	0.006	-0.120	0.009
No	74 (54.8%)	139 (41.6%)	213 (45.4%)						
Vomiting									
Yes	40 (29.6%)	132 (39.5%)	172 (36.7%)	0.644	0.419	0.990	0.027	-0.093	0.044
No	95 (70.4%)	202 (60.5%)	297 (63.3%)						
Abdominal pain									
Yes	32 (23.7%)	113 (33.8%)	145 (30.9%)	0.608	0.385	0.959	0.020	-0.099	0.032
No	103 (76.3%)	221 (66.2%)	324 (69.1%)						
Diarrhoea									
Yes	21 (15.6%)	89 (26.6%)	110 (23.5%)	0.507	0.300	0.857	0.006	-0.119	0.010
No	114 (84.4%)	245 (73.4%)	359 (76.5%)						
Joint pain									
Yes	77 (57.0%)	207 (62.0%)	284 (60.6%)	0.815	0.543	1.223	0.187	-0.046	0.323

*OR = Odd Ratio

	Malaria diagnosis		Total	OR	95% Confidence Interval		p-value	Spearman Correlation Coefficient	
	Negative	Positive			Lower	Upper		value	p-value
Fever									
No	58 (43.0%)	127 (38.0%)	185 (39.4%)						
Shivers									
Yes	33 (24.4%)	136 (40.7%)	169 (36.0%)	0.471	0.301	0.738	0.001	-0.153	< 0.001
No	102 (75.6%)	198 (59.3%)	300 (64.0%)						
Anxiety									
Yes	51 (37.8%)	185 (55.4%)	236 (50.3%)	0.489	0.325	0.736	0.001	-0.153	< 0.001
No	84 (62.2%)	149 (44.6%)	233 (49.7%)						
Fatigue									
Yes	52 (38.5%)	190 (56.9%)	242 (51.6%)	0.475	0.316	0.715	0.001	-0.166	< 0.001
No	83 (61.5%)	144 (43.1%)	227 (48.4%)						
Total	**135 (28.8%)**	**334 (71.2%)**	**469 (100%)**						
*OR = Odd Ratio									

The relationship between preventive measures and risk factors of malaria

The relationship between wearing protective clothes and malaria showed that individuals who did not wear protective clothes were more than twice as likely to test positive for malaria compared to those who did wear protective clothes; *p-value* 0.001. A total of 225 (67.4%) tested positive for malaria, and 110 (81.5%) of those who tested negative did not wear protective clothes, the odds ratio for wearing protective clothes is 2.132 (95%CI [1.305–3.482]). The association of wearing protective clothes with malaria was significantly positively correlated (Spearman Correlation coefficient 0.141, *p-value* 0.002).

The relationship was also found statistically significant difference for malaria positivity and using of insecticides; presence of trees; and presence of stagnant water, *p-values* were 0.040, 0.035, and 0.014, respectively. At the same times the odds ratios for those who are not using insecticides, or have trees in or around their houses, and existence of stagnant water were more likely to test positive for malaria; 1.462 (95%CI [0.976–2.19]), 1.479 (95% CI [0.989–2.21]), and 1.621 (95% CI [1.071–2.453]), respectively. However, no statistically significant association was observed for using insecticides (0.085, *p-value* 0.065), presence of trees (0.088, *p-value* 0.056), whereas, presence of stagnant water showed a positively statistically significant association with malaria positivity (0.106, *p-value* 0.022).

The association of using smoke as a repellent, using of bed nets, and closing of windows and doors at night with malaria positivity was neutral did and not show neither significant difference nor significant association (Table 3).

Table 3
relationship of malaria preventive measures and risk factors with malaria patients

	Malaria diagnosis		Total	Odds ratio	95% Confidence Interval		p-value	Spearman Correlation Coefficient	
	Negative	Positive			Lower	Upper		value	p-value
Wearing protective clothes									
No	110 (81.5%)	225 (67.4%)	335 (71.4%)	2.132	1.305	3.482	0.001	0.141	0.002
Yes	25 (18.5%)	109 (32.6%)	134 (28.6%)						
Using of mosquito repellants									
No	108 (80.0%)	252 (75.4%)	360 (76.8%)	1.302	0.798	2.124	0.175	0.049	0.292
Yes	27 (20.0%)	82 (24.6%)	109 (23.2%)						
Using of insecticides									
No	79 (58.5%)	164 (49.1%)	243 (51.8%)	1.462	0.976	2.19	0.040	0.085	0.065
Yes	56 (41.5%)	170 (50.9%)	226 (48.2%)						
Presence of trees									
No	75 (55.6%)	153 (45.8%)	228 (48.6%)	1.479	0.989	2.21	0.035	0.088	0.056
Yes	60 (44.4%)	181 (54.2%)	241 (51.4%)						
Presence of stagnant water									
No	88 (65.2%)	179 (53.6%)	267 (56.9%)	1.621	1.071	2.453	0.014	0.106	0.022
Yes	47 (34.8%)	155 (46.4%)	202 (43.1%)						
Using of smoke as repellent									
No	87 (64.4%)	194 (58.1%)	281 (59.9%)	1.308	0.865	1.979	0.121	0.059	0.204
Yes	48 (35.6%)	140 (41.9%)	188 (40.1%)						

	Malaria diagnosis		Total	Odds ratio	95% Confidence Interval		p-value	Spearman Correlation Coefficient	
	Negative	Positive			Lower	Upper		value	p-value
Wearing protective clothes									
Using of bed nets									
No	53 (39.3%)	139 (41.6%)	192 (40.9%)	0.907	0.603	1.364	0.358	-0.022	0.639
Yes	82 (60.7%)	195 (58.4%)	277 (59.1%)						
Closing of windows and doors									
No	43 (31.9%)	101 (30.2%)	144 (30.7%)	1.078	0.701	1.659	0.406	0.016	0.732
Yes	92 (68.1%)	233 (69.8%)	325 (69.3%)						
Total	**135 (28.8%)**	**334 (71.2%)**	**469 (100%)**						

The relationship between the different preventative measures and malaria risk factors with malaria infection base on location

According to locality, the relationship between the different preventative measures and malaria diagnosis showed that in Al Hasahisa, among individuals who did not have trees in or around their houses, 84.0% tested positive for malaria. The odds ratio for the presence of trees is 1.377 (95%CI [1.208–1.570]), indicating that individuals who did not have tree near or in their houses are less likely to test positive for malaria compared to those who have trees near or in their houses; *p-value* 0.010. As well, the association of trees presence with malaria was negatively statistically significant (Spearman Correlation Coefficient –0.239, *p-value* 0.017).

The relationship and association between wearing protective clothes, using of mosquito repellants, using of insecticides, presence of stagnant water, using of smoke as a repellent, using of bed nets, and closing windows and doors with malaria in Al Hasahisa did not show any statistically significance (Table 4, Supplementary File 1: Table S1).

Table 4
relationship of malaria preventive measures and risk factors with malaria patients according to their localities

Patient location	Malaria diagnosis		Total	p-value	Odds ratio	95% Confidence Interval	
	Negative	Positive				lower	Upper
Al Hasahisa							
Wearing protective clothes							
No	0 (0.0%)	2 (100%)	2 (2.0%)	0.591	1.307	1.171	1.458
Yes	23 (23.5%)	75 (76.5%)	98 (98.0%)				
Using of mosquito repellants							
No	4 (12.1%)	29 (87.9%)	33 (33.0%)	0.056	0.348	0.108	1.126
Yes	19 (28.4%)	48 (71.6%)	67 (67.0%)				
Using of insecticides							
No	0 (0.0%)	6 (100%)	6 (6.0%)	0.199	1.324	1.180	1.485
Yes	23 (24.5%)	71 (75.5%)	94 (94.0%)				
Presence of trees							
No	0 (0.0%)	16 (100%)	16 (16.0%)	0.010	1.377	1.208	1.570
Yes	23 (27.4%)	61 (72.6%)	84 (84.0%)				
Presence of stagnant water							
No	0 (0.0%)	10 (100%)	10 (10.0%)	0.063	1.343	1.190	1.516
Yes	23 (25.6%)	67 (74.4%)	90 (90.0%)				
Using of smoke as repellent							
No	3 (15.8%)	16 (84.2%)	19 (19.0%)	0.309	0.572	0.151	2.168
Yes	20 (24.7%)	61 (75.3%)	81 (81.0%)				
Using of bed nets							

Patient location	Malaria diagnosis		Total	p-value	Odds ratio	95% Confidence Interval	
	Negative	Positive				lower	Upper
Al Hasahisa							
No	0 (0.0%)	4 (100%)	4 (4.0%)	0.345	1.315	1.175	1.471
Yes	23 (24.0%)	73 (76.0%)	96 (96.0%)				
Closing windows and doors							
No	0 (0.0%)	0 (0.0%)	0 (0.0%)	n.a.	n.a.	n.a.	n.a.
Yes							
Total	**23 (23.0%)**	**77 (77.0%)**	**100 (100%)**				
East Al Gazira							
Wearing protective clothes							
No	31 (25.4%)	91 (74.6%)	122 (91.0%)	0.036	0.746	0.673	0.827
Yes	0 (0.0%)	12 (100%)	12 (9.0%)				
Using of mosquito repellants							
No	28 (26.9%)	76 (73.1%)	104 (77.6%)	0.040	3.316	0.932	11.796
Yes	3 (10.0%)	27 (90.0%)	30 (22.4%)				
Using of insecticides							
No	26 (28.6%)	65 (71.4%)	91 (67.9%)	0.022	3.040	1.077	8.579
Yes	5 (11.6%)	38 (88.4%)	43 (32.1%)				
Presence of trees							
No	26 (29.9%)	61 (70.1%)	87 (64.9%)	0.009	3.580	1.272	10.075
Yes	5 (10.6%)	42 (89.4%)	47 (35.1%)				
Presence of stagnant water							

Patient location	Malaria diagnosis		Total	p-value	Odds ratio	95% Confidence Interval	
	Negative	Positive				lower	Upper
Al Hasahisa							
No	22 (27.2%)	59 (72.8%)	81 (60.4%)	0.123	1.823	0.765	4.344
Yes	9 (17.0%)	44 (83.0%)	53 (39.6%)				
Using of smoke as repellent							
No	21 (28.0%)	54 (72.0%)	75 (56.0%)	0.096	1.906	0.817	4.443
Yes	10 (16.9%)	49 (83.1%)	59 (44.0%)				
Using of bed nets							
No	18 (26.5%)	50 (73.5%)	68 (50.7%)	0.235	1.468	0.652	3.304
Yes	13 (19.7%)	53 (80.3%)	66 (49.3%)				
Closing windows and doors							
No	5 (21.7%)	18 (78.3%)	23 (17.2%)	0.551	0.908	0.307	2.684
Yes	26 (23.4%)	85 (76.6%)	111 (82.8%)				
Total	**31 (23.1%)**	**103 (76.9%)**	**134 (100%)**				
Al Managel							
Wearing protective clothes							
No	79 (37.4%)	132 (62.6%)	211 (89.8%)	0.002	6.583	1.507	28.751
Yes	2 (8.3%)	22 (91.7%)	24 (10.2%)				
Using of mosquito repellants							
No	76 (34.1%)	147 (65.9%)	223 (94.9%)	0.400	0.724	0.222	2.357
Yes	5 (41.7%)	7 (58.3%)	12 (5.1%)				

Patient location	Malaria diagnosis		Total	p-value	Odds ratio	95% Confidence Interval	
	Negative	Positive				lower	Upper
Al Hasahisa							
Using of insecticides							
No	53 (36.3%)	93 (63.7%)	146 (62.1%)	0.270	1.242	0.709	2.174
Yes	28 (31.5%)	61 (68.5%)	89 (37.9%)				
Presence of trees							
No	49 (39.2%)	76 (60.8%)	125 (53.2%)	0.068	1.572	0.910	2.713
Yes	32 (29.1%)	78 (70.9%)	110 (46.8%)				
Presence of stagnant water							
No	66 (37.5%)	110 (62.5%)	176 (74.9%)	0.061	1.760	0.909	3.408
Yes	15 (25.4%)	44 (74.6%)	59 (25.1%)				
Using of smoke as repellent							
No	63 (33.7%)	124 (66.3%)	187 (79.6%)	0.369	0.847	0.438	1.636
Yes	18 (37.5%)	30 (62.5%)	48 (20.4%)				
Using of bed nets							
No	35 (29.2%)	85 (70.8%)	120 (51.1%)	0.054	0.618	0.359	1.062
Yes	46 (40.0%)	69 (60.0%)	115 (48.9%)				
Closing windows and doors							
No	38 (31.4%)	83 (68.6%)	121 (51.5%)	0.189	0.756	0.441	1.296
Yes	43 (37.7%)	71 (62.3%)	114 (48.5%)				
Total	**81 (34.5%)**	**154 (65.5%)**	**235 (100%)**				

In East Al Gazira locality, the relationship between malaria and wearing of protective clothing as a preventive measure, among individuals who did not Wearing protective clothes, 74.6% tested positive for malaria, while 25.4% of those who tested negative did not wear protective clothing. Although, the odds ratio was 0.746 (95%CI [0.673–0.827]), this indicates wearing protective clothing in East Al Gezira contribute in reducing the risk of infection; *p-value* 0.036. The association of wearing protective clothes and malaria was positively statistically significant (Spearman Correlation Coefficient 0.172, *p-value* 0.047). Also, using of mosquito repellants, using of insecticides, presence of trees was also showing statistically significant relationships with malaria infection; *p-values* 0.040, 0.022, and 0.009, respectively, but, in terms of association with malaria, only using of insecticides and presence of trees showed positively statistically significant association with malaria (Spearman Correlation Coefficients; 0.188 and 0.218, and *p-values* 0.033 and 0.011, respectively). However, the odds ratio showed that it is more likely to have malaria infection when not using mosquito repellants; 3.316 (95% CI [0.932–11.796]) or insecticides; 3.040 (95% CI [1.077–8.579]), while more likely to have the infection when trees are near or in the house; 3.580 (95% CI [1.272–10.075]) (Table 4, Supplementary File 1: Table S1)

In Al Managel locality, the relationship between malaria and wearing of protective clothing was the only preventive measure showing positively statistically significant association with malaria (Spearman Correlation Coefficient 0.185, *p-values* 0.004). Among the individuals who did not wear protective clothes, 62.6% tested positive for malaria, while 37.4% of those who tested negative did not wear protective clothing. The odds ratio was 6.583 (95%CI [1.507–28.751]), this indicates wearing protective clothing in Al Managel contribute significantly in reducing the risk of malaria infection; *p-value* 0.002 (Table 4, Supplementary File 1: Table S1).

Risk factors associated with malaria

We studied several potential risk factors that might be associated with malaria infection. These potential risk factors include age, gender, no using protective measures such as wearing protective clothing, using mosquito repellents, using insecticides, living near trees and stagnant water, using of smoke as a repellent, bed nets, and closing of windows and doors (Table 5).

Table 5
Logistic regression analysis for estimating malaria preventive and risk factors associated with malaria positive patients

Risk Factors	Beta coefficient	p-value	95% Confidence Interval	
			Lower	Upper
1–4 years	-0.792	0.120	0.167	1.229
5–14 years	-0.588	0.247	0.205	1.503
15–59 years	-0.488	0.292	0.247	1.523
More than 59 years	-0.143	0.737	0.375	2.001
Patient’s gender	-0.331	0.106	0.481	1.073
Wearing protective clothes	-0.757	0.003	0.287	0.766
Using mosquito repellants	-0.264	0.292	0.471	1.254
Using of insecticides	-0.380	0.065	0.457	1.024
Presence of trees	-0.391	0.056	0.452	1.011
Presence of stagnant water	-0.483	0.022	0.408	0.933
Using smoke as a repellent	-0.268	0.204	0.505	1.157
Using bed nets	0.098	0.638	0.733	1.659
Closing of windows and doors	-0.075	0.732	0.603	1.427

According to the our findings, utilizing protective clothing presents a significant defense against malaria with a negative beta coefficient of -0.757 and a *p*-value of 0.003. Thus, individuals who wear protective clothes are at a lesser risk of contracting the disease. On a similar note, stagnant water serves as a significant contributing factor for malaria, with a negative beta coefficient of -0.483 and a p-value of 0.022. Consequently, individuals who reside near stagnant water bodies are at a higher risk of contracting malaria.

Other risk factors that showed trend toward significance included the use of insecticides, the presence of trees, and the use of smoke as a repellent (*p-values* 0.065 and 0.056, respectively). The age group, gender, using mosquito repellants, using smoke as a repellent, using bed nets, and closing of windows and doors at night did not show significant association with malaria risk, with *p-values* greater than 0.1. Overall, the results suggest that the only protective measures; wearing protective clothing and avoiding areas near stagnant water can be effective in reducing the risk of contracting malaria (Table 5).

Discussion

Identifying risk factors associated with malaria infection locally is essential for successfully controlling and eventually eliminating malaria. Several well-known risk factors such as wide spectrum of endemic vectors [27], invasive competent vectors [20, 28], climate change [3, 10] and the rapidly spreading insecticides resistance are hindering the global efforts to eliminate malaria [29]. Nevertheless, several anthropological factors related to human behaviours and practices have a substantial influence on increasing malaria transmission [4, 5].

The current research examined various malaria prevention and risk factors across 469 individuals who underwent malaria diagnosis at different healthcare facilities in Al Gezira state. Of these participants, 71.2% were confirmed to have malaria, while the remaining 28.8% tested negative.

Although this prevalence may appear high compared to some studies, it is consistent with previous research indicating high malaria prevalence in Al Gezira state, particularly during the malaria transmission season [7]. Nonetheless, malaria infections in this state during the transmission season may still reach epidemic levels when compared to other states in the country, as shown in previous studies [9, 30].

Despite the common assumption that pregnancy makes females more vulnerable to malaria, recent evidence has shown that male outdoor behaviours such as nocturnal outdoor settlements can result in higher exposure to mosquito bites, putting them at an equal risk for contracting the disease. Therefore, gender cannot be solely attributed to malaria risk factors in females. [6]. This study revealed a slightly higher proportion of females who tested positive for malaria in comparison to males. While similar findings have been reported earlier [31], this may be due to more complex behaviours, such as sleeping indoors, which may offer to some extent protection against outdoor vector biting [4, 27]. Generally, one who spent time outside are more susceptible to malaria infection than their counterparts [32]. However, the difference in malaria prevalence between males and females was not statistically significant (*p-value* = 0.065), which suggests that exposure to infected mosquitoes may be similar among both sexes.

Interestingly, although the highest proportion of positive malaria cases was found among patients aged 5–14 years, the increased proportion of malaria cases among patients aged 5–14 years may be attributed to several factors. Children within this age group are more likely to have underdeveloped immune systems, which make them more susceptible to infection. Moreover, they may play outdoors in the evening, increasing their exposure to mosquito bites, and subsequently malaria transmission. In addition, they may not have developed adequate knowledge or implement effective preventive measures to reduce their risk of contracting the disease. Overall, various social, environmental, and immunological factors may make children aged 5–14 more vulnerable to malaria. Interestingly, our study showed that the differences between the age groups were not statistically significant. This could suggest that vector contact and malaria transmission may be shifting towards equilibrium across the different age groups. One possible explanation for this could be an increased community awareness about malaria prevention measures such as the use of bed nets, especially for protecting young children under 5 years or less than

14 years [7]. This behaviour is particularly important in rural areas where access to healthcare and preventative measures may be limited.

Revised: Conducting additional research to determine the specific factors contributing to the diverse patterns of malaria transmission among different age groups is of utmost importance for safeguarding public health. Identifying the underlying reasons behind such discrepancies can enable the development of more targeted and effective interventions to control the spread of the disease. Therefore, it is imperative that we prioritize the exploration of these factors and commit to implementing evidence-based strategies for malaria prevention and control. Doing so can have a significant impact on reducing the burden of malaria on communities.

The epidemiology of malaria in Sudan is characterized by a considerable variability [21]. While this study focuses on a single state, it found statistically significant differences in the positivity rates of malaria diagnosis among the different localities (*p-value* = 0.024). Al Hasahisa locality had the highest proportion of positive malaria cases, whereas East Al Gazira had the lowest. This confirms the heterogeneity of malaria transmission in Sudan. This heterogeneity is mainly influenced by the proportional distribution of the risk factors such as climate, geography, and socio-economic status, as well as environmental conditions, abundance of the various vectors, as well as socioeconomic characteristics, local risky behaviours and practices [10, 27, 33]. Several studies have also reported similar variations in malaria prevalence across the different regions in Sudan [34, 35].

Concerning the patients' signs and symptoms, this study highlighted the insignificant association of fever with malaria positivity in the studied population. Although this is contrary to several studies where fever is significantly associated with malaria, the existence of several causative agents of febrile illness in Sudan could be considered a reason of fever development in malaria-free patients.

Furthermore, the types of malaria parasites prevalent in Sudan could play a role in the lack of association between fever and malaria positivity. Some species of malaria are known to cause asymptomatic infections or present with atypical symptoms, including absence of fever [36, 37]. Overall, the lack of a significant association between fever and malaria positivity in the studied population highlights the complexity of diagnosing febrile illnesses in malaria-endemic regions and underlines the importance of exploring alternate diagnostic approaches and screening for a wide range of infectious and non-infectious causes of fever. These causative agents mainly could be arboviral, parasitic or bacterial diseases including but not limited to dengue fever [13], chikungunya [12], rift valley fever [18], *Leishmania* species [17], *Toxoplasma gondii* [38], *Helicobacter pylori* [39], and recently the COVID-19 pandemic [40–42]. As well, the increased proportion of diarrhoea among the participants may highlight the increased diarrhoeal diseases pathogens, which later when the infection disseminate lead to malaria-like symptoms such as fever or headache [43].

The findings of this study indicate that various preventative measures contribute in reducing the risk of contracting malaria. These measures include the use of insecticides, wearing protective clothing, and avoid formation of stagnant water near houses. These results align with previous studies that have demonstrated the effectiveness of these measures in preventing the transmission of malaria [44, 45]. For instance, a study conducted in Ethiopia discovered that the use of insecticide-treated bed nets reduced the risk of malaria infection among children [44]. Similarly, another study in Burkina Faso found the use of insecticide-treated curtains in the rooms reduced the risk of malaria infection among pregnant women [5].

However, in the local context, there are some notable differences in the findings of this study when compared to previous studies. For instance, the relationship between the presence of trees and malaria infection is inconsistent with previous studies demonstrating how change in ecosystem and the deforestation can heighten the risk of malaria transmission through decreasing the natural predators of mosquitos [46]. This discrepancy may be due to variations in the geography of the studied areas, where the presence of trees in or around houses may vary. Additionally, it's possible that the types of existed trees could have different effects on the presence of the malaria vector, where some indigenous trees provide a suitable habitat while others may act as a deterrent and work in a preventive manner such as *Azadirachta indica*, commonly known as neem [47, 48].

The observed protective effects of wearing protective clothing and the risk associated with stagnant water near houses are similar to a study conducted in Kenya reporting wearing protective clothing reduced the risk of malaria infection [49], and, in a systemic review, individuals living in areas near stagnant water formations were at a higher risk of malaria [50]. However, in the local context of Al Hasahisa locality, the observed insignificant association between wearing protective clothing and malaria prevention could be attributed to the interference of various human behavioural factors. These factors may include the use of other preventive methods such as smoke or sesame oil as repellents or closing windows and doors to prevent mosquito entry into rooms during the night.

Although the use of smoke as a repellent could play a protected role against exposure to insect bites, however, the present study did not demonstrate significance, which is similar to previous findings [51]. This could be attributed to variations in the repellence and lethal effects of different types of wood used for smoking the area.

While the study has explored various preventive measures and risk factors associated with malaria, the relatively sample size might have potentially impacted the generalizability of our findings to the entire country and similar settings in other countries. Therefore, we recommend investigating the impacts of these factors and their interchangeable interaction on malaria transmission in other areas with stable malaria transmission.

This study has several limitations, including the susceptibility to encounter selection bias, as participants who agree to participate may differ in characteristics from those who decline, potentially leading to a recall bias due to the reliance on self-reported data. Participants may not accurately remember all details of their past behaviours. Although the current study provides insights into malaria prevalence and risk factors, it is important to note that the research was conducted in a hospital setting and not within the broader community. As a result, there is a possibility that the study may have underestimated malaria prevalence within this region.

Additionally, the study did not discuss the potential influence of confounding variables such as socioeconomic status, education level, and other health conditions, which could have partially impacted the results. Therefore, it is crucial to acknowledge these limitations when interpreting the study's findings and drawing conclusions, and these limitations in future research should be addressed.

Conclusions

The results of this study underscore the significance of implementing preventive measures, such as wearing protective clothing and avoiding stagnant water formation in malaria-prone regions. While other risk factors like the use of insecticides, presence of trees, and using of smoke as a repellent showed a trend towards significance, their statistical significance was not established. Therefore, future studies with larger sample sizes and in diverse contexts are necessary to better comprehend the role of other preventive measures in mitigating malaria risk, given that their effectiveness may vary depending on the local context. The findings of this study can provide valuable insight for the development of targeted malaria control strategies that consider specific risk factors for different regions. As a result, public awareness campaigns can be launched to educate individuals on the importance of protective measures such as wearing protective clothing, using mosquito repellents and insecticides, and enhancing access to protective tools. Additionally, measures to limit stagnant water, such as improving drainage systems, filling potholes, and clearing blocked gutters, can be implemented. Effective malaria control requires collaboration between governments, healthcare organizations, and local communities. With collective efforts, comprehensive strategies, and interventions, the burden of malaria on affected communities can be alleviated.

Abbreviations

LMICs
Low- and middle-income countries
95% CI
95% Confidence Interval.

Declarations

Ethics approval and consent to participate

This study has been approved by the Faculty of Medicine, Al Gezira University Research Ethics Committee. Participants recruited in this study all agreed to participate by signing an inform consent by the patient himself or by his or her legal guardians in case of children less than 18 years old.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Not applicable.

Authors' contributions

MAS, AA, and NSM conceived the study; DIO, MAA, and MAS conducted the field work; HA, OF, MSEA, AEA, and EES analysis and interpretation of the data. AA and NSM drafted the manuscript; YA, MA, EES and AA critically revised the manuscript for intellectual content. All authors read and approved the final manuscript.

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Figures

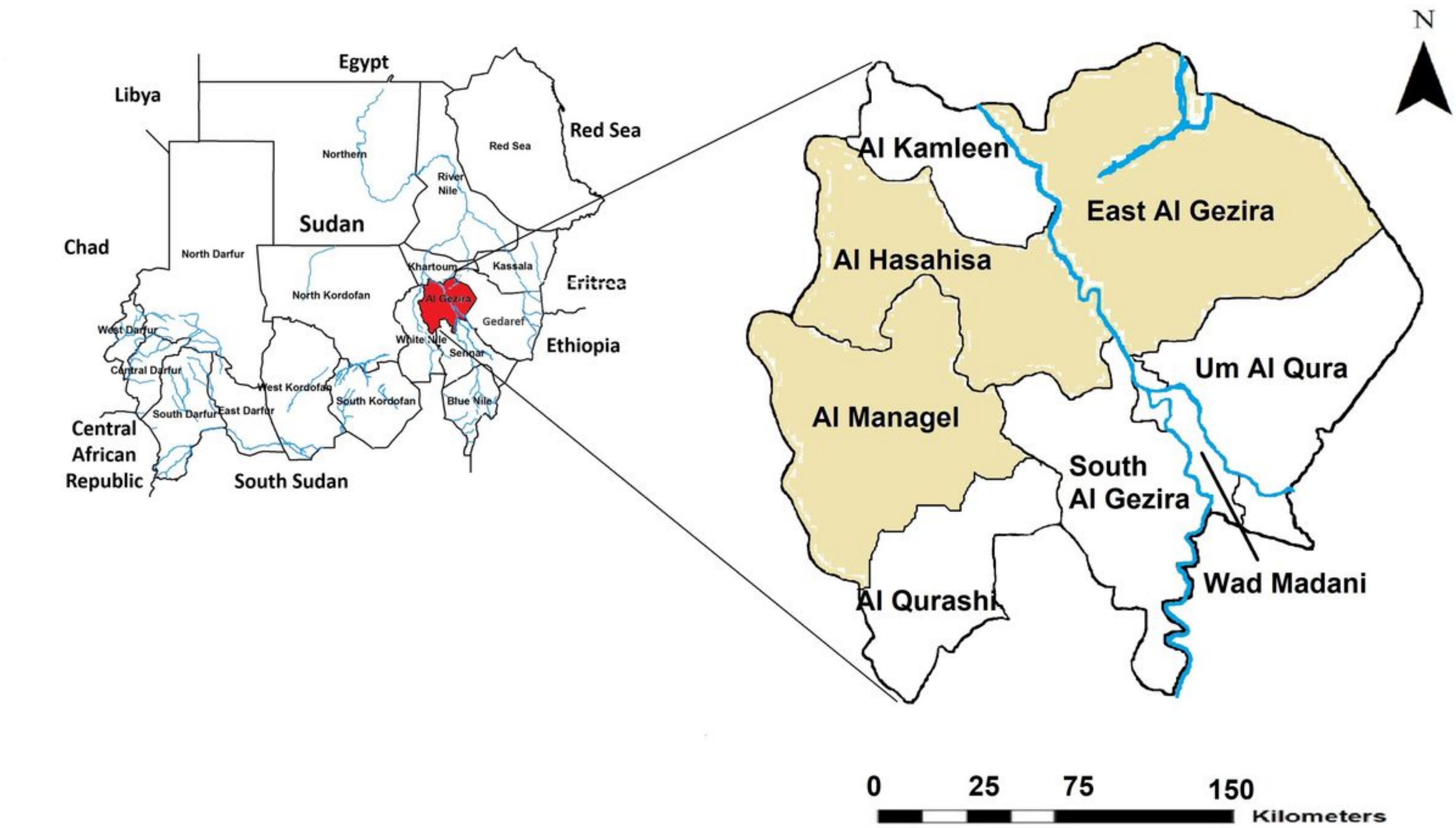

Figure 1

Map of Al Gezira state, Sudan. The map shows the different study localities included. Highlighted in Red in the left-side of the map is Al Gezira state location in Sudan. Highlighted in the right-side map (Al Gezira state) is the different localities included in the study.

Supplementary Files

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- SupplementaryFile1.docx