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Species Composition and Distributions of Anopheles Mosquitoes in the Highland Town of Debre Tabor: Implication of Malaria Elimination

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Research Article

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Abstract

Introduction: In Ethiopia, malaria remains one of the major public health and socioeconomic problems of the country. In the country, currently the disease is spreading to elevations of up to 2,900 meter above sea level, which challenging the country's previous agroecological classification of malaria prevalence and elimination goal held by 2030. Therefore, this study investigates the potential malaria vectors and generating base line evidence that will help improve malaria control in the highland community of Debre Tabor.

Methods: Longitudinal entomological survey using Disease Control and Prevention light trap was performed to collect indoors and outdoors feeding Anopheles mosquitoes. Nine resident households were sampled from each of four villages in each month from 06:00 PM (sunset) to 06:00 AM (sunrise). Adult mosquitoes were identified using morphological keys. Data were analyzed using IBM SPSS version 21. Non-normally distributed data were log-transformed [$\log_{10}(x + 1)$]. Differences in mean mosquito densities were assessed using independent-samples t-tests and one-way ANOVA, followed by Tukey's honest significant difference test for significant comparisons. Statistical significance was set at $p < 0.05$.

Results: In the highland, 1671 Anopheles mosquitoes belonging to 7 morphologically identified species were collected. The dominant species was *An. gambiae* s.l (50.7%), followed by *An. cinereus* (29.8%), and *An. demeilloni* (16.2%) ($p = 0.032$). Though these species were found throughout the year, the highest proportion of *Anopheles* mosquitoes was collected during the post-rainy season.

Therefore, this finding has important implications for Ethiopia's malaria elimination goal by 2030, as the expansion of malaria vectors into remote highland areas may create additional challenges for achieving this target. Furthermore, these findings highlight the importance of continued malaria-vector surveillance and prevention activities throughout the year, including in high-altitude urban area, yet sporozoite ELISA and blood-meal identification assays were not performed.

1. Introduction

Malaria is a life-threatening disease caused by *Plasmodium* species that infect humans. The disease is transmitted by the bite of infected female Anopheles mosquitoes [**1**]. Currently, it dominantly affects the sub-Saharan African countries [**2**].

In Ethiopia, malaria remains one of the major public health and socioeconomic problems in the country, despite a dramatic reduction in the last two decades [**3**]. This is because three-fourths (approximately 75% of the country's landmass) of the total area of the country is malaria-ridden/malarious, and two-thirds of the population (around 69%) live below 2000 meters sea level and are at risk of malaria [**4,5**]. However, malaria is currently spreading to elevations of up to 2,900 m.a.s.l. in northwestern Ethiopia [**6,7,8**], which challenging the country's previous agroecological classification of malaria prevalence [**3,9**].

In Ethiopia, *Plasmodium falciparum* and *P. vivax* are the two predominant malaria parasites, with *P. falciparum* accounting for the majority of reported malaria cases. National reports indicate that *P. falciparum* accounts for approximately 65–72% of malaria cases, while *P. vivax* accounts for approximately 28–35% [**3,5**]. Now, these parasites are largely transmitted by *Anopheles arabiensis* and *An. stephensi*, the major malaria vector of Ethiopia, and *An. pharoensis*, *An. funestus*, and *An. nili* are secondary vectors [**10,11**].

The country has been preventing malaria for the past 20 years through the distribution of long-lasting insecticidal nets (LLINs), the use of indoor residual sprayings (IRSs), the introduction of artemisinin-based combination therapy (ACT) with rapid diagnostic tests (RDTs), early diagnosis, prompt treatment of cases, and the use of intermittent preventive therapy to prevent and control malaria among pregnant women [**12,13**]. Being this, the country could override malaria and recently has planned malaria elimination by 2030 [**13,14**].

However, onward from 2022, malaria has shown an alarming increment due to forced relocation, the COVID-19 pandemic's disruption of malaria prevention and control efforts, the presence of insecticide-resistant malaria vectors, antimalarial drug-resistant *Plasmodium* species, neglected *P. vivax* infections, the presence of new invasive species (*An. stephensi*), under-utilization of intervention, a prolonged civil war, increased number of man-made mosquito breeding sites, gaps in service delivery and health system weaknesses, poor community awareness toward malaria and control intervention practices, and the presence of increased global [**15,16,17,18, 19**].

In particularly, the spreading malaria at the higher elevations (2,900 m.a.s.l) is reported by various parts of Ethiopia [**6,7,8**]. This may be due to several interacting factors: increasing temperatures (warmer land surfaces) changes in rainfall patterns, the availability of suitable mosquito breeding habitats, land-use changes, population movement, sustained local transmission, and reduction and disruptions to malaria prevention and control programmes [**6,20,21,22, 23**]. However, a recent study made in high altitude *P. falciparum* and *P. vivax* reservoirs in Ethiopia was not linked to recent travel [**8**]. All the aforementioned evidence contradicts the country's previous agroecological classification of malaria prevalence [**3,9**].

According to evidence from health institutions (unpublished data, personal communication) and open-source reports [**18, 24**], malaria cases have been reported in Debre Tabor Town over the past three years. So far, However, no entomological studies have been conducted in the town. These findings highlight the importance of investigating potential malaria vectors in Debre Tabor Town and other similar areas where locally acquired malaria infections occur. Therefore, a longitudinal entomological study was conducted in Debre Tabor Town from December 2024 to November 2025 to identify potential malaria vectors.

2. Materials and Methods

2.1 Study Area Descriptions

This study was conducted in the Debre Tabor town in South Gondar Administrative Zone of Amhara National Regional State, Northwestern Ethiopia from Dec 2024 – Nov 2025. Debre Tabor Town, the administrative capital of South Gondar Zone, is located in the Amhara Regional State of northwestern Ethiopia, approximately 97 km from Bahir Dar (the capital city of Amhara region) and 667 km from Addis Ababa (the capital city of Ethiopia). Geographically, the town lies between 11.83° and 11.87° N latitude and 37.98° and 38.03° E longitude [**25**], covering an area of approximately 4300 hectares [**26**]. It is characterized by undulating highland topography, with elevations ranging from approximately 2,447 to 2,838 m above sea level [**27**]

According to the traditional Ethiopian agroecological classification, Debre Tabor falls within the Dega (moderate temperate conditions) zone, characterized by relatively low temperatures and substantial seasonal rainfall. The mean annual temperature 15°C [ranges 9.6°C (between January - June) – 21°C (between February and May)] and rainfall have been reported as approximately 1553.7 mm. The maximum rainfall occurs in July or August [**26**].

Figure 1: **Map of study area, Debre Tabor Town**

According to the Ethiopian Statistics Service population projection for 2025, the town had an estimated population of 143,249, comprising 73,550 males and 69,699 females [**28**]. Currently, the town has 13 kebeles (9 in town and 4 in rural). Socioeconomically, Debre Tabor serves as an important administrative, commercial, and service center, with residents engaged in public employment, private businesses, trade, manufacturing, and other informal economic activities.

Debre Tabor Town is characterized by a few marshes and numerous streams, some of which flow throughout the year, including during the dry season. These streams include Mello, Kega-woha, Daba-matebiya, Gebre-wuha, Zufil Wonze, Seli Wonze, and Tabor Wonze. Although malaria has only recently been reported in Debre Tabor Town (unpublished data, personal communication), it is the most common case in the neighboring districts of Fogera [**8,29**], Libo-Kemekem [**30**], Addis Zeman [**31**], Estie [**17**], and Farta [**32**]. Lake et al. [**17**] also reported a resurgence of malaria in Debre Tabor Town. Furthermore, a study conducted among pregnant women attending Debre Tabor Comprehensive Specialized Hospital between October 15 and November 15, 2020, found that nine (3.9%) of the 232 participants had a history of malaria infection during the preceding year [**24**]. However, published evidence documenting the historical occurrence of malaria in Debre Tabor Town remains limited, and no entomological studies have been conducted in the town until now. Therefore, the present longitudinal study was designed to assess potential malaria vectors in Debre Tabor Town from December 2024 to November 2025.

2.2 Study Design

Longitudinally adult Anopheles mosquitoes were collected from December 2024 to November 2025 in four villages, in Debre Tabor town.

2.3 Sampling and Sampling Techniques

Currently, Debre Tabor town has 13 kebeles (9 in town and 4 in rural). Of these, four (4) kebeles were selected via random sampling techniques. The kebeles were 01, 02, 09, and Hiruye-Abargaye and in each kebele, one village was nominated through lottery method, namely Hiruye, Kebro-Meda, Ajebar-Urael, and Industry-Tabor (Fig. 1).

Totally, 36 houses were selected (9-houses for each village). Among 9 houses, 3-houses near to the breeding habitats, 3 at the center of the village, and 3 at the peripheral of the village were concentrated. These kinds of arrangement helped to understand how far mosquitoes can flying to feed and to hide.

2.4 Data collection

Indoor host seeking mosquitoes: Adult Anopheles mosquitoes were collected once in a month, from 06:00 PM (sunset) to 06:00 AM (sunrise) in 36 selected houses using Center for Disease Control and Prevention (CDC) light trap (Model 512; J. W. Hock Co., Atlanta, USA), nine per village. The CDC light traps were hung on approximately 1.5 m above the floor [**33**]. In all the selected houses, occupants were provided with new untreated nets prior to the start of the entomological survey. After collection, the collection bags were be retrieved from traps in the morning from 06:00 to 06:30 AM and mosquitoes were killed using cotton wool treated with chloroform.

Outdoor host seeking mosquitoes was collected by CDC-light traps from 06:00Am to 06:00PM hrs in each village. Traps were set 9–10 meters (depending on the size of compound) away each sentinel house used for indoor mosquito collection. The number of human occupants and other potential vertebrate hosts in each surveyed house the previous night were recorded.

Mosquito identification

Morphologically Anopheles mosquitoes were identified using standardized identification keys [**34,35**].

2.5 Data Analysis

Data was entered in to Microsoft Excel (Microsoft Corporation, 2016) and analyzed using IBM SPSS version-21 soft-ware packages (SPSS Inc, Chicago, IL). Before any analysis, non-normalized data were transformed [log10 (x + 1)]. Mean variations between Anopheles and Culex and between the indoor and outdoor host seeking mosquitoes were tested using independent samples T-test ($p < 0.05$). Variation in mean densities between species and species among villages were analyzed using one-way analysis of variance (ANOVA) ($p < 0.05$). Significant means (ANOVA) were separated using Tukey test (HSD). Moreover, descriptive statistics (percentages and mean values, tables, graphs, and figures) were used to express results. All statistical analyses were performed at the 5% significance level.

3. Results

3.1 Species composition and abundance of adult Anopheles mosquitoes in Debre Tabor town

A total of 8580 female mosquitoes were collected in Debre Tabor district using CDC-light traps. Of these, 80.5% (n = 6909) belonged to the genus Culex, while the rest, 15% (n = 1671) were from the genus Anopheles. Result showed that there was significance difference in the mean score between Culex (mean ± SD = 575.7500 ± 275.14463) than for Anopheles (139.2500 ± 108.01189), t (11) = -6.32, P = 0001.

Morphologically, six species of the genus Anopheles were identified in the four villages, belonged to *An. gambiae s.l* (50.7%), *An. cinereus* (29.8%), *An. demeilloni* (16.2%), *An. coustani* (0.5%), *An. squamosus* (0.5%), and *An. nili* (0.1%). One-way-ANOVA was not run for *An. coustani, An. squamosus*, and *An. nili* because rareness in frequency. The Tukey HSD post-hoc test showed a statistically significant difference in transformed species (*An. gambiae* s.l, *cinereus* and *demeilloni*) between *An*. *demeilloni* and *An. gambiae* s.l ($p < 0.05$). However, no statistically significant differences were observed between *An. demeilloni* and *An. cinereus* or between *An. cinereus* and *An. gambiae* s.l ($p > 0.05$). The mean transformed species of Anopheles mosquitoes as highest for *An. gambiae* (1.6474), followed by *An. cinereus* (1.5521) and *An. demeilloni* (1.2383) (F2, 33 = 0.550, p = 0.032) (Table 1).

Table 1
Transformed mean Anopheles mosquito density by species and village in Debre Tabor Town, Ethiopia

Species	**N**	**%**	**Mean ± SD**	**P - value**
An. gambiae s.l	884	52.9	1.6474 ± 0.49510^{a}	0.032
An. cinereus	498	29.8	1.5521 ± 0.26959^{ba}	
An. demeilloni	270	16.2	1.2383 ± 0.33654^{bc}	
An. coustani	9	0.5		
An. squamosus	8	0.5		
An. nili	2	0.1		
Total	1671			
Sites				
Hiruye-Abargaye	541	32.4	1.5614 ± 0.32037	0.107
Kebro-Meda	518	31	1.5024 ± 0.42513	
Ajebar-Urael	306	18.1	1.1891 ± 0.50300	
Industry-Tabor	306	18.1	1.2349 ± 0 .49428	
Total	1671			

N.B: Means with the same letter (s) in the same column are not significantly

different from each other at P < 0.05.

3.2 Spatiotemporal dynamics of adult Anopheles mosquitoes

3.2.1 Spatial distribution of adult Anopheles mosquitoes

In total, 1,671 Anopheles mosquitoes were collected from the four villages. Of these, 32.4% (n = 541) were collected from Hiruye-Abargaye, 31.0% (n = 518) from Kebro-Meda, 18.3% (n = 306) from Industry-Tabor, and 18.3% (n = 306) from Ajebar-Urael. However, there was no statistically significant difference between the sites (one-way ANOVA, F = 2.154, p = 0.107) (Table 2).

Table 2
Mean (Mean ± SD) transformed seasonal dynamic of Anopheles

Variables	Frequency	%	Mean ± SD	P-value
Dry season	209	12.5	1.0712 ± 0.80174	0.990
Pre rainy season	182	10.9	1.0976 ± 0.76666	
Rainy season	544	32.6	1.2443 ± 1.12177	
Post rainy season	736	44	1.1875 ± 1.22099	
Total	1671			

mosquitoes in Debre Tabor Town, Dec 2024 - Nov 2025

3.2.2 Temporal distribution of adult Anopheles mosquitoes

Figure 2 shows seasonality of Anopheles species from December 2024- November 2025. Female Anopheles mosquitoes were collected during all seasons and in every month of the study period. However, a large proportion of *Anopheles* mosquitoes was recorded during the post-rainy season (n = 736, 44%), followed by the rainy season (n = 544, 32.6%), dry season (n = 209, 12.5%), and pre-rainy season (n = 182, 10.9%), although the seasonal difference was not statistically significant [F(3, 20) = 0.039, p > 0.05]. Overall, the highest number of mosquitoes was recorded in September, whereas the lowest number was observed in December. The abundance of individual species also varied across months. A large proportion of *An. gambiae* s.l was recorded in September, during the post-rainy season, whereas the lowest number was observed in December. *An. cinereus* was most abundant in September, while relatively few individuals were recorded in November and December. The monthly abundance of *An. demeilloni* showed considerable variation, with the highest number recorded in August, followed by September, whereas relatively few individuals were recorded in December. Medically important species, including *An. coustani* s.l. and *An. nili*, were rarely encountered. *An. coustani* s.l was recorded in December, January, March, and August, whereas *An. nili* was recorded only in January and October (Table 2).

Figure 2. **Monthly Anopheles counts in Debre Tabor Town, between Dec 2024 – Nov 2025**

3.3 Mean densities comparison of Anopheles mosquitoes using CDC-Traps

A total of 1671 female Anopheles mosquitoes were collected by CDC-light traps. The average proportion of indoor Anopheles mosquitoes (58.4%) was higher than outdoor proportion (41.6%). However, a paired-samples t-test was revealed that there was no a statistically significant difference between the mean transformed counts of the two trap-counts (t = 0.883, df = 11, p = 0.396). Similarly, a paired-samples t-test was run for three species. Except *An. cinereus* [t (11) = 2.288, p = 0.043], the mean indoor density of *An. gambiae* s.l and *An. demeilloni* was equal to mean outdoor density of *An. gambiae* s.l and *An. demeilloni* (p > 0.05) (Fig. 3).

Figure 3. **CDC-Light Trap distribution of Anopheles mosquitoes, from Dec 2024 - Nov 2025**

4. Dissuasion

4.1 Species composition and dynamic of adult mosquitoes

Th aim of this study was to generate base line data about the diversity, abundance, and distribution of Anopheles mosquitoes in the Debre Tabor Town. Morphologically, six species of the genus Anopheles were identified in the Debre Tabor town, belonged to *Anopheles gambiae* s.l (50.7%), *An. cinereus* (29.8%), *An. demeilloni* (16.2%), *An. coustani* (0.5%), *An. squamosus* (0.5%), and *An. nili* (0.1%). Consistent to this finding, Lemma et al. [**36**] and Esayas et al. [**37**] reported *An. gambiae* s.l, *An. cinereus, An. demeilloni* and *An. coustani* in higher altitude city (up to 2,900 m.a.s.l) of Gondar (sub-city Kaha, Azezo, Bamba Sefer). Though altitudinal difference is apparent, the presence of *An. arabiensis, An. coustani, An. squamosus, An. cinereus, An. demeilloni* were reported in Bure district (2,350 m.a.s.l.) [**38**], Akaki Kality Sub-City of Addis Ababa (2125 m.a.s.l) [**39**], and Addis Zemen (above 2,000 m.a.s.l) **[40]**, Ethiopia. The occurrence of such species in various altitude could be linked with the presence of suitable breeding habitats (e.g., stream pools, temporary pools, and other sunlit water bodies) and broad ecological tolerance.

In this study area, out of 1,671 Anopheles species, the most abundant species was *An. gambiae* s.l (15.7%), followed by *An. cinerea*, and *An. demilioni* (p = 0.032). Similarly, higher prevalence of *An. gambiae* s.l was among the other identified species in the Gamo-Gofa, Wolaita, South Omo, and Hadiya zones, Southern Nation Nationalities and Peoples Regional States, Ethiopia [**41**]and Hadiya Zone [**42**]. The dominance of *An. gambiae* s.l. across the various study sites suggests that the ecological requirements of this species were relatively similar across the sites. For example, in Hadiya Zone, the major larval habitat types identified included ditches, riverbeds, water pans, and swamps [**43**]. Similarly, comparable breeding habitats were identified in Debre Tabor Town, including stream pools, rain pools, hoof prints, drainage channels, marshes, human-made containers, and sunlit water bodies (Appendix I).

Moreover, the existence of *An. gambiae* s.l (2,772 m.a.s.l.) at a higher altitude, which has not been reported so far, could be favored by the presence of suitable microclimatic conditions, breeding habitats, climatic warming due to climate change, ecological adaptation of some *Anopheles* species, and land-use changes, which may allow malaria vectors to occur at elevations above 2,500 m.a.s.l [**43,44**].

Contrary to this finding, Kindu et al. [**40**] reported a large proportion of *An. cinereus* than *An.gambiae* (s.l.) in Addis Zemen town, Ethiopia. Similarly, Negesse et al. [**39**] reported *An. christyi* (64.7%) as predominant species followed by *An. gambiae* s.l. (15.7%), *An. cinereus* (10.6%; 112/1054), *An. demeilloni* (2.8%; 30/1054) in Akaki Kality Sub-City of Addis Ababa, Ethiopia. In Shebe Sambo district, Jimma Zone, Southwest Ethiopia, indicated the predominant *An. coustani* (84.4%) followed by *An. gambiae* s.l (11.3%) [**45**]. Such differences may reflect variation in the availability and characteristics of larval habitats, climatic and seasonal conditions, geographical setting, and sampling approaches. Therefore, the predominance of a particular *Anopheles* species is likely to be determined by the ecological suitability of the study area and the species-specific adaptation to available habitats. In general, the variation in *Anopheles* species composition and relative abundance among studies may be attributed to differences in local ecological and environmental conditions, breeding-habitat availability, seasonality, altitude, and mosquito collection methods.

In Ethiopia, *An. gambiae* s.l (presumably *An. arabiensis*) is the leading malaria vector across the country [**17**]. Its presence across all sampling sites in Debre Tabor Town suggests its potential role in local malaria transmission, which is supported by reports from health centers and other sources indicating malaria occurrence in the town (unpublished data, personal communication) [**18**]. Although malaria transmission in Ethiopia has traditionally been concentrated at elevations below 2,000 m above sea level, recent studies have documented malaria transmission at higher elevations, including approximately 2,772 m in Northwest Ethiopia [**6**]. Furthermore, *P. falciparum* and *P. vivax* infections have been detected at elevations of up to 2,900 m.a.s.l [**8**]. These findings highlight the potential for malaria transmission in high-altitude towns such as Debre Tabor.

In contrast to the present findings, *An. cinereus* (n = 325; 90%) was the most dominant species among the six identified species in Gondar City [**36**]. Furthermore, this species tested positive for *Plasmodium* parasites in Gondar[**36**] and has also been reported as a potential malaria vector in Eritrea [**46**]. These findings suggest that *An. cinereus* may have a role in malaria transmission in highland areas, and this species requires a close attention and further examination to determine its role in malaria transition.

In the present study, *An. cinereus* was the second most dominant species in this high-altitude area. In line with this finding, *An. cinereus* and *An. demeilloni* were the second and third most abundant species, respectively, in Addis Zemen Town [**40**]. The occurrence of *An. cinereus* has also been reported in other parts of Ethiopia, including Akaki Kality Sub-City, Addis Ababa [**39**], and Bure district [**38**]. In contrast, *An. cinereus* (n = 325; 90%) was the most dominant species among the six identified species in Gondar city [**36**]. Furthermore, this species tested positive for *Plasmodium* parasites in Gondar town [**36]** and has also been reported as a potential malaria vector in Eritrea [**46**]. These findings suggest that *An. cinereus*

may have a role in malaria transmission in highland areas, highlighting the need for further investigation to establish its potential role in malaria transmission.

The present study also detected *An. demeilloni* (n = 270, 16.2%). Corroborate to this study, Gone et al. [**47**], Daygena et al. [**48**], and Esayas et al. [**37**] reported *An. demeilloni* in the highland locality of Gidole town (2650 m.a.s.l), Dirashe district (Layignaw-Arguba villages, 2614 m.a.s.l), and the Gondar zuria (e.g., Chinchaye and Debre Selam villages), Ethiopia, respectively. However, the proportion of *An. demeilloni* in this study was lower as compared with other studies report, such as Gondar zuria (n = 1133; 24.1%) [**37**] and the high land part of Boreda district in Gamo zone (n = 420, 61.7%) [**49**], Ethiopia. In the highland part of Boreda district in Gamo zone, southwestern Ethiopia, the proportion of *An. demeilloni* was the first dominant species than others 13-species [**49**]. Naturally *An. demeilloni* appears to be more commonly associated with cooler highland environments than warmer lowland areas. It has been documented in various Ethiopian highland localities [**34,37,38,50**] other parts of Africa [**51**].

Moreover, *An. coustani* s.l. and *An. nili* were the other recorded species at higher altitudes, although their proportions were very low. The presence of *An. coustani* s.l has been reported in various highland parts of Ethiopia, including Bure district, Jabi Tehnan district, Addis Ababa (Akaki Town and its environs), and Hadiya zone [**38, 42, 52, 53**], respectively. In one study, it was even reported as the dominant species (n = 3,088, 84.4%) compared with other identified species (*An. gambiae* s.l, n = 415, 11.3%; *An. pharoensis*, n = 128, 3.5%; and *An. squamosus*, n = 28, 0.8%) in Kishe kebele (the lowest administrative level), located in Shebe Sambo District, Jimma Zone, Southwest Ethiopia [**45**]. In general, although much attention has not been given to this species by the Ethiopian Ministry of Health, it has been found to be infected with *Plasmodium* species and to act as a secondary malaria vector in many countries in Africa. For instance, this has been reported in Jimma Zone [**54,55,56**], Jabi Tehnan district [**40**], the Arjo-Didessa sugarcane plantation irrigation scheme [**57**], Dembiya district [**58]**, Asendabo town (Omo Nada district of Jimma Zone), Lare town (Lare district of Nuer Zone) [**59**], and Bure district [**60**], Ethiopia. Elsewhere in Africa, *An. coustani* s.l has been reported to play a major role in malaria transmission, particularly in Kenya (Taveta district, Lake Victoria, and Ahero and Iguhu districts) [**61,62**] and Cameroon [**63]**. Therefore, the Ethiopian government should give attention as like primary and secondary malaria vectors of the country, and LLITs and IRSs against Anopheles mosquitoes must include this species too.

Besides the primary vector, this study also recorded the secondary malaria vector *An. nili*. This species has previously been documented in the lowlands of Ethiopia, particularly in the Gambela region [**64,65,66**] and in the highland areas of Ethiopia, such as Jabi Tehnan district in the Amhara Region [**52]** and Akaki Kality Sub-City of Addis Ababa [**39**]. In both elevations, *An. nili* was found to be infected by *Plasmodium* [**52,64,65]**. The Ethiopian Ministry of Health has already classified this species as a secondary malaria vector [**67**], and existing vector-control interventions also consider this species. Although a sporozoite ELISA was not performed, the presence of *An. nili* in the present study highlights the need for increased attention and surveillance, similar to that given to other major malaria vectors.

4.2 Spatial distribution of adult Anopheles mosquitoes

In total, using CDC light traps, 1,671 Anopheles mosquitoes were collected at the higher altitude of Debre Tabor town throughout the year (2,722 m a.s.l.). This number was higher than those reported in studies conducted in the highlands of Dirashe district (n = 1,268) [**48**], four zones (Gamo-Gofa, Wolaita, South Omo, and Hadiya) of the Southern Nations, Nationalities, and Peoples' Region (SNNPR) (n = 1,445) [**41**], Shebe Sambo district, Jimma Zone (n = 1,336) [**45**], and Jabi Tehnan district, Amhara Region (n = 1,318) [**52**], Ethiopia. This variation is probably linked to the fact that malaria was relatively recently established in Debre Tabor Town, and the community may not yet use LLINs correctly and consistently. Furthermore, IRSs had not been implemented in the town at the time of the study. These conditions were confirmed during the sampling period and may have contributed to the relatively high proportion of mosquitoes recorded in the current study.

On the other hand, in the current study, 1,671 female Anopheles mosquitoes were collected over 576 trapping nights using CDC light traps, yielding an average of 2.90 mosquitoes per trapping night compared with a study conducted in the highland areas of Gondar Zuria, Ethiopia (n = 4,697) [**37**]. Esayas et al. [**37**] collected their specimens over 368 trapping nights, their average catch was approximately 12.76 mosquitoes per trapping night. This difference may be associated with differences in numbers of trapping night, sampling locations, and timing. Besides, variations in ecological conditions, breeding-site availability, climatic and seasonal factors, species composition, and vector-control activities may also have influenced the observed mosquito abundance.

Of the total female Anopheles mosquitoes collected, 32.4% (n = 1,671) were collected from Hiruye-Abargaye, 31.0% from Kebro-Meda, 18.3% from Industry-Tabor, and 18.3% from Ajebar-Urael. However, the differences in mosquito abundance among the four sites were not statistically significant (p = 0.107). This finding may partly reflect similarities in the ecological conditions of the study sites. During the sampling period, similar potential mosquito breeding habitats, including marshes, annually flowing streams, and man-made ponds, were observed across each site. Previous studies in Ethiopia have demonstrated that Anopheles larval occurrence and abundance are influenced by habitat type, water temperature, vegetation cover, water flow, habitat permanence, and the presence of aquatic predators and competitors [**68,69,70]**. Similarly, research in the Ghibe river basin demonstrated that larval density varied across habitat types and was associated with environmental characteristics, including temperature, vegetation, and sunlight exposure [**71**].

4.3 Temporal (Seasonal) trends of Anopheles mosquitoes

Anopheles mosquitoes were collected during all seasons and in every month of the study period. A large proportion of an overall *Anopheles* mosquitoes was recorded during the post-rainy season (44.0%), followed by the rainy season (32.6%) than dry season (12.5%), and pre-rainy season (10.9%), although the seasonal difference was not statistically significant (p > 0.05). Similar to this study, Adugna et al. [**72**] observed large density of Anopheles mosquitoes after and before the main rainy season along Lake Tana, northwest Ethiopia. The present study is also comparable with the previous reports made in Ethiopia [**37, 45, 68,73**]. In Arjio Dedessa sugar cane irrigation scheme, it was possible to seen large numbers of Anopheles mosquitoes in the post rain season (September to November) and minimum

number in dry season (December and January) [**57**]. Relatively, the high abundance of *Anopheles* mosquitoes during the post-rainy season in the present study may reflect the persistence of suitable breeding habitats following the rainy period. The study sites contain several perennial streams and marshes that may maintain relatively stable breeding habitats throughout the year.

4.4 Mean densities comparison of Anopheles mosquitoes using CDC-Traps

The mean indoor density of Anopheles mosquitoes (n = 584; 2.03 mosquitoes /trap-night) was higher than outdoor catches (n = 416; 1.44 mosquitoes/trap-night) though statistically insignificant (p = 0.396). This is in line with the report made in Bure district [**38**], different parts of Ethiopia (Medebay Zana, Mirab Abaya, and Wondo Genet) [**74**], and Western Kenya [**75**], where there was no difference between indoor and outdoor catches. The comparable distribution observed in the present study may partly be associated with species-specific host-seeking behaviour, overlapping biting activities in indoor and outdoor environments, and the availability of human and domestic animal hosts around residential areas. Contrary to this study, outdoor catches were greater than indoor catches in Jabi Tehnan district [**52**], Arjo-Didessa Sugar Cane Plantation [**76**], Shebe Sambo district [**45**], and Kersa district [**77**], Ethiopia. On the other hand, in the highland area of Kenya, all identified vectors were collected indoor only [**78**]. A study made in Zambia indicated substantial indoor catches than outdoor catches [**79**]. These differences may partly be attributed to human activities, lifestyles, LLIN use [**37,77**], animal hosts, and variations in mosquito feeding preferences [**80,81**]. While some Anopheles species preferentially feed on humans, others prefer animals or feed on both [**82**]. Furthermore, house construction and indoor environmental conditions may influence mosquito distribution between indoor and outdoor environments [**83**].

5. Conclusions

This study morphologically identified seven *Anopheles* species in Debre Tabor Town, a high-altitude area of northwestern Ethiopia, using CDC light traps. To the best of our knowledge, this represents the first entomological investigation of malaria vectors in the town. The identified species included *An. gambiae* s.l, an important malaria-vector group, and other potential malaria vectors, including *An. coustani*, *An. cinereus*, *An. nili*, and *An. demeilloni*. Although the occurrence of *Anopheles* species varied across months and seasons, *An. gambiae* s.l, *An. cinereus*, and *An. demeilloni* were detected throughout the study period. The highest proportion of *Anopheles* mosquitoes was collected during the post-rainy season. The detection of these mosquito species in a high-altitude setting highlights the potential for malaria transmission in areas traditionally considered to be at lower risk. This finding has important implications for Ethiopia's malaria elimination goal by 2030, as the expansion of malaria vectors into remote highland areas may create additional challenges for achieving this target. Furthermore, climate change, particularly rising temperatures, may contribute to the expansion of malaria transmission into previously less suitable highland environments by improving conditions for mosquito survival, development, and parasite development. Consequently, highland communities, which may have limited acquired immunity to malaria, could become increasingly vulnerable to malaria-related morbidity.

Totally, even though the present study did not directly assess the effects of climate change, sporozoite ELISA, and blood-meal identification assays, its findings provide important baseline entomological evidence to support strengthened vector surveillance and targeted malaria prevention and control strategies in high-altitude areas. Therefore, incorporating these areas into national malaria elimination efforts is essential to address the potential challenges posed by changing climatic conditions and the geographical expansion of malaria vectors. Furthermore, future studies incorporating sporozoite detection, blood-meal identification, and molecular characterization of morphologically identified Anopheles species are recommended to confirm their role in malaria transmission, determine their host-feeding patterns, and accurately identify species within morphologically sibling species. Such investigations would provide a more comprehensive understanding of their epidemiological significance and inform the development of evidence-based, locally tailored malaria surveillance, prevention, and vector-control strategies.

List of abbreviations

m.a.s.l meter above sea level

LLINs long-lasting insecticidal nets

IRSs indoor residual sprayings

ACT artemisinin-based combination therapy

RDTs rapid diagnostic tests

CDC Center for Disease Control and Prevention

ANOVA one-way analysis of variance

HSD honest significant difference

SNNPR Southern Nations, Nationalities, and Peoples' Region

Declarations

Ethics approval and consent to participate

Competing interests

The author declares that there are no competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

This study was conducted after obtaining ethical clearance from the Ethical Committee Board of the Department of Biology, Debre Tabor University. Permission was subsequently obtained from the Debre Tabor health offices and Kebele administrative offices. Finally, informed verbal consent was obtained from all selected study households after the purpose of the study had been explained to them in their local language (Amharic).

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Author Contribution

TA conceived and designed the study, collected and analysed the data. Finally, TA wrote, reviewed, and approved the final manuscript.

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Availability of data and materials

All data necessary to support the findings and conclusions of this manuscript are included in the article. Additional information can be made available upon reasonable request.

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Figures

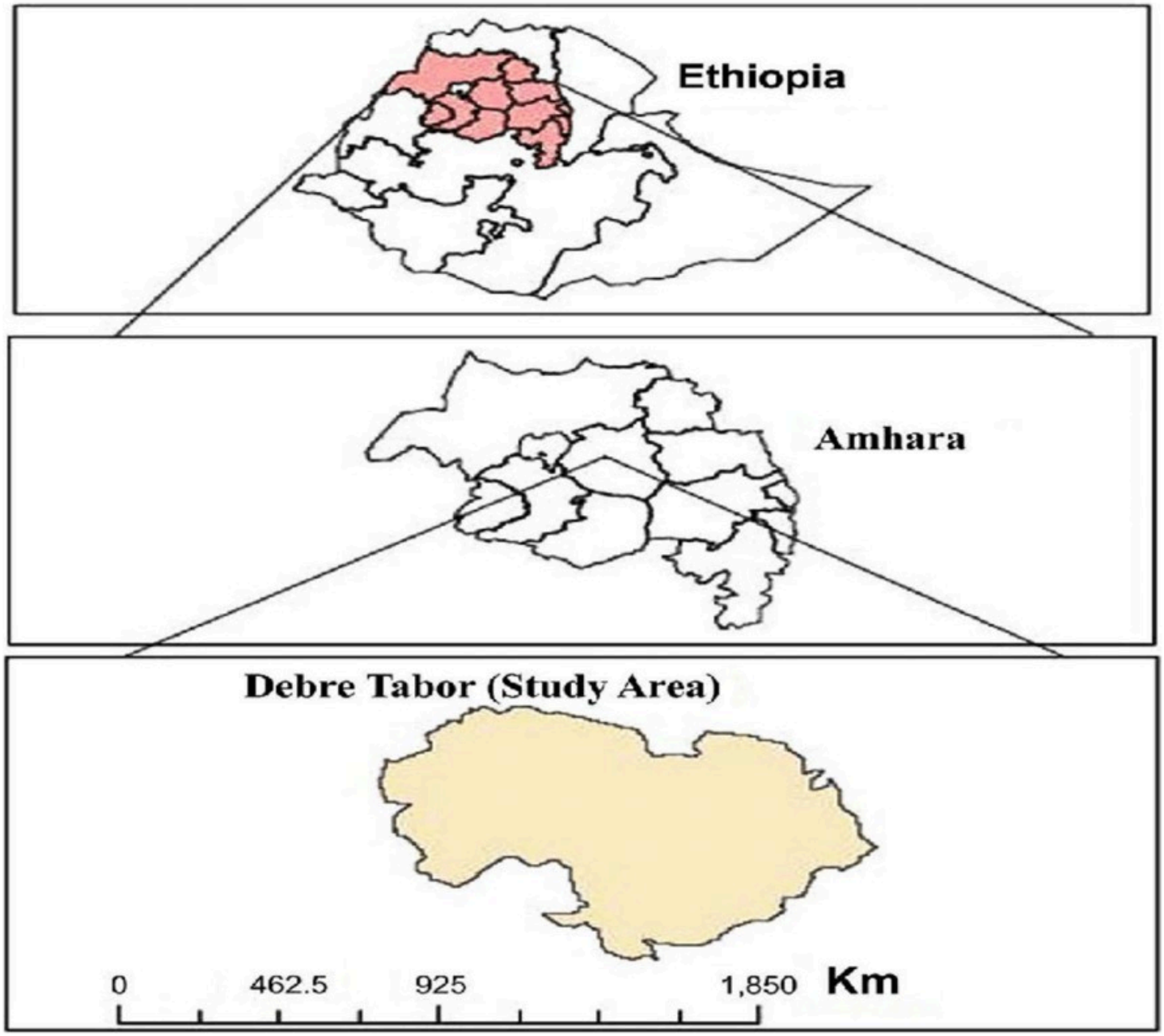


Figure 1

Map of study area, Debre Tabor Town

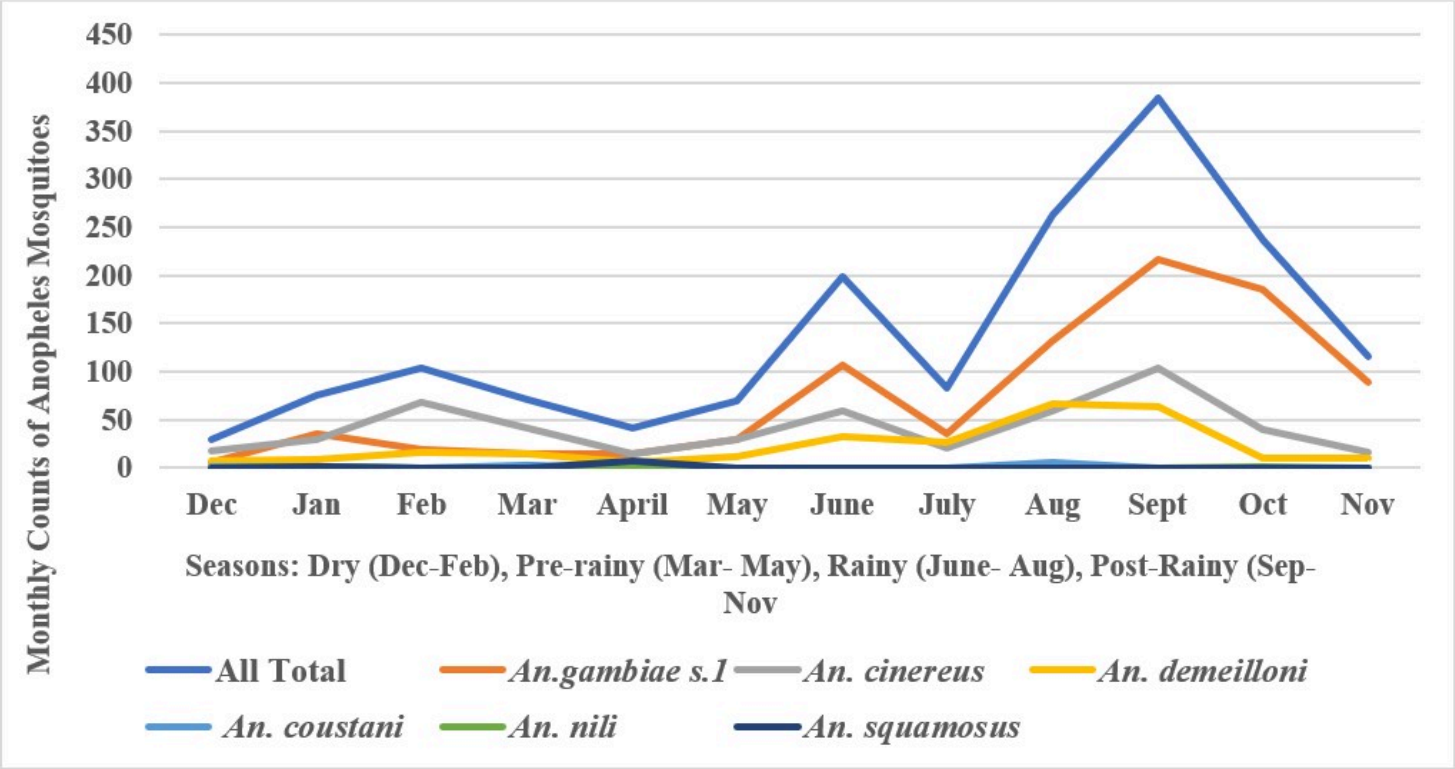
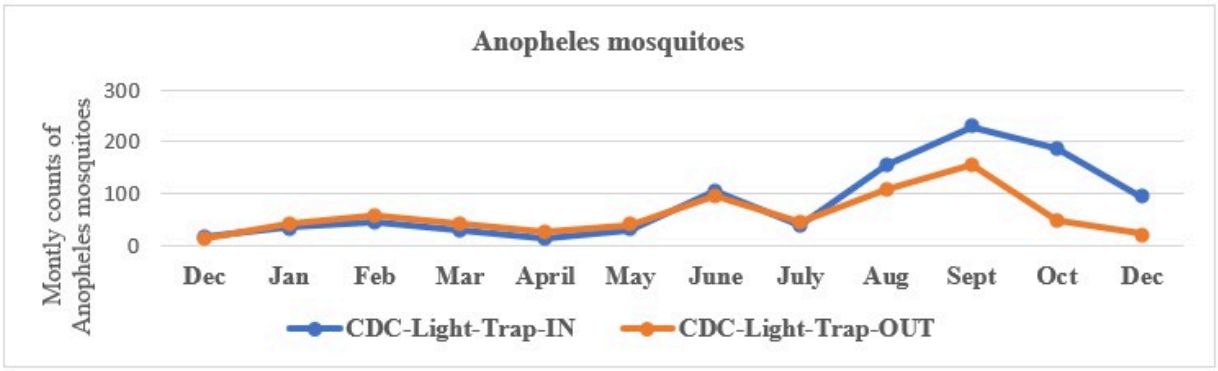
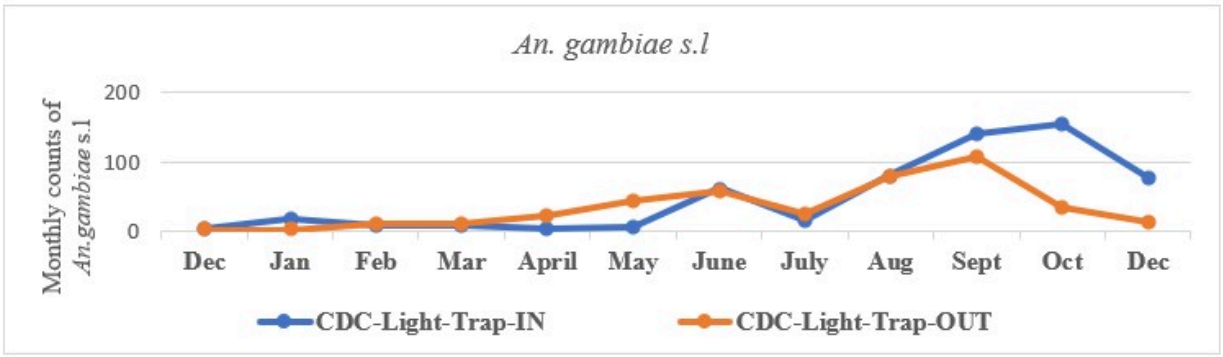
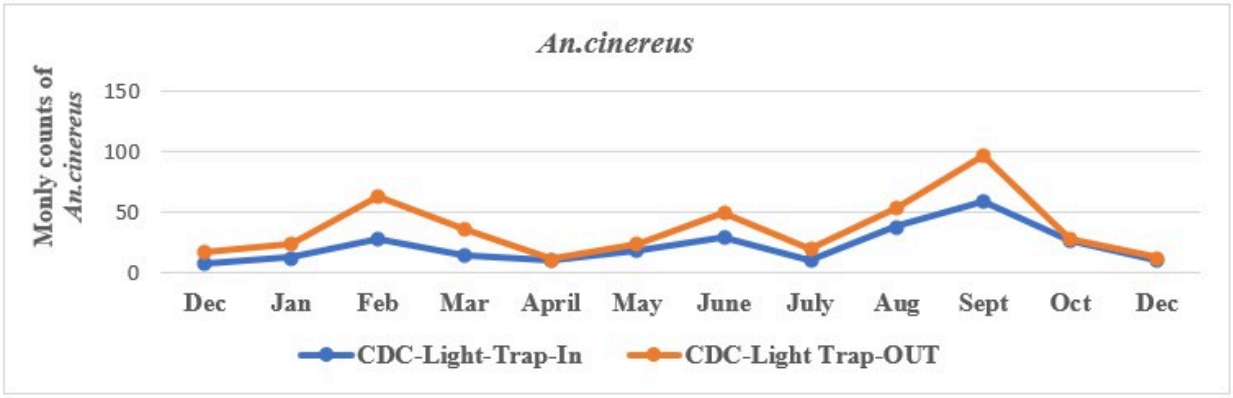


Figure 2

Monthly Anopheles counts in Debre Tabor Town, between Dec 2024 – Nov 2025







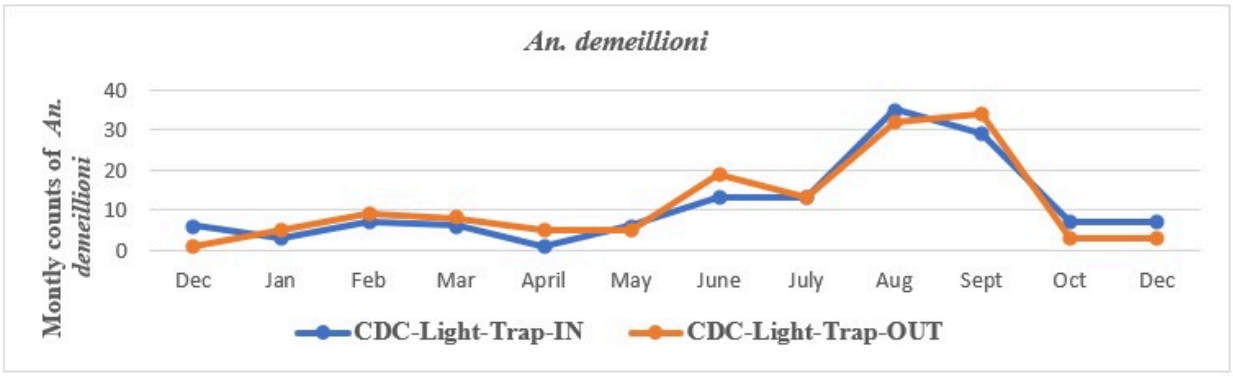


Figure 3

CDC-Light Trap distribution of Anopheles mosquitoes, from Dec 2024 - Nov 2025

Supplementary Files

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- AppendixIforMJ.docx