Alemu *et al. Malaria Journal* (2024) 23:397
https://doi.org/10.1186/s12936-024-05228-y

Malaria Journal

RESEARCH

Open Access

Malaria burden and associated risk factors among malaria suspected patients attending health facilities in Kaffa zone, Southwest Ethiopia

Aster Alemu[1], Beshada Lemma[1], Temesgen Bekele[1], Geleta Geshere[1], Eba Alemayehu Simma[1], Chernet Tuge Deressa[2] and Tsige Ketema[1*]

Abstract

Background Ethiopia has been progressing very well in controlling malaria in the past few years. However, shortly after the COVID-19 pandemic, an unpredictable malaria resurgence was observed in almost all malaria-endemic areas of the country, although the exact cause of which has not yet been identified. Therefore, this study aimed to investigate malaria burden and associated risk factors in one of the endemic zones of Ethiopia.

Methods A health facility-based retrospective and cross-sectional study design was conducted in the Kaffa zone, southwest of Ethiopia. Hence, a seven-year retrospective data on malaria positivity rate, interventional activities undertaken in the area, and climatic variables were collected from the patient's medical records, district health bureau, and meteorological institute, respectively. For the cross-sectional study, all malaria-suspected patients seeking medication at the health facilities in the Kaffa Zone administrative centre, Bonga town, during the study period (January–June 2024), were recruited in the study. Data on the patient's socio-demographic, socio-economic, behavioural, health facilities and environmental factors were collected using a structured face-to-face interview questionnaire. Data was analysed using Statistical Package for Social Science software (SPSS) (version 26) and the statistical tools used were descriptive statistics and logistic regression models. A significant level was considered at $p < 0.05$.

Results The study findings revealed a significant increment in malaria positivity trend (39.43%, n = 188,201/477,276, $p < 0.0001$) between July 2018 and June 2024. Also, the malaria positivity rate documented in the cross-sectional study was 50.72% (n = 315/621). *Plasmodium falciparum* was the dominant malaria parasite. The study identified weakened control measures ($p = 0.006$), limited awareness of the population ($p < 001$), and socio-demographic factors such as education ($p = 0.037$), age ($p = 0.008$), housing condition ($p < 0.0001$), low-income level ($p < 001$), and travel history to malaria-endemic areas ($p = 0.001$)] as risk factors associated with high malaria positivity rate. In addition, indoor residual spraying (IRS) and mean maximum temperature activity increased by 1 unit, and the malaria positivity rate decreased by 28 times ($p < 0.0001$) and 1.3 ($p = 0.003$), respectively. The months of July and September were strongly and positively associated with higher malaria positivity in the area ($p < 0.05$).

Conclusion Even though Ethiopia was able to achieve a remarkable malaria burden reduction in the past few years, the recent interrupted malaria control activities, seasonal variability, and patient and health facility-associated factors

*Correspondence:
Tsige Ketema
tsigeketema@gmail.com
Full list of author information is available at the end of the article

have contributed to the current high malaria positivity rate documented in Kaffa zone, Southwest Ethiopia. This urges the need for immediate community sensitization activities to enhance the awareness of malaria, besides designing integrated vector control interventional strategies to tackle the current alarming situation in the zone.

Keywords Malaria, Resurgence, Bonga, Kaffa zone, IRS, ITNs, Plasmodium, Ethiopia

Background

Malaria continues to be a significant public health issue worldwide. In 2022, approximately 249 million cases and 608,000 deaths from malaria were reported globally [1]. As evidence in various studies revealed, there was a significant decline in malaria mortality and morbidity from 2000 to 2015 [2]. From 2019 to 2021, an increase in cases and deaths of malaria was recorded. Infants, children under 5 years, pregnant women, travellers and people with HIV or AIDS are at higher risk of malaria [1–3]. The fundamental malaria prevention measures use long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS), alongside improved treatment regimens and expanded testing programmes; these measures have significantly decreased the population of malaria vectors in many areas of Africa [4]. However, malaria prevalence could vary due to different factors, such as changes in weather conditions, environmental factors, human behaviour and socioeconomic conditions and healthcare infrastructures [5, 6].

The public health authorities of Ethiopia worked hard to achieve the malaria eradication goal set by the World Health Organization (WHO) by 2030. Accordingly, substantial malaria burden reduction was observed in many endemic areas of the country in the past few years [2, 3, 7]. However, in the recent few years, the scenario has changed, and an unexpected sudden malaria burden increment was observed in almost all malaria-endemic areas of the country [8, 9]. The cause for the observed malaria burden increment could be multifactorial. Some of the identified risk factors are the presence of mosquito breeding sites, poor bed net utilization, poor environmental management, lack of awareness of malaria transmission and socio-demographic and socio-economic variables [10–12]. Although the current situation in most malaria-endemic regions showed high malaria resurgence, the current magnitude of malaria burden in Kaffa zone, one of the malaria-endemic areas in Ethiopia, has not been assessed. Therefore, the current study was designed to determine the magnitude of the malaria burden in the zone and its associated risk factors to synthesize information that could assist national policymakers in evidence-based decisions on malaria prevention and control strategies in the region.

Methods

Description of the study area

The study was conducted in Kaffa Zone, located 449 km southwest of Addis Ababa (Ethiopia's capital city). The study site was selected due to its historically high malaria burden and substantially affected by the current malaria resurgence in the country. According to recent information from the National Statistical Agency (CSA) of Ethiopia, the total population of the zone was 2,151,716, of which males were 1,411,778, and females were 739,938 [13]. In the zone, the altitude ranges from 500 to 3000 m. This zone is geographically found between 6°24' and 8°13' north latitude and 35°30' to 36°46' east longitude. The zone has diverse topography consisting of highland, midland, and lowland. The major source of economy in this area was agriculture and trade. It has a warm and humid climatic condition with moderate temperature. The average annual temperature in the zone lies between 10.1 and 27.5 °C and the annual average precipitate varies between 1001 and 2200 mm. The Kaffa zone consists of many *woredas* (districts) namely Bita, Bonga, Chena, Cheta, Dacha, Awurada, Gesha, Gewate, Gimbo, Adiyo, Sayilem, Wacha, Telo, Daka, Awurada Town, Shishinda Town, Shishonde and Goba.

Study population and design

A health facility-based cross-sectional and retrospective study design was employed. The study population for the retrospective study was all individuals diagnosed and received treatment for malaria infection at all the districts and town administrations found in the Kaffa zone from January 2018 to June 2024. Similarly, for the cross-sectional study the study population were malaria-suspected patients who visited three public health facilities in the central town of Kaffa zone, Bonga, from January to June 2024.

Sample size determination and sampling techniques

Data of all malaria suspected patients diagnosed and treated at all health facilities found in the Kaffa zone were considered in the retrospective study. In the cross-sectional study, a sample size was determined by using a single population proportion formula. In this calculation, $Z\alpha/2 = 1.96$ for the 95% level of confidence interval (CI), ± 5% level of precision, and 50% prevalence was considered. Accordingly, the final sample size obtained was 384. Considering a maximum of 40% non-response rate, the final adjusted sample size was 621. The patients were selected purposively, based on the availability of the symptomatic malaria suspected patients during the study period.

Data collection and processing

For the retrospective study, data collection involved document analysis to obtain socio-demographic information and information about malaria infection details from the medical records, laboratory reports, and diagnostic records found in the town health bureauxs. In addition, information related to the malaria intervention, such as the distribution of insecticide-treated bed nets and indoor residual spraying, was collected from the district health department. Then a survey on the contemporary malaria positivity rate, interventional activities, and other risk factors were collected through microscopic examination of blood samples collected from malaria-suspected patients (patients with malaria symptoms such as fever, shivering, headache, fatigue, vomiting, diarrhoea, prostration, and others) attending the health facility during the study period. Briefly, from a lancet-pricked finger, a single drop of blood sample was collected on a clean glass slide for the preparation of thin and thick blood films. After an air-dried thin smear was fixed using methanol, the two blood films were stained by Giemsa (10%) and then observed under a light microscope (100x). The slides found positive were re-checked by laboratory technicians blinded to the test result. Those patients found positive for malaria infection were identified, and data collection was started using a predesigned data collection format and structured face-to-face interview questionnaire. The data was collected by the principal investigator with the help of health professionals working in the hospital and research assistants. In addition, key informant interviews were conducted with key informants such as healthcare providers and program managers at Bonga Gebiretsadik Showa General Hospital, the Health Centre, five clinics, and the head of the district health bureaux.

Data analysis

The collected data was thoroughly reviewed and checked for completeness, accuracy, and consistency. Duplicate or irrelevant records were removed, and any missing data or inconsistencies were resolved by referring back to the original sources. To minimize errors, the accuracy of data entry was verified through a double-checking process. Data was analysed using Statistical Package for Social Sciences (SPSS) software version 26. Statistical tools such as descriptive statistics (percentage, proportions, and mean), bivariate correlation analysis, and logistic regression models were used. The bivariate analysis was conducted to identify risk factors associated with malaria positivity rate using odds ratios (ORs) and their 95% confidence intervals (CI). The multiple linear regression model used to analyse the effect of independent variables (risk factors) on the dependent variables (malaria positivity rate) was computed using the following formula: Y (malaria positivity rate) $= \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + --- \beta nXn$, where Y was the dependent variable, X1, X2,..., Xn were the independent variables, and βO was the Y-intercept, which represented the value of Y.

Results

Malaria positivity trend

Between 2018 and 2024, the pooled malaria positivity rate recorded among clinically suspected malaria patients was 39.43% (n = 188,201/477,276). This figure was significantly higher ($p < 0.0001$, 95% CI 39.29, 39.57%). The trend showed an increasing pattern as it goes from July 2018 and June, 2024. In the past few years (2022–2024) the malaria positivity rate has almost doubled. In terms of *Plasmodium* species proportion, *Plasmodium falciparum* is the dominant parasite (71.71% total infection, from which 48.71% was due to *P. falciparum* mono-infection). In this study setting there was a significant number of *P. falciparum* and *Plasmodium vivax* mixed infections (23%, 95%CI 22.9, 23.12%, $p < 0.0001$). Malaria positivity rates among patients of different ages and sexes were evenly distributed. The mean temperature (minimum and maximum) and rainfall in these years were consistent with the overall value of 19.82 °C average temperature and 5.59 mm rainfall (Table 1).

The highest rate of malaria positivity was noted between August and December in the years 2018 to 2021, even though the rate varied from year to year. After 2022, though, the pattern shifted, with an unexpectedly high rate of malaria positive observed all year long with a somewhat unpredictable decline across months. Since November 2021, there has been a noticeable increase that has been fairly large and abrupt (more than 50% of the positivity rate has been confirmed in certain districts) (Fig. 1).

From October to March, the maximum temperature consistently rises. However, between 2018 and 2021, a decline was observed in June and September. This trend from June 2022 to June 2024, as irregular fluctuations were noted in a few months. Despite these variations, the patterns of minimum temperature and rainfall patterns remained relatively stable over the years (Fig. 2).

Districts within the Kaffa zone have shown diverse levels of malaria burden. However, the rate of malaria positivity has been steadily rising in all districts in recent

Table 1 Malaria positivity rate and associated risk factors in Kaffa zone, Southwest Ethiopia from 2018 to 2024

Year	Total tested	Total positive	Positivity rate	Plasmodium species (%)			Age (year)			Sex		Meteorological variable			
				P.f	*P.v*	Mixed infection	< 5	5 to 14	> 14	Male	Female	Mean Tmin (°C)	Mean Tmax (°C)	Av Temp (°C)	Mean RF (mm)
2018	13,324	3365	25.26	1218 (36.2)	808 (24.01)	1339 (39.8)	889 (26.42)	1097 (32.6)	1379 (40.98)	1630 (48.44)	1735 (51.56)	13.29	26.99	14.98	3.55
2019	27,531	5515	20.03	2426 (43.99)	1193 (21.63)	1896 (34.38)	1314 (23.83)	1259 (22.8)	2942 (53.35)	3269 (59.27)	2246 (40.73)	13.07	27.92	20.37	6.74
2020	28,698	5937	20.69	2869 (48.32)	1609 (27.1)	1459 (24.57)	1335 (22.49)	1833 (30.9)	2869 (48.32)	3142 (52.92)	2795 (47.08)	12.94	28.87	21.03	5.17
2021	27,604	8161	29.56	3569 (43.73)	2781 (34.08)	1811 (22.2)	1788 21.91)	2429 (29.8)	3944 (48.33)	3988 (48.87)	4173 (51.13)	12.95	27.8	20.35	3.78
2022	50,808	21,939	43.18	7866 (35.85)	3741 (17.05)	10,332 (47.1)	4970 (22.65)	7249 (33)	9720 (44.30)	11,518 (52.5)	10,421 (47.5)	12.53	28.21	20.36	6.75
2023	157,213	66,569	42.34	34,712 (52.14)	19,505 (29.3)	12,352 (18.6)	13,324 (20.02)	25,471 (38.3)	27,774 (41.72)	32,946 (49.49)	33,623 (50.51)	13.1	27.95	21.83	7.56
2024	172,098	76,715	44.58	39,008 (50.85)	23,560 (30.71)	14,147 (18.44)	18,381 (23.96)	25,214 (32.9)	33,120 (43.17)	40,456 (52.74)	36,259 (47.26)	13.03	28.4	20.7	7.3
Total	477,276	188,201	39.43	91,668 (48.71)	53,197 (28.27)	43,336 (23)	60,315 (32.05)	57,035 (30.3)	70,759 (37.60)	96,949 (51.5)	91,252 (48.49)	12.98	27.96	19.82	5.59

P.f P. falciparum, *P.v P. vivax*, mixed infection refers to infection with both *P. falciparum* and *P. vivax*. *Temp Min* minimum temperature, *Temp Max* maximum temperature, *Av.temp.* average temperature, *Av.RF* average rainfall

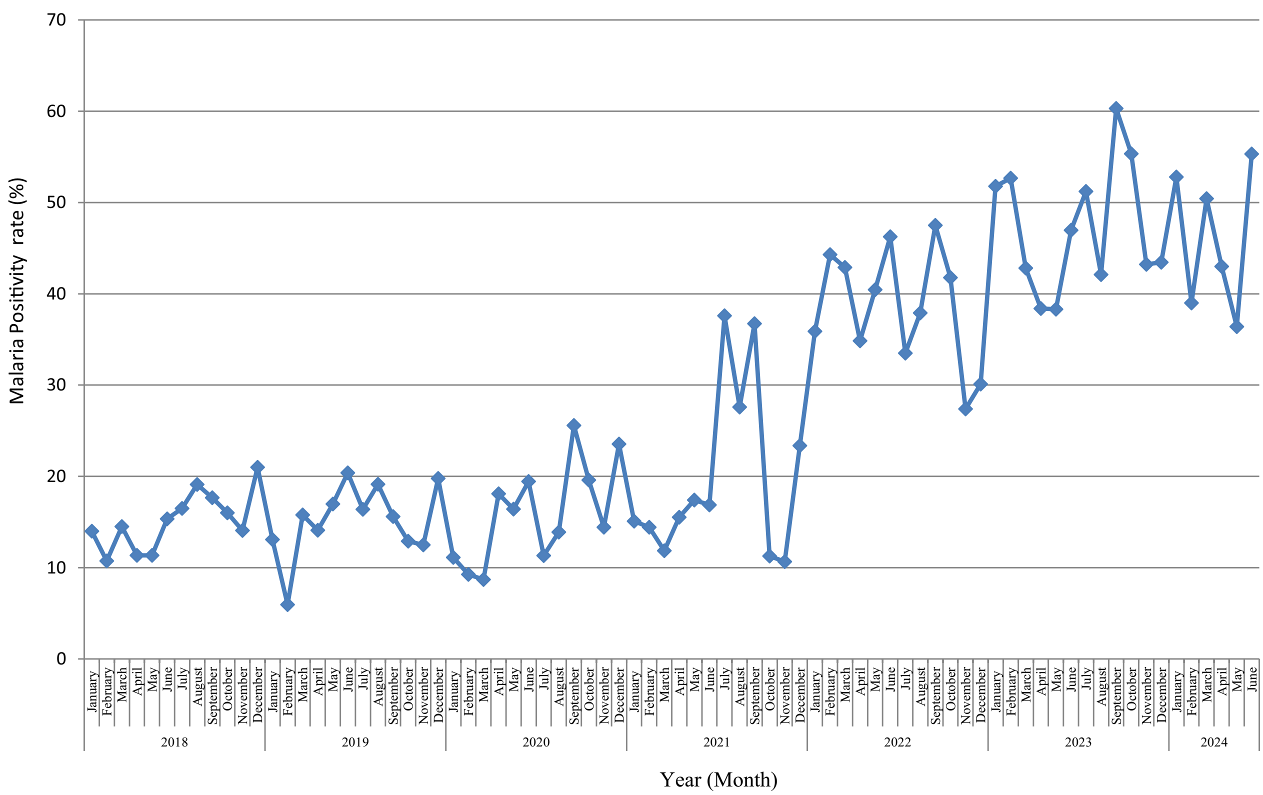

Fig. 1 Trend of malaria positivity rate in Kaffa zone, southwest of Ethiopia from 2018 to 2024

years. In many districts in the past, such as Saylem and Gesha, the prevalence of malaria was quite low for a few years in a row. Conversely, some districts, such as Chena, Bonga, Decha, and Gimbo, have seen a high malaria burden in recent years (Table 2).

Impact of some variables on the malaria positivity rate

The effect of socio-demographic variables such as season, interventional activities, and climate factors on the malaria positivity rate from retrospective data showed that patients aged above 14 years ($\beta = 0.158$, $p = 0.008$), and male sex ($\beta = 0.442$, $p = 0.018$) were positively associated with increased malaria positivity rate. Also, the analysis has shown that, a significant effect of the time change (year) on the malaria positivity rate, indicating as the year increased by 1 unit, the malaria positivity rate increased by 5.46 ($p < 0.001$). Likewise, some months such as September ($\beta = 9.82$, $p = 0.04$), and July ($\beta = 13.7$, $p = 0.005$), were significantly and positively associated with increased malaria positivity rate in the zone.

A statistically significant negative association was observed between intervention activities and the malaria positivity rate. As the indoor residual spraying (IRS) activity increased, the malaria positivity rate decreased by 28 times ($p < 0.001$). However, there was no significant effect were found concerning different *Plasmodium* species and overall malaria prevalence. Among the climatic variables analysed, maximum temperature was negatively associated with the malaria positivity rate. For every 1-unit increase in maximum temperature, the malaria positivity rate decreased by 1.3 ($p = 0.003$), while rainfall and minimum temperature do not affect the malaria burden. Among the districts or administrative towns included in the analysis, Bita ($\beta = 19.65$, $p = 0.0002$) and Decha ($\beta = 11.71$, $p = 0.02$) exhibited significantly high positivity rate (Table 3).

Socio-demographic characteristics of the study participants

In the cross-sectional study, a total of 621 (315 were males and 306 were females) clinically malaria-suspected patients were included, among which 315 (50.72%) were microscopically confirmed malaria-positive. Also, in terms of age, 25.4% were under 5 years old, 84 (13.5%) were 5–14 years old, and 379 (61%) were above 14 years old. The percentage of males and females tested malaria-positive was 30.11% (n = 187) and 20.61% (n = 128), respectively. The travel history data indicated that individuals with no travel history were 94.36% (n = 586), among which 48.15% (n = 299) were found negative,

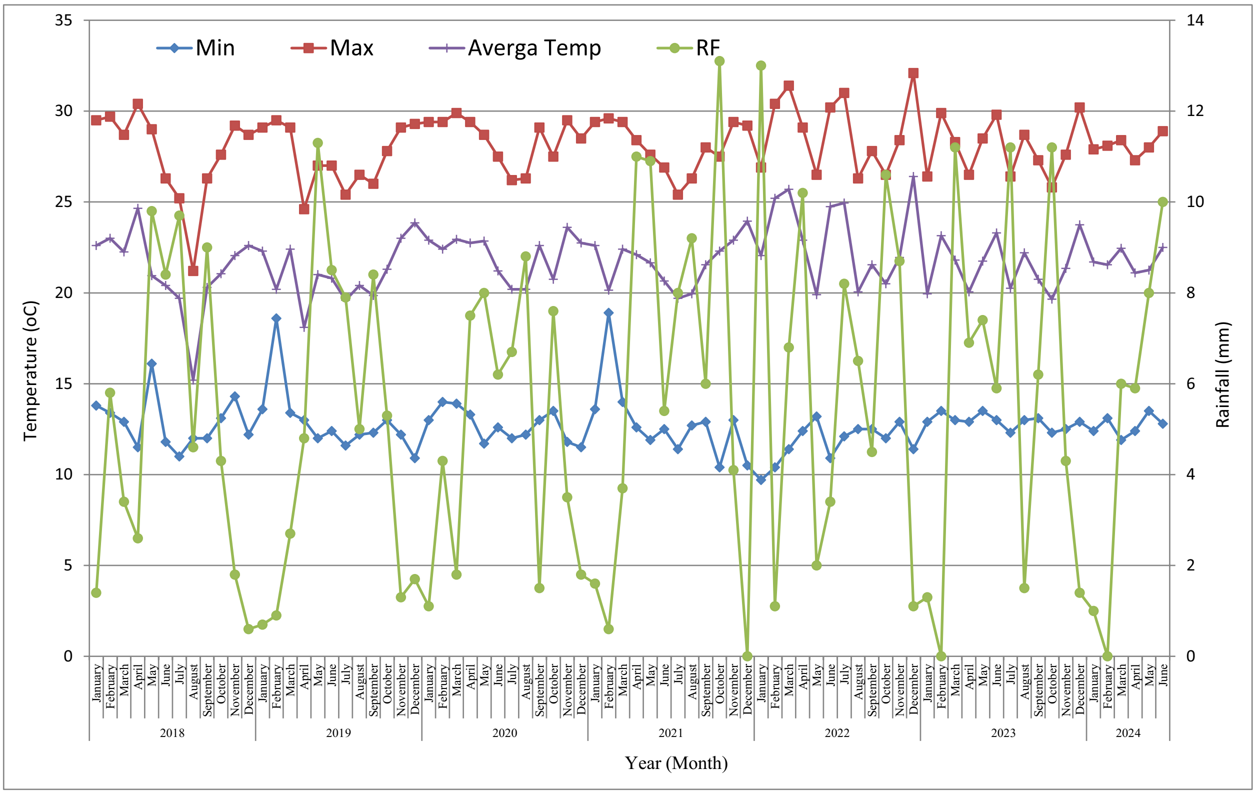

Fig. 2 Pattern of climatic variables (minimum, maximum and average temperatures, and rainfall) in Kaffa zone, from 2018 to 2024

while 46.225 (n = 287) were tested positive for malaria infection. The low-income category had a higher positivity rate (24.3%) compared to the medium (16.26%) and high (0.87%) categories. Those with travel history had 5.64% cases, with 1.13% negative and 4.51% positive cases. The dominant *Plasmodium* species in the study area was *P. falciparum* (79%), while *P. vivax* mono-infection showed lesser distribution (3.5%). Regarding age, the dominant age group with high malaria positivity was those > 14 years (31.9%), followed by younger children < 5 years (11.1%). Malaria positivity rate was higher among patients with ≥ 5 family size (56.68%) and merchant occupation (35.91%), followed by farmer (30.59%) and illiterate educational background (33.01%). Malaria positivity in pregnant women was 6.44% (Table 4).

Patients' awareness about malaria interventional activities

Most of the study participants had a history of malaria episodes (78.74%, n = 489). Most of the patients were treated with artesunate (58.41%, n = 184), a treatment option recommended for severe malaria infection, followed by AL (31.75%, n = 100) for their past malaria infection. The patient's adherence to the infections seems poor, as most of them replied they had no adherence (73.1%, n = 454) to the full dose of anti-malarial drugs. The number of patients whose family members sleep under ITNs was only 8% and none of the participants had outdoor activities. In the most recent years, 2023/2024, there are no ITNs distributed, or IRS services provided in the study area. Many participants strongly disagree (71.82%, n = 446) with the sufficiency of previously distributed ITNs and most of them don't properly use what they have (74.07%, n = 460).

Regarding the patient's knowledge of common malaria symptoms, and health education provided in the study area, although only a few participants said there was health education provided to them (32%, n = 198), most of them (56%, n = 347) had a better understanding about malaria symptoms. On the other hand, participants knew about malaria prevention and control activities, only very few were aware of the larva source management (3.06%), and the use of traditional medicinal plants for malaria prevention (4.7%). None of the study participants knew about biological control agents and participated in malaria interventional activities in the locality (Table 5).

According to the regression analysis, certain socio-demographic variables such as males had shown a significantly (0.492 times) higher risk of getting malaria infection compared to females (AOR = 0.492, 95% CI 0.36–0.68, p < 0.001). The children found in the age

Table 2 Malaria positivity rate in the districts found in Kaffa zone, southwest Ethiopia, from 2018 to 2024

District/town	2018		2019		2020		2021		2022		2023		2024		Total		
	Tested	+ ve	Tested	+ ve	Tested	+ ve	Tested	+ ve	Tested	+ ve	Tested	+ ve	Tested	+ ve	Tested	+ ve	% + ve
Bonga	941	195	1675	334	2939	322	1675	336	2082	601	9325	3290	16,458	5844	35,095	10,922	31.12
Gimbo	1687	489	3021	607	2823	706	3021	236	5054	3694	24,929	11,633	28,492	14,358	69,027	31,723	45.96
Adiyo	123	36	513	140	709	244	513	116	714	850	2487	879	7672	2384	12,731	4649	36.52
Awurada	6	5	49	34	97	28	49	34	178	97	1720	812	4009	2112	6108	3122	51.11
Bita	408	333	3309	1196	1162	304	3309	1312	3073	2187	13,523	5791	10,243	5231	35,027	16,354	46.69
Chena	1662	943	3862	1841	3729	1311	3862	1980	8062	3945	17,084	8261	12,542	6939	50,803	25,220	49.64
Cheta	60	41	309	140	261	68	309	84	933	416	3140	1573	2885	1494	7897	3816	48.32
Decha	892	333	1213	394	1064	298	1213	897	1692	808	11,737	7866	15,474	6267	33,285	16,863	50.66
Deka	39	10	12	12	68	42	12	0	113	376	1763	380	951	223	2958	1043	35.26
Gebret-sadik Hospital	5054	398	10,864	515	10,124	1850	10,864	2457	17,990	3468	29,141	6792	27,146	9852	111,183	25,332	22.78
Gesha	0	0	0	0	0	0	0	0	98	50	1539	434	2195	764	3822	1248	32.65
Gewata	1095	176	1251	108	752	46	1251	236	3373	2276	8736	4784	16,116	10,899	32,574	18,525	56.87
Goba	505	135	187	48	2874	336	187	182	1787	778	6131	3071	4894	2584	16,565	7134	43.07
Saylem	0	0	0	0	1	1	73	51	54	15	1253	253	1771	447	3152	767	24.33
Shishinda Town	221	62	153	20	760	120	153	67	1203	978	6266	2900	4673	2357	13,429	6504	48.43
Shishinda	472	122	328	35	576	78	328	51	1559	933	8554	4411	9868	2194	21,685	7824	36.08
Tello	159	87	785	91	759	183	785	122	2843	467	8702	2758	4993	1817	19,036	5525	29.02
Wacha	0	0	0	0	0	0	0	0	0	0	1183	681	1716	949	2899	1630	56.23
Total (%)	13,324	3365 (25.26)	27,531	5515 (20.03)	28,698	5937 (20.69)	27,604	8161 (29.56)	50,808	21,939 (43.18)	157,213	66,569 (42.34)	172,098	76,715 (44.58)	477,276	188,201	39.43

Table 3 Effect of some risk factors on the malaria positivity rate Kaffa zone, Southwest Ethiopia from 2018 to 2024

Variables	Estimate	Std. Error	t value	Pr (>|t|)
Intercept	− 0.0001	1.18	− 9.3	< 2e−16 ***
Year	5.46	0.58	9.32	< 2e−16 ***
Pf	− 0.0008	0.007	− 0.122	0.90302
P.v	0.014	0.011	1.334	0.18247
Mixed	− 0.04	0.123	− 0.358	0.72015
< 5	*Ref.*	*Ref.*	*Ref.*	*Ref.*
5–14	− 0.140	0.103	− 1.36	0.177
> 14	0.158	0.154	1.92	0.008**
Female	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Male	0.442	0.185	2.39	0.018*
ITN	4.52	2.97	1.52	0.13
IRS	− 28	5.05	− 5.54	3.85e−08***
Min. Temp	0.84	0.77	1.08	0.28
Max. Temp	− 1.3	0.45	− 2.9	0.003**
Rainfall	0.5	0.3	1.7	0.09
Awurada	− 12.57	0.22	− 0.6	0.57
Bita	19. 65	5.27	3.7	0.0002***
Bonga Town	− 6.27	5.14	− 1.2	0.22
Chena	0.196	5.09	0.04	0.97
Cheta	0.133	5.44	0.02	0.98
Decha	11 71	5.17	2.27	0.02*
Deke	2.03	5.08	0.4	0.69
Gawata	5.54	5.09	1.09	0.28
Gesh	− 5.03	5.11	− 0.98	0.32
Gimbo	8.85	5.09	1.74	0.08
Goba	− 5.63	5.09	− 1.1	0.27
Shis	5.61	5.08	1.1	0.27
Shis T	− 5.49	5.28	− 1.04	0.29
Wach	− 2.56	5.09	− 0.5	0.61
Adiyo	*Ref.*	*Ref.*	*Ref.*	*Ref.*
January	− 0.99	4.813	− 0.2	0.84
February	0.431	4.821	0.09	0.93
March	− 0.15	4.815	− 0.03	0.97
April	*Ref.*	*Ref.*	*Ref.*	*Ref.*
May	1.58	4.813	0.32	0.75
June	4.28	4.817	0.9	0.38
July	13.7	4.819	2.8	0.005**
August	3.96	4.815	0.81	0.42
September	9.82	4.817	2.01	0.04*
October	0.11	4.828	0.02	0.98
November	− 3.92	4.825	− 0.8	0.42
December	1.05	4.816	0.2	0.83

* = p<0.05, ** = p<0.01, *** =p<0.001

Std. Error standard error, *Min. temp* Minimum temperature, *Max. Temp* Maximum temperature, *Min.temp.* Minimum temperature, *Pf P. falciparum, P.v P. vivax, Mixed P. falciparum and P.v P. vivax infection*

group between 5 and 14 had 33 times higher less chance of getting malaria infection than those acknowledged as biologically risk group, under 5 years of age children (AOR = − 33, 95% CI 1.93–554.4 p = 0.016). Also, patients aged more than 14 years had a 92 times higher risk of malaria infection compared to those under 5 years of age children (AOR = 92, 95% CI 1.74–4846.53, p = 0.025). Similarly, those patients with a travel history to malaria-endemic areas in the nation had a 4.17 times higher risk of malaria infection than those without a travel history (AOR = 4.17, 95% CI 1.79–9.7, p = 0.001). Contrarily, malaria patients living in good housing conditions (0.09 times), with good awareness about malaria (transmission, common symptoms and prevention methods) (0.066 times), availability of malaria control activities (0.59 times), and educated patients had (0.075 times) have lower chance of getting malaria infection than their counterpart (Table 6).

Response of key informants on malaria and challenges

Findings from the key informant interview with the healthcare providers and health authorities in the district showed that there was a shortage of healthcare workers in the health facilities, insufficient medication or drugs for the treatment of malaria, insufficient healthcare infrastructures, such as reagents for diagnosis, and inadequate hospital beds for inpatient service, which could suggest the presence of a weakened healthcare system struggling to handle the current vast malaria burden in the district. Due to the shortage of healthcare workers (doctors, nurses and others), there was tremendous overburdening of the existing staff, which hinders effective case management, robust surveillance and monitoring treatment, in place. The lack of robust surveillance and monitoring systems in place and limited access to rapid diagnostic tests (RDTs) or lack of other diagnosis options to improve a prompt malaria diagnosis was also raised by the key informants as a grave concern.

Regarding the population's knowledge and practice toward malaria interventional activities, the key informants stated that there was limited knowledge of the major prevention and control measures inadequate understanding of malaria as a life-threatening disease, and negligence in the proper utilization of the tools (misuse of insecticide-treated bed nets (ITNs), unwillingness of communities to remove household items during indoor residual spraying, lack of attention and prioritization of malaria control efforts, poverty, inattentive practices among key stakeholders such as health extension workers and other health care workers fail to educate the population on malaria issues, and professionals seeking personal benefits instead of supporting the community, were challenges encountered during the implementing

Table 4 Socio-demographic and behavioural characteristics of the study participants in Bonga town, Kaffa zone, Southwest Ethiopia, January to May 2024

Variables	Parameters	Malaria test		Total (%)
		Negative (%)	Positive (%)	
Age	< 5	89 (14.33)	69 (11.11)	158 (25.44)
	5–14	36 (5.80)	48 (7.73)	84 (13.53)
	> 14	181 (29.15)	198 (31.88)	379 (61.03)
Sex	Male	128 (20.61)	187 (30.11)	315 (50.72)
	Female	178 (28.66)	128 (20.61)	306 (49.28)
Family size	< 5	138 (22.22)	131 (21.10)	269 (43.32)
	≥ 5	168 (27.05)	184 (29.63)	352 (56.68)
Plasmodium species	*P. falciparum*		248 (39.94)	248 (79)
	P. vivax		11 (1.77)	11 (3.5)
	Mixed		56 (9.02)	56 (17.5)
Occupation	Farmer	99(15.94)	91(14.65)	190(30.59)
	Merchant	108 (17.39)	115 (18.52)	223 (35.91)
	Student	61 (9.82)	70 (11.27)	131 (21.10)
	Employed	28 (4.51)	29 (4.67)	57 (9.18)
	Unemployed	10 (1.61)	10 (1.61)	20 (3.22)
Household income level[a]	Low	151(24.3)	248 (39.9)	399(64.25)
	Medium	101(16.26)	61(9.82)	162 (26.17)
	High	54 (0.87)	6 (0.966)	60 (9.66)
Travel history to malaria endemic areas	Yes	7 (1.13)	28 (4.51)	35 (5.64)
	No	299 (48.15)	287 (46.22)	586 (94.36)
Education level	Illiterate	107 (17.23)	98 (15.78)	205 (33.01)
	Primary school	87 (14.01)	99 (15.94)	186 (29.95)
	Secondary school	81 (13.04)	79 (12.72)	160 (25.76)
	Higher educated	31 (4.99)	39 (6.28)	70 (11.27)
Type of house	Thatch roof	9 (1.45)	303 (48.79)	312 (50.24)
	Corrugate sheet roof	297 (47.83)	12 (1.93)	309 (49.76)
Pregnant women	Yes	44 (7.09)	40 (6.44)	84 (13.53)
	No	262 (42.19)	275 (44.28)	537 (86.47)

[a] Refers to daily income < 50 birr per person = low, daily income 50–200 birr per person = medium, daily income > 200 birr per person = high

of intervention activities. In addition, the availability of many mosquito breeding sites in the locality was reported as the main challenge to ensuring the prevention and control of malaria in the study area.

Discussion

The malaria positivity rate observed in the retrospective study (39.43%) was too far from the finding of a similar study from central Ethiopia (17.4%) in 2022/23, and Southwest Ethiopia (13.6%) [8, 9]. The difference could be due to differences in geographical location, altitude, data collection methods, and the study population. Also, there was a sharp and rapid malaria burden increment detected in the cross-sectional study conducted in 2024 (50.72%) among clinically malaria-suspected patients who attended the health facilities during the study period. The malaria burden detected in this study was too far from the earlier reports from Dembiya district, north-western Ethiopia (22.4%) in 2018 [14], and Mizan-Aman town, southwest Ethiopia, (21.1%) in 2021 [8]. This implies the recent malaria situation in the Kaffa zone has been worsening in recent years, with the disease becoming more widespread in the population.

This study also identified significant seasonal fluctuation in malaria prevalence, with higher rates observed from July to September [15]. This seasonal variation of malaria prevalence might be due to the existence of favourable environmental conditions and increased mosquito breeding sites during the post-rainy months, which leads to higher malaria transmission [16]. Understanding this seasonal pattern of malaria prevalence is crucial for proper planning and execution of malaria control interventions, as it can help trace the target resources during the high-transmission seasons so that malaria

Table 5 Health Care System and KAP of the patients about malaria in Bonga town, Kaffa zone, Southwest Ethiopia from (January to May 2024)

Variables	Parameters	Malaria test		Total (%)
		Negative (%)	Positive (%)	
Previous malaria episodes	Yes	239 (38.56)	250 (40.26)	489 (78.74)
	No	67(10.89)	65 (10.56)	132 (21.26)
Drug received for the previous malaria infection	AL alone		100 (31.75)	100 (31.75)
	AL plus PQ		26 (8.25)	26 (8.25)
	Artesunate		184 (58.41)	184 (58.41)
	CQ plus PQ		5 (1.59)	5 (1.59)
Practice of adherence to full dose of antimalarial drugs	No	226 (36.39)	228 (36.71)	454 (73.11)
	Yes	80 (12.88)	87 (14.01)	167 (26.89)
All family members sleep under bed net	Yes	42 (6.76)	7 (1.13)	49 (8)
	No	264 (42.51)	308 (49.59)	572 (92.11)
Insecticide treated bed nets (ITNs) distributed[a]	No	306 (49.28)	315 (50.72)	621(100)
House sprayed (IRS)[a]	No	306 (49.28)	315 (50.72)	621 (100)
Outdoor activities	No	306 (49.28)	315 (50.72)	621 (100)
Sufficiency of ITN distributed per household in the past	Neutral	38 (6.12)	45 (7.25)	83 (13.37)
	Disagree	52 (8.37)	40 (6.44)	92 (14.81)
	Strongly disagree	216 (34.78)	230 (37.04)	446 (71.82)
Proper utilization and maintenance of bed nets	No	225 (36.23)	235 (37.84)	460 (74.07)
	Yes	81 (13.04)	80 (12.88)	161 (25.93)
Health education ever received on malaria[b]	No	207 (33.33)	216 (34.78)	423 (68.12)
	Yes	99 (15.94)	99 (15.94)	198 (32)
Patients' awareness on the common malaria symptoms	No	140 (22.54)	134 (21.58)	274 (44.12)
	Yes	166 (26.73)	181 (29.15)	347 (56)
Knowledge on larval source management	No	296 (47.67)	306 (49.28)	602 (96.94)
	Yes	10 (1.61)	9 (1.45)	19 (3.06)
Knowledge on traditional medicinal plants used for prevention of malaria	No	292 (47.02)	300 (48.31)	592 (95.3)
	Yes	14 (2.25)	15 (2.42)	29 (4.7)
Knowledge on the use of biological control agents	No	306 (49.28)	315 (50.72)	621 (100)
Participation on any intervention activities	No	306 (49.28)	315 (50.72)	621 (100)

[a] Refers to education ever received on malaria transmission, prevention and control methods, and the need for early malaria diagnosis and treatment

[b] Refers to ITNs distributed, or IRS service provided in 2023/2024, LSM = larval source management, AL = Artemether lumefantrine, CQ = chloroquine

interventional activities will be successfully addressed. The main human malaria parasite in the study areas was *P. falciparum* (as mono-infection and mixed infection with *P. vivax*). The dominant presence of this deadly parasite in the study area should alert the concerned health authorities to undertake prompt interventional measures, as there is a possibility of increased risk of severe life-threatening malaria pathologies [17], thereby the number of deaths due to this parasite could be minimized and malaria-associated public, economic, and social impacts could be controlled [18].

Some socio-demographic and behavioral characteristics, such as being male, being uneducated, having low income, having poor living conditions, and having inadequate knowledge/awareness of the population on malaria (transmission, prevention, and control), were substantially associated with increased malaria burden. This finding agreed with a report from sub-Saharan Africa, where low quality of knowledge, and living conditions significantly impacted malaria transmission dynamics [19], although occupation was not found to be significantly associated with malaria burden in this study. The gender disparity observed could be attributed to the differences in outdoor activities and occupational exposures, which may increase the risk of mosquito bites for male patients than females. Patients' age above 14 years was also associated with higher vulnerability. The sex and age-related patterns observed in this study were supported by studies from Metehara in Central Ethiopia [8], where males were more affected than females, and the

Table 6 Association between some variables and the malaria positivity rate in Bonga town, Kaffa zone, Southwest Ethiopia, January to May 2024

Variables	Alternatives	Negative (%)	Positive (%)	COR	AOR (95% C.I)	P-value
Constant				5.58	265.262	0.033
Age	< 5	89 (14.33)	69 (11.1)	Ref.	Ref.	Ref.
	5–14	36 (5.80)	48 (7.7)	− 3.49	− 33 (1.93–554.4)	0.016
	> 14	181 (29.15)	198 (31.9)	− 4.52	92 (1.74–4846.53)	0.025
Sex	Male	128 (20.61)	187 (30.1)	− 0.71	0.492 (0.36–0.68)	0.000
	Female	178 (28.66)	128 (20.6)	Ref.	Ref.	Ref.
Occupation	Merchant	108 (17.39)	115 (18.5)	− 0.85	1.08 (0.7–1.66)	0.734
	Student	61 (9.82)	70 (11.3)	− 17.3	0.97 (0.54–1.74)	0.926
	Employed	28 (4.51)	29 (4.7)	− 18.14	0.94 (0.38–2.35)	0.893
	Unemployed	10 (1.61)	10 (1.61)	1.42	0.86 (0.59–1.27)	0.457
	Farmer	99(15.94)	91(14.7)	Ref.	Ref.	Ref.
Level of household income	Medium	101 (16.26)	61 (9.8)	− 2.69	− 0.068 (0.03– 0.16)	.000
	High	54 (8.70)	6 (0.97)	− 2.69	− 0.068 (0.03– 0.16)	.000
	Low	151 (24.32)	248 (39.9)	Ref	Ref	Ref.
Education level	Educated	87 (14.01)	99 (15.9)	− 2.59	− 0.075 (0.007–0.85)	0.037
	Illiterate	107 (17.23)	98 (15.8)	Ref.	Ref.	Ref.
Housing condition	Corrugated sheet roof	297 (47.83)	12 (1.9)	− 8.62	− 0.09 (0.002–0.33)	0.000
	Thatch roof	9 (1.45)	303 (48.8)	Ref.	Ref.	Ref.
Travel history to malaria endemic areas	Yes	7 (1.13)	28 (4.5)	1.43	4.17 (1.79–9.7)	0.001
	No	299 (48.15)	287 (46.2)	Ref.	Ref.	Ref.
Awareness about malaria transmission	Yes	64 (10.31)	160 (25.8)	− 2.72	− 0.07 (0.03–0.13)	0.000
	No	241 (38.81)	155 (25)	Ref.	Ref.	Ref.
Knowledge on malaria control measures	Good	75 (12.08)	51 (8.2)	− 0.53	− 0.59 (0.41–0.86)	0.006
	Poor	231 (37.20)	264 (42.5)	Ref.	Ref.	Ref.

COR crude odd ratio, *AOR* adjusted odd ratio, *Ref* represents reference category

Mixed refers to infection by both *P. falciparum* and *P. vivax*

Afar region of Ethiopia, where a higher burden of malaria was reported to older age groups [10]. Also, the type of house was identified as a risk factor for malaria infection, which was supported by another study [20]. According to Ayele et al. [21], the construction material of the walls, roof and floor of a house and toilet facilities and the availability of electricity were the risk factors identified with malaria infection. Although evidence is limited, housing condition is an important risk factor for malaria risk. The presence of a ceiling possibly provides a protective effect [22]. Screening doors and windows can aid in directly blocking vector entry, while modern wall and roof materials may encompass fewer gaps, change the attractiveness of the inner environment to mosquitoes or offer fewer resting sites for mosquitoes than traditional materials [22]. Patients' travel history was another significant factor associated with an increased risk of malaria infection, as there is a potential exposure risk in endemic regions of the same country [11].

The most widespread and universally accepted interventional methods of malaria transmission prevention and control are the use of insecticide-treated bed nets and the application of indoor residual spraying [23]. The ITN was recognized as a higher preventive measure [24]. It works by killing or repelling the vectors that try to feed on humans while sleeping. Similarly, IRS involves spraying the indoor walls and eaves of homes with a residual insecticide, which creates a long-lasting insecticidal effect that kills mosquitoes that land on the treated surfaces [1]. In the past few decades, because of the broader application of these interventional strategies, the malaria burden has significantly reduced and has nearly reached eradication [7]. However, the inadequacy of execution and cut of the ITNs distribution in recent years could be one of the pivotal factors for the current malaria resurgence in the study area, although a significant impact was not observed. Similarly, the participants have reported that none of them have received ITN or got IRS service in the past three years. Those old ITNs were even used by only a few members of the family, although they could lose their potency, and the torn ITNs might not be protective against the mosquitoes anymore [25, 26].

Findings from the key informants revealed some key challenges delaying the malaria control efforts and contributing to the malaria resurgence were inadequate awareness of the population towards malaria prevention and control, misconceptions and poor knowledge of the interventional approaches (poor adherence to the drugs), and a limited number of health care providers. Moreover, there was a weak healthcare system in the study area (lack of robust surveillance and monitoring systems and healthcare facility infrastructure). These findings were similar to the findings from Ethiopia and elsewhere [12, 27]. It will hinder the early detection of outbreaks and limit the ability to implement targeted control measures [28]. Thus, addressing these gaps through targeted education and awareness creation campaigns should be planned and taken as a priority agenda for local and regional health authorities. In addition, limited access to RDTs or other rapid diagnostic options in the context of high malaria burden could lead to delayed diagnoses and treatment of malaria patients and allow the parasite to replicate in the human body for longer, increasing transmission risk and potentially contributing to the emergence of drug-resistant strains [29].

Furthermore, in this study, seasonal variability (maximum temperature) was identified as one of the key risk factors associated with the high malaria burden in the study area. There is a fact on the influence of seasonal change on the mosquito population, which in turn affects malaria transmission rates [30], high rainfall is associated with a rise in malaria cases due to increased mosquito populations as vector breeding sites increase [31], and a positive association between increased malaria burden and temperature rise [32] is expected as temperature controls the growth and development of vectors, and regulates the survival of vectors and parasite development in the vector body. In the current study, maximum temperature was found to suppress malaria positivity rate, which implies the vector and parasite development in the vector body require optimum temperature, which is 16 °C to 18 °C [33].

Limitation of the study

This study included primary and secondary data from patients' medical records, meteorological agencies in the country, and the zonal health offices. Hence, large size of data using large sample size was collected in the study. However, its triangulation against the primary data and drawing solid conclusion was difficult. Because data obtained from secondary sources contain limited information on some variables such as socio-demographic, socio-economic, behavioural characteristics, knowledge, attitude, and practice of the study participants. In addition, as the current malaria burden is varying from place to place and season to season in the same country, due to diverse ecological zones, generalizing this finding to other settings might be difficult.

Conclusion

The study findings revealed the presence of a high malaria burden in the study area. The socio-demographic and socio-economic characteristics of the patients, level of community awareness on the malaria transmission, prevention, and control, travel history to malaria-endemic areas, climatic variability, a weakened healthcare system, a shortage of staff, and interrupted implementation of interventional activities (e.g., IRS) were among the main risk factors associated with the documented high malaria burden in Kaffa zone. These findings could serve as an input for the national health authorities at different levels, as well as other concerned bodies, to understand the major risk factors for the malaria resurgence in the study area, and to improve the healthcare system through boosting the available resources (human and material), besides raising the community's awareness and engagement, supplying adequate infrastructure to the health facilities, and along with interventional tools essential to addressing the present challenging situation.

Abbreviations

ACT	Artemisinin-based combination therapy
AOR	Adjusted odd ratio
COR	Crude odd ratio
IRS	Indoor residual spraying
ITN	Insecticide-treated bed net
LSM	Larval source management
RDT	Rapid diagnostic test

Author contributions

AA and BL: involved in conceptualization, method design, data collection and curation, data analysis and interpretation, and write-up of the manuscript draft. TK: participated in supervision of the study, conceptualization, methodology design, data analysis and interpretation, write-up of the draft manuscript, review and editing. BL, EA, GG, CT and TB: participated in the conceptualization of the study, methodology design, manuscript review and editing.

Funding

The study was financed by Jimma University as part of the Staff Research Mega Project (Grant number: NS/II/24/02).

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Before the commencing of data collection, ethical approval was obtained from Jimma University, Institutional Review Board (IRB) (RSG/149/2024). Informed consent was obtained from all participants who participated in the interview and focus group discussion. Privacy and confidentiality were ensured, right and well-being of the respondents was protected.

Competing interests

The authors declare no competing interests.

Author details
[1]College of Natural Sciences, Department of Biology, Jimma University, Jimma, Ethiopia. [2]College of Natural Sciences, Department of Mathematics, Jimma University, Jimma, Ethiopia.

Received: 21 August 2024 Accepted: 17 December 2024
Published online: 23 December 2024

References

1. WHO. World Malaria Report 2023. Geneva, World Health Organization, 2023. https://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2023.
2. Jemal A, Ketema T. A declining pattern of malaria prevalence in Asendabo Health Center Jimma zone, Southwest Ethiopia. BMC Res Notes. 2019;12:290.
3. Tefera S, Bekele T, Getahun K, Negash A, Ketema T. The changing malaria trend and control efforts in Oromia Special zone, Amhara Regional State, North-East Ethiopia. Malar J. 2022;21:128.
4. Nalinya S, Musoke D, Deane K. Malaria prevention interventions beyond long-lasting insecticidal nets and indoor residual spraying in low- and middle-income countries: a scoping review. Malar J. 2022;21:31.
5. Shiferaw M, Alemu M, Tedla K, Tadesse D, Bayissa S, Bugssa G. The prevalence of malaria in Tselemti Wereda, North Ethiopia: a retrospective study. Ethiop J Health Sci. 2018;28:539–46.
6. Editorial. Malaria progress stumbles, but new tools offer hope. Lancet Microbe. 2022;3:e1.
7. Taffese HS, Hemming-Schroeder E, Koepfli C, Tesfaye G, Lee MC, Kazura J, et al. Malaria epidemiology and interventions in Ethiopia from 2001 to 2016. Infect Dis Poverty. 2018;7:103.
8. Duguma T, Tekalign E, Abera M. Trends of malaria prevalence in selected districts of Kaffa Zone, Southwest Ethiopia. J Trop Med. 2022;2022:3556140.
9. Mandefro A, Tadele G, Mekonen B, Golassa L. Analyzing the six-year malaria trends at Metehara Health Centre in Central Ethiopia: the impact of resurgence on the 2030 elimination goals. Malar J. 2023;23:32.
10. Mitiku BD, Alemayehu BK, Taklu MM. Malaria outbreak and contracting factors in Afar Region, Ethiopia, 2016. J Public Health Epidemiol. 2018;10:233–40.
11. Debash H, Nigatie M, Bisetegn H, Feleke DG, Tesfaw G, Amha A, et al. Malaria surveillance, outbreak investigation, response and its determinant factors in Waghemra Zone, Northeast Ethiopia: unmatched case–control study. Sci Rep. 2023;13:9938.
12. Workineh B, Mekonnen FA, Sisay M, Gonete KA. Malaria outbreak investigation and contracting factors in Simada District, Northwest Ethiopia: a case-control study. BMC Res Notes. 2019;12:280.
13. Central Statistical Agency (CSA). Population Size of Towns by Sex, Region, Zone and Woredas, July 2021.https://www.statethiopia.gov.et/wp-content/uploads/2020/08/Population-of-Towns-as-of-July-2021.pdf.
14. Tarekegn M, Tekie H, Dugassa S, Wolde-Hawariat Y. Malaria prevalence and associated risk factors in Dembiya district, North-western Ethiopia. Malar J. 2021;20:372.
15. Tigu F, Gebremaryam T, Desalegn A. Seasonal profile and five-year trend analysis of malaria prevalence in Maygaba Health Center, Welkait District, Northwest Ethiopia. J Parasitol Res. 2021;2021:6727843.
16. Tsegaye A, Demissew A, Hawaria D, Abossie A, Getachew H, Habtamu K, et al. *Anopheles* larval habitats seasonality and environmental factors affecting larval abundance and distribution in Arjo-Didessa sugar cane plantation, Ethiopia. Malar J. 2023;22:350.
17. Plewes K, Leopold SJ, Kingston HWF, Dondorp AM. Malaria: what's new in the management of malaria? Infect Dis Clin North Am. 2019;3:39–60.
18. Schiess N, Villabona-Rueda A, Cottier KE, Huether K, Chipeta J, Stins MF. Pathophysiology and neurologic sequelae of cerebral malaria. Malar J. 2020;19:266.
19. Degarege A, Fennie K, Degarege D, Chennupati S, Madhivanan P. Improving socioeconomic status may reduce the burden of malaria in sub-Saharan Africa: a systematic review and meta-analysis. PLoS ONE. 2019;14:e0211205.
20. Patrick SM, Bendiane MK, Kruger T, Harris BN, Riddin MA, Trehard H, et al. Household living conditions and individual behaviours associated with malaria risk: a community-based survey in the Limpopo River Valley, 2020, South Africa. Malar J. 2023;22:156.
21. Ayele DG, Zewotir TT, Mwambi HG. Prevalence and risk factors of malaria in Ethiopia. Malar J. 2012;11:195.
22. Tusting LS, Ippolito MM, Willey BA, Kleinschmidt I, Dorsey G, Gosling RD, et al. The evidence for improving housing to reduce malaria: a systematic review and meta-analysis. Malar J. 2015;14:209.
23. Okumu FO, Moore SJ. Combining indoor residual spraying and insecticide-treated nets for malaria control in Africa: a review of possible outcomes and an outline of suggestions for the future. Malar J. 2011;10:208.
24. Kebede Y, Sudhakar M, Alemayehu G, Abebe L, Birhanu Z. Comparing insecticide-treated nets access-use based on universal household and population indicators vis-a-vis measures adapted to sleeping spaces in Ethiopia. Malar J. 2021;20:355.
25. Santos EM, Coalson JE, Munga S, Agawo M, Jacobs ET, Klimentidis YC, et al. "After those nets are torn, most people use them for other purposes": an examination of alternative bed net use in western Kenya. Malar J. 2020;19:272.
26. Scott J, Kanyangarara M, Nhama A, Macete E, Moss WJ, Saute F. Factors associated with the use of insecticide-treated net for malaria prevention in Manica District, Mozambique: a community-based cross-sectional survey. Malar J. 2021;20:200.
27. Paaijmans KP, Lobo NF. Gaps in protection: the actual challenge in malaria elimination. Malar J. 2023;22:46.
28. Haileselassie W, Parker DM, Taye B, David RE, Zemene E, Lee M, et al. Burden of malaria, impact of interventions and climate variability in Western Ethiopia: an area with large irrigation based farming. BMC Public Health. 2022;22:196.
29. Ashley EA, Dhorda M, Fairhurst RM, Amaratunga C, Lim P, Suon S, et al. Spread of artemisinin resistance in *Plasmodium falciparum* malaria. N Engl J Med. 2014;371:411–23.
30. Asgarian TS, Moosa-Kazemi SH, Sedaghat MM. Impact of meteorological parameters on mosquito population abundance and distribution in a former malaria endemic area, central Iran. Heliyon. 2021;7: e08477.
31. Mafwele BJ, Lee JW. Relationships between transmission of malaria in Africa and climate factors. Sci Rep. 2022;12:14392.
32. Beloconi A, Nyawanda BO, Bigogo G, Khagayi S, Obor D, Danquah I, et al. Malaria, climate variability, and interventions: modelling transmission dynamics. Sci Rep. 2023;13:7367.
33. Mironova V, Shartova N, Beljaev A, Varentsov M, Grishchenko M. Effects of climate change and heterogeneity of local climates on the development of malaria parasite (*Plasmodium vivax*) in Moscow Megacity Region. Int J Environ Res Public Health. 2019;16:694.

Publisher's Note