Habitat characteristics and spatial distribution of *Anopheles* mosquito larvae in malaria elimination settings in Dembiya District, Northwestern Ethiopia

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Abstract
The persistence and productivity of larval habitat is a major factor that regulates adult *Anopheles* mosquitoes’ density and malaria transmission intensity. A study on *Anopheles* mosquitoes breeding habitat diversity, distribution, characteristics and larval density in different seasons across various habitat types is important to design effective larval control strategies. This study was aimed to investigate the *Anopheles* species composition, the productivity of larval breeding habitats, and their spatial distribution in selected localities of Dembiya District. A longitudinal study on characteristics and productivity of *Anopheles* larval breeding habitats was conducted from June 2018 to May 2019 in selected localities of Dembiya District. *Anopheles* larvae were collected using standard WHO dipper (350 ml capacity) and droppers depending on the size of the breeding habitats. Physicochemical characteristics of breeding habitats were measured and *Anopheles* mosquitoes were identified by using morphological keys and polymerase chain reaction (PCR). Logistic regression was used to assess the association of environmental factors with the presence or absence of *Anopheles* mosquitoes larvae. A total of 1,629 *Anopheles* larvae and 185 pupae were collected from both localities. These comprise *Anopheles arabiensis*, *An. pharoensis*, *An. coustani*, *An. christyi*, *An. squamosus*, *An. demeilloni*, *An. danicalicus*, and *An. cinereus*. The highest density of *Anopheles* larvae was collected from at a drying water canal (14.7 ± 3.5 larvae/dip) and the lowest larval density was recorded in rain water pools (0.2 ± 0.2 larvae/dip). The presence or absence of *Anopheles* larvae were significantly associated with physical characteristics of the breeding habitats such as turbidity (mid turbid) (AOR = 66.03; 95% CI: 2.01-2168.24, \( p = 0.019 \)) and presence of grasses (AOR = 12.62; 95% CI: 1.29-122.78, \( p = 0.029 \)). This study indicated that breeding sites persist and support *Anopheles* mosquito breeding activities and impact malaria control and elimination programs. Incorporating vector control strategies targeting *Anopheles* larvae as a part of malaria intervention strategies could enhance the malaria control and elimination program in the study area.

Keywords *Anopheles* larvae · Breeding habitat · *Anopheles arabiensis* · *Anopheles pharoensis* · Drainage canal · Dembiya

Introduction
Mosquitoes are responsible for the transmission of different types of diseases such as malaria, yellow fever, dengue, and West Nile fever (Alonso et al. 2011; Braack et al. 2018). Malaria is a life-threatening infectious disease caused by protozoan parasites of the genus *Plasmodium* that are transmitted through the bites of infected female *Anopheles* mosquitoes. Globally, an estimate of 241 million malaria cases and 627,000 deaths were reported in 2020, of which 95% of malaria cases and highest proportion of deaths were reported from a WHO Africa region (WHO, 2021). In this
region 80% of all malaria deaths are recorded in children’s under the age of 5. From the total malaria case across the globe 55% is recorded in sub-Saharan Africa (WHO, 2021). In Ethiopia, more than 60% of the population is at risk of malaria infection and 68% of the country’s landmass is malarious (FMoH 2014). The diverse ecology and favorable environmental conditions of the country supported the rapid development of Anopheles mosquitoes and Plasmodium parasites (Taffese et al. 2018).

There are more than 400 different species of Anopheles mosquitoes worldwide, of which around 30 are known malaria vectors (WHO, 2018). In Ethiopia, An. arabiensis is the primary malaria vector, whereas An. funestus, An. pharoensis and An. nili are secondary vectors (Gillies and Coetzee 1987). The most important stage of the Anopheles mosquito life cycle such as egg-laying, larval and pupal development, and adult emergence takes place in the aquatic environment (Oyewole et al. 2009). Different species of Anopheles mosquitoes have their own preferred aquatic habitats. For instance, An. arabiensis prefers to breed in temporary, small, sunlit, clear, and shallow freshwater pools (Gimnig et al. 2001; Edillo et al. 2006; Himeidan and Rayah 2008).

The abundance and distribution of potential breeding habitats of Anopheles mosquitoes determine the density of adult Anopheles mosquitoes and transmission of malaria parasites (Carter et al. 2000; Rejmánková et al. 2013). Several environmental characteristics like climate, physical, chemical, and biological conditions of the breeding habitats have effects on the development and survival of the Anopheles mosquito larvae (Mereta et al. 2013; Roux and Robert 2019). Anthropogenic factors like agricultural expansion, construction of dams and urbanization affects the diversity and distribution of Anopheles mosquito breeding habitat and larval development (De Silva and Marshall 2012). Climate change associated with these anthropogenic effects favors rapid development of Anopheles mosquitoes and Plasmodium parasite in areas with antecedently low malaria transmission (Alonso et al. 2011).

In Ethiopia, malaria control program mainly depends on the management of clinical malaria cases or control efforts targeting adult mosquitoes by selective indoor residual spray (IRS) and insecticide-impregnated bed nets (LLINs) (FMoH 2014). However, these strategies are challenged by the development of drug resistant Plasmodium parasites and insecticide resistant vector species (Messenger et al. 2017; Taffese et al. 2018; Loha et al. 2019). Considering this, interests are rising to use larval source management as a part of integrated vector management in the country (Gari and Lindtjørn 2018; Asale et al. 2019). Nevertheless, our knowledge about mosquitoes breeding habitat diversity, distribution and characteristics is limited and insufficient to design effective malaria intervention strategies by larval control (Rejmánková et al. 2013).

Therefore, the aim of this study was to assess species composition, distribution, and ecology of Anopheles mosquito larvae and pupae in malaria endemic localities of Dembiya District, Northwestern Ethiopia. The result of this study will provide important information to design effective vector control strategies by larval source management.

**Methods**

**Description of the study area**

A longitudinal study on species composition, breeding habitat characteristics, and spatial distribution of Anopheles mosquito larvae and pupae was conducted from June 2018 to May 2019 in two localities (Guramba Bata and Arebiya) of Dembiya district in north Gondar Administrative Zone of Amhara Regional State, Northwestern Ethiopia (Fig. 1). The district is located at 12°39’59.99” N and 37°09’60.00” E. Kola Diba is the administrative center of the district, located 750 km north of Addis Ababa and 35 km southwest of Gondar. The district is bordered by Lake Tana in the south. Dembiya district has 45 localities with an estimated population of approximately 271,000. The majority of the population (91%) lives in rural areas, with most engaged in farming activities; the remaining 9% live in urban areas. The district has 49,528 rural households with 4.3 mean household sizes (CSA, 2007).

The elevation of Dembiya District ranges from 1500 m to 2600 m a.s.l. The agro-ecology of the District is mid-altitude (Woynadega) with a mean annual minimum temperature of 11 °C and a maximum of 32 °C, respectively. The mean annual rainfall ranges from 995 mm to 1175 mm. Land use data from the district agricultural bureau indicated that most

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**Fig. 1** Map of the study area (Tarekegn et al. 2021)
Species identification

Anopheles mosquito larvae and pupae were separated from Culicines using a hand lens (10X) based on gross morphological characteristics (Verrone 1962; Gillies and Coetzee, 1987). The 3rd and 4th instar Anopheles larvae, and Anophelines pupae collected from each type of breeding habitat, were transferred to separately labeled mosquito breeders (BioQuip, Dimensions: 7–3/4″ (195 mm) high x 3–5/8″ (92 mm) diameter) and reared in the field laboratory based on WHO guidelines (WHO, 1975). The adult Anopheles that emerged from field collected larvae and pupae were used for species identification based on morphological characteristics (Verrone 1962; Gillies and Coetzee 1987). Morphologically identified adult An. gambiae sensu lato was individually preserved in Eppendorf tubes with silica gel and cotton for further molecular identification.

Species identification using rDNA–polymerase chain reaction (PCR)

Preserved adult An. gambiae s.l specimens from field collected and reared larvae and pupae were further identified.
to sibling species using a ribosomal DNA polymerase chain reaction (PCR) by including the primers for *An. gambiae s.s.*, *An. arabiensis*, *An. quadriannulatus* and *An. amharicus* (Scott et al. 1993).

**Physico-chemical characteristics of larval habitats**

Physical characteristics of the breeding habitats (positive or negative for *Anopheles* larvae or pupae), including habitat type, water depth, turbidity, vegetation, presence of algae, bottom substrate, habitat stability, lotic or lentic water, sunlight intensity, and distance from nearby houses were measured and recorded (Minakawa et al. 1999).

Chemical characteristics of the breeding habitats (positive or negative for *Anopheles* larvae or pupae) such as temperature, pH, and conductivity were measured at the field with HANNA© HI 98,130 Combo pH & EC tester (Hanna Instruments Inc., Kehl am Rhein, Germany) with the probes placed 2 to 3 cm below the water surface.

**Data analysis**

The density of *Anopheles* larvae and pupae was expressed as the total number of *Anopheles* larvae per total number of dips taken. After checking for normality, all dependent variables were $\log_{10}(x + 1)$ transformed, and subjected to statistical analysis. Since the data were found to be normally distributed after transformation, parametric tests such as one-way analysis of variance (ANOVA) and student t-test (for independent variables with two categories) were used to analyze differences in mean larval densities among breeding habitat types and other environmental variables. When significant differences were observed in one-way ANOVA, means were separated using Tukey’s HSD (Tukey’s Honestly Significant Difference) test at $\alpha = 0.05$. Multiple logistic regression analysis was used to detect the best predictor environmental variables associated with the presence or absence of *Anopheles* mosquito larvae (Sattler et al. 2005). The percentages of species composition of *Anopheles* mosquitoes collected from each breeding habitat was calculated (number of *Anopheles* mosquitoes species *×* 100/total number of species identified). Pearson correlation analysis was used to assess the relationship between larval densities and chemical characteristics such as pH, temperature, and conductivity. The data were analyzed using SPSS version 20 (Armonk, NY: IBM Corp), $p \leq 0.05$ were considered as significant.

**Results**

**Breeding habitat types and abundance of *Anopheles* larvae and pupae**

During the one-year study period, a total of 108 potential larval habitats (60.2% from Arebiya and 39.8% from Guramba Bata) were assessed for the presence of *Anopheles mosquitio* larvae. From the total sampled potential habitats only 41 were positive for *Anopheles* larvae and pupae (Table 1). Of these the predominantly encountered larval habitats were rain pools (17.6% (n = 19)), and river pool (17.6% (n = 19)). More than 80% of the larval breeding habitats were recorded during the long rainy season. Whereas during the dry season, the distribution of *Anopheles* larvae and pupae were restricted to water pools at riversides, pits dug for plastering a house, and temporary habitats around the hand pump water well.

The highest mean densities of *Anopheles* larvae were recorded from breeding sites in drainage canals (14.7 ± 3.5 larvae/dip), followed by abandoned burrow pits dug for plastering houses (8.8 ± 3.1 larvae/dip), swamps (3.8 ± 1.2 larvae/dip), and hoof prints (3.2 ± 1.2 larvae/dip). In addition,

| Table 1 | Distribution of *Anopheles* mosquito larvae and pupae in different breeding habitats in the two localities of Dembiya District, Northwestern Ethiopia |
|---------|------------------------------------------------------------------------------------------------------------------------------------------|
| Habitat type | No. of breeding sites surveyed (%) | No. of dips | No. of larvae collected | Mean (larvae/dip) ± se | No. of pupae collected | Mean (pupae/dip) ± se |
| Riversides | 19 (17.6) | 99 | 279 | 2.0 ± 0.9<sup>ab</sup> | 48 | 0.3 ± 0.1<sup>ab</sup> |
| Burrow pits | 14 (12.96) | 70 | 421 | 8.8 ± 3.1<sup>bc</sup> | 49 | 0.99 ± 0.4<sup>ab</sup> |
| Drainage canals | 12 (11) | 48 | 566 | 14.7 ± 3.5<sup>c</sup> | 59 | 1.6 ± 0.6<sup>b</sup> |
| Tire tracks | 8 (7.4) | 24 | 9 | 0.4 ± 0.4<sup>a</sup> | 3 | 0.1 ± 0.1<sup>a</sup> |
| Hoof prints | 7 (6.5) | 19 | 63 | 3.0 ± 1.2<sup>a</sup> | 5 | 0.0 ± 0.0<sup>a</sup> |
| Swamps | 14 (12.96) | 56 | 205 | 3.8 ± 1.2<sup>a</sup> | 9 | 0.2 ± 0.1<sup>c</sup> |
| Rain pools | 19 (17.6) | 69 | 30 | 0.2 ± 0.2<sup>a</sup> | 0 | 0.0 ± 0.0<sup>a</sup> |
| Puddles | 7 (6.5) | 33 | 56 | 2.7 ± 2.7<sup>a</sup> | 12 | 0.6 ± 0.6<sup>ab</sup> |
| Streams | 8 (7.4) | 30 | 0 | 0.0 ± 0.0<sup>a</sup> | 0 | 0.0 ± 0.0<sup>a</sup> |
| Total | 108 (100%) | 448 | 1629 | 0.0 ± 0.0<sup>a</sup> | 185 | 0.0 ± 0.0<sup>a</sup> |

The mean larval and pupal densities with different letter designations in a column are significantly different with Tukey’s HSD post hoc analysis at $\alpha = 0.05$
Anopheles larvae were also recorded from puddles (2.7 ± 2.7 larvae/dip), water pools at riversides (2.0 ± 0.9 larvae/dip), and tire tracks (0.4 ± 0.4 larvae/dip) (Table 1). The difference in mean densities of Anopheles mosquitoes larvae and pupae among habitats was statistically significant ($F_{(8, 99)} = 9.85, p = 0.000$) and ($F_{(8, 99)} = 3.46, p = 0.001$), respectively (Table 1).

**Species specific monthly distribution of Anopheles larvae and pupae**

The species-specific monthly distribution of the dominant Anopheles mosquitoes is indicated in Fig. 4a,b. The highest density of *An. arabiensis* in Arebiya was recorded during June (16.5%), September (9.1%), and May (21.6%) (Fig. 4a). Similarly, in Guramba Bata the highest density *Anopheles* larvae were also recorded from puddles (2.7 ± 2.7 larvae/dip), water pools at riversides (2.0 ± 0.9 larvae/dip), and tire tracks (0.4 ± 0.4 larvae/dip) (Table 1). The difference in mean densities of Anopheles mosquitoes larvae and pupae among habitats was statistically significant ($F_{(8, 99)} = 9.85, p = 0.000$) and ($F_{(8, 99)} = 3.46, p = 0.001$), respectively (Table 1).

**Species composition and monthly distribution of Anopheles larvae and pupae**

The species composition of *Anopheles* mosquitoes identified from the two study sites during the study period is presented in Table 2. A total of 1,629 *Anopheles* larvae and 185 pupae were collected from the two localities. From the total collected immature stages of *Anopheles* mosquitoes, 52.3% (852) larvae and 65.9 (122) pupae were from Arebiya and 47.7% (777) larvae and 34.1% (63) pupae were from Guramba Bata. The difference in mean *Anopheles* larval and pupal density between the two study sites were not statistically significant ($t_{(106)} = -0.454, p = 0.651$) and ($t_{(106)} = 0.70, p = 0.485$), respectively.

From the total collected *Anopheles* larvae and pupae, 835 females and 788 males have successfully emerged into adults. The rest 191 larvae and pupae were not able to emerge to adult. Therefore, only 835 female *Anopheles* mosquitoes were subjected to species identification based on morphological features. All *An. gambiae s.l* samples used for species identification using PCR were found to be *An. arabiensis*. Eight species of *Anopheles* mosquitoes such as *An. arabiensis*, *An. pharoensis*, *An. coustani*, *An. christyi*, *An. squamosus*, *An. demeilloni*, *An. danicalicus*, and *An. cinereus* were identified (Table 2). From the total identified *Anopheles* species, *An. arabiensis* (59.2%) was dominant followed by *An. pharoensis* (35.3%) and *An. coustani* (2.99%). The least common species were *An. danicalicus* and *An. cinereus* (Table 2).

The monthly distribution of *Anopheles* larvae and pupae showed that the highest density of *Anopheles* larvae in Arebiya was collected in June, September, October, and May (Fig. 3a). In the meantime, less density of *Anopheles* larvae was recorded during July and August, which is corresponding to pick monthly rainfall, which creates unstable larval breeding habitat due to over flooding. Similarly, in Guramba Bata high larval density was recorded starting from June, August, September, and October (Fig. 3b). However, the density of *Anopheles* mosquito larvae sharply declines in both study areas during a dry season (January, February, and March) (Fig. 3a,b).

**Species specific monthly distribution of Anopheles mosquitoes**

The species-specific monthly distribution of the dominant *Anopheles* mosquitoes is indicated in Fig. 4a,b. The highest density of *An. arabiensis* in Arebiya was recorded during June (16.5%), September (9.1%), and May (21.6%) (Fig. 4a). Similarly, in Guramba Bata the highest density

| Species            | Arebiya | Guramba Bata | Total |
|--------------------|---------|--------------|-------|
| *An. arabiensis*   | 297     | 197          | 494   | (59.2) |
| *An. pharoensis*   | 113     | 182          | 295   | (35.3) |
| *An. christyi*     | 6       | 2            | 8 (1) |
| *An. squamosus*    | 3       | 0            | 3 (0.4) |
| *An. coustani*     | 9       | 16           | 25    | (2.99) |
| *An. demeilloni*   | 2       | 4            | 6 (0.7) |
| *An. danicalicus*  | 0       | 1            | 1 (0.1) |
| *An. cinereus*     | 0       | 3            | 3 (0.4) |
| **Total**          | 430 (51.5) | 405 (48.5)  | 835  | (100) |
of *An. arabiensis* was recorded during June (12.8%), July (10.4%), and September (12.3%), but its number sharply declined after the end of the long rainy season (Fig. 4b). The number of *An. pharoensis* reached its peak around the end of the main rainy season in the two study areas (Fig. 4a,b).

### Anopheles species specific breeding habitat types

The associations of species-specific *Anopheles* larvae in different breeding habitat types are presented in Table 3. *Anopheles arabiensis* larvae were collected from drainage canals, burrow pits, water pools at riversides, tire tracks, hoof prints, and puddles (Table 3). A high number of *An. arabiensis* was collected near the edge of a small temporary and permanent habitat with still and mid turbid water, grass, and had full sunlight access. *Anopheles pharoensis* was collected from a wide range of permanent habitats such as water pools at riversides, swamps, and grassy burrow pits (Table 3). The breeding habitats of *An. pharoensis* were relatively turbid, full of vegetation, and had partial sunlight access. *Anopheles coustani* was collected from permanent habitats such as riverside water pools, burrow pits, and swamps (Table 3). The most common breeding sites of this species were usually permanent habitats with relatively turbid water, vegetation, and partial sunlight access.

### Association of Anopheles larval densities with physical characteristics of larval breeding habitat types

The associations of mean larval densities with physical variables of the breeding habitat types are presented in Table 4. The densities of *Anopheles* larvae were significantly associated with shallow depth (≤ 0.5 m), medium turbidity, availability of grasses, muddy bottom substrates, distance to the nearest house (≤ 100 m), and presence of algae (p ≤ 0.05) (Table 4).

A bivariate analysis showed that average depth (COR = 2.54; 95% CI: 0.98–6.6, p ≤ 0.05) turbidity (COR = 28.4; 95% CI: 3.61-224.27, p ≤ 0.05), vegetation (COR = 17.82; 95% CI: 5.62–56.54, p ≤ 0.05), distance to the nearest house (COR = 32.7; 95% CI: 4.15-257.27, p ≤ 0.05) and presence of algae (COR = 4.92; 95% CI: 1.99–12.11, p ≤ 0.05) were significantly associated with the presence or absence of *Anopheles* larvae (Table 5).

The final model for the parameters associated with presence or absence of *Anopheles* larvae showed that turbidity...
Correlation of chemical characteristics of larval habitat with Anopheles density

The total density of *Anopheles* larvae was positively correlated with temperature ($r = 0.331$ and $p = 0.013$) and pH ($r = 0.697$ and $p = 0.00$). However, the density *Anopheles* larvae was negatively correlated with conductivity ($r = -0.321$, $p = 0.016$) (Table 6).

Discussion

This study showed that the spatio-temporal distribution and species composition of *Anopheles* mosquito larval density were greatly affected by the physicochemical characteristics of the breeding habitat and the rainfall pattern of the localities. Describing larval habitat characteristics in terms of environmental attributes and identifying relationships between breeding habitat and larval density is important to develop novel methods of vector control by targeting the aquatic stage of *Anopheles* mosquitoes in areas with high vector intervention strategies.

During this study rain pools, river pools, burrow pit, swamp, drainage canal, tire track, hoof print, puddle, and stream were the encountered larval breeding habitats, of which rain pools and river pools were dominantly observed breeding habitats during the rainy season. Rain during the rainy season produces many rain pools and river edges, which are potential sites for larval development. In concurrent with this study, *Anopheles* mosquitoes prefer to breed at the edges of rivers and streams, in temporary rain pools, ponds, dams, drainage ditches, burrow pits, rice fields, swamp margins, roadside puddles, and in tree holes close to human dwellings (Shililu et al. 2003; Yohannes et al. 2005; Omlin et al. 2007). In addition, similar habitat types were recorded in previous studies elsewhere in Ethiopia (Mereta et al. 2013) and Kenya (Imbahale et al. 2011).

The distribution of *Anopheles* larvae during the dry season was limited to water pools at riversides, pits dug for plastering a house, drainage canals, and water pools around hand pump water well. This is because during the dry season the water will be confined to temporary habitats such as riversides, burrow pits, drainage canals, and swamps which are important for the reproduction of *Anopheles* mosquitoes. Similarly, studies showed that the number and size of *Anopheles* breeding habitat are reduced during the dry season (Animut and Negash 2018). This restricted distribution of *Anopheles* mosquito breeding habitat during the dry season makes them more vulnerable for larval management. Therefore, larval management during a dry season is less costly than management during a wet season in areas where the dry season is associated with limited breeding habitats (WHO, 2013). Dry season larval management will hamper the exponential reproduction rate of *Anopheles* larvae at the end of the long rainy season hence it will limit malaria transmission (Animut and Negash 2018). This approach could be effective to reduce malaria transmission associated with insecticide resistant malaria vectors and outdoor host seeking mosquitoes, as it manages the immature stage (egg, larvae, and pupae) confined in a small aquatic environment (Killeen et al. 2002).

The result of this study indicated that the density of *Anopheles* larvae varies among habitat types, where a significantly highest density was recorded from water pools at drainage canal and the grassy edge of burrow pits. This larval density variation in the different habitats could be explained by the spatio-temporal differences in food resource and predation pressure in different habitats and the complex interaction between physicochemical factors such as water turbidity, depth, temperature, salinity, and dissolved oxygen (Mala and Irungu 2011; Kipyab et al. 2015; Roux and Robert 2019).
Anopheles mosquito species such as *An. arabiensis*, *An. pharoensis*, *An. coustani*, *An. christyi*, *An. squamosus*, *An. demeilloni*, *An. danalicus*, and *An. cinereus* were identified from the two study areas. This result is in line with findings from the west Gojam zone (Animut and Negash 2018), south-central Ethiopia (Animut et al. 2012), and Central Ethiopia (Kenea et al. 2011). The highest density of *Anopheles* larvae was recorded during the rainy seasons. The reason is that rainfall and humidity strongly affect the availability of larval habitat, *Anopheles* species, and distribution (Imbahale et al. 2011).

*Anopheles arabiensis* was the dominant species identified in the study area, similar to reports from southwest Ethiopia (Getachew et al. 2020), Addis Zemen, South Gondar, Ethiopia (Kindu et al. 2018), South-central Ethiopia (Animut et al. 2012), and Western Kenya (Kweka et al. 2012). The highest density of *An. arabiensis* was recorded in June and September when the rainy season starts and retreats. Similar observations have shown that populations of *An. arabiensis* usually increase as the rains withdraw (Getachew et al. 2020). The result of this study indicated that *An. arabiensis* was dominantly distributed in small temporary habitats with still and less turbid water and grasses and full sunlight access. The reason for this could be the presence of less larval predation pressure in small temporary habitats than permanent habitats and temporary habitats with full sunlight access provide warmer water, which resulted in a high algal density (source of food for larvae) and rapid development of larvae to pupae (Gimnig et al. 2002). In concurrent with this study, *An. arabiensis* was reported to breed in small, temporary habitats with algae such as footprints, rain pools, puddles, tire tracks, and garden wells (Mattah et al. 2017). These species were also identified from temporary habitats such as swamps, irrigation canals, sand pools, canal leakage pools, water harvesting pools, and brick-making pits in central Ethiopia (Kenea et al. 2011).

*Anopheles pharoensis* was dominantly distributed in aquatic habitats with turbid, full of vegetation, and partial sunlight access. Different reports also supported this observation, claiming that the density of *An. pharoensis* was higher in aquatic habitats with floating vegetation and with shady conditions (Teklu et al. 2010).

Physical characteristics of the *Anopheles* mosquito breeding habitat such as low turbidity and the presence of grass were the limiting factors that determine the presence or absence of *Anopheles* mosquito larvae in this study. In addition, the density of *Anopheles* mosquito larvae was positively correlated with temperature and pH and negatively correlated with water conductivity. Conductivity measures the amount of inorganic matter and ions in water, therefore as turbidity of the water increases due to flooding conductivity also increases proportionally, which in turn affects the development of the larval population (Edillo et al. 2006). Low water turbidity and full sunlight access increase the water temperature and hence leads to a rapid larval development (Paaijmans et al. 2010). This result coincides with previous works conducted in the highlands of Ethiopia (Dejenie et al. 2011), Kenya (Minakawa et al. 1999), and Tanzania (Emidi et al. 2017).

| Factors            | Variables | COR (95% CI)          | AOR (95% CI)          | p-value |
|--------------------|-----------|-----------------------|-----------------------|---------|
| Average depth      | ≤ 0.5     | 2.5 (0.98–6.60)*      | 0.4 (0.04–4.32)       | 0.450   |
|                    | ≥ 0.5     | 1                     | 1                     |         |
| Turbidity          | Low       | 3.6 (0.35–37.36)      | 22.5 (0.66-774.51)    | 0.084   |
|                    | Med       | 28.4 (3.61-224.27)*   | 66 (2.01-2168.24)     | 0.019   |
|                    | High      | 1                     | 1                     |         |
| Vegetation         | No        | 1                     | 1                     |         |
|                    | Grass     | 17.8 (5.62–56.54)*    | 12.6 (1.29-122.78)    | 0.029   |
|                    | Muddy     | 21.7 (2.64-177.76)    | 8.6 (0.24-308.82)     | 0.238   |
|                    | Clay      | 0.00 (0.00)           | 0.00 (0.00)           | 0.997   |
|                    | Sandy     | 1                     | 1                     |         |
| Water current      | Stagnant  | 0.36 (0.12–1.05)      | 0.1 (0.01-1.29)       | 0.077   |
|                    | Flowing   | 1                     | 1                     |         |
| Light intensity    | Full sunlight | 2.1 (0.76–5.79) | 2.21 (0.25–19.92)    | 0.479   |
|                    | Shaded    | 1                     | 1                     |         |
| Distance           | ≤ 100 m   | 32.7 (4.15-257.27)*   | 27.99 (0.65-1215.17)  | 0.083   |
|                    | 100-200 m | 1.39 (0.08-23.71)     | 0.99 (0.01-132.14)    | 1.00    |
|                    | 201-300 m | 0.00                  | 0.00                  |         |
|                    | 301-400 m | 1                     | 1                     |         |
| Algae              | Present   | 4.92 (1.99–12.11)*    | 6.94 (0.78-62.09)     | 0.083   |
|                    | Absent    | 1                     | 1                     |         |
| Water persistency  | Temporary | 1.15 (0.51–2.61)      | 1.51 (0.23–9.99)      | 0.67    |
|                    | Permanent | 1                     | 1                     |         |
| Surface debris     | Low       | 1.81 (0.54–6.08)      | 7.90 (0.53-117.17)    | 0.133   |
|                    | Medium    | 1.11 (0.34–3.68)      | 0.723 (0.07–7.89)     | 0.791   |
|                    | High      | 1                     | 1                     |         |

* indicates statistically significant values at $p = 0.05$
were identified as the dominant species. Breeding habitats such as drainage canals and burrow pits served as a potential reproduction site of *Anopheles* mosquitoes in the study area. The distribution of *Anopheles* mosquito larvae is greatly affected by physicochemical characteristics of the breeding habitats such as water turbidity, vegetation cover, pH, temperature, conductivity, and season. A malaria control and elimination program in the study area should incorporate larval management strategies such as using larvicides and source reduction as a part of integrated vector management (IVM). Further study on identification of the natural predators of *Anopheles* mosquitoes larvae/pupae in the study area is recommended.

### Abbreviations

| Abbreviation | Description                          |
|--------------|--------------------------------------|
| CL           | Confidence Limit                      |
| DF           | Degree of freedom                     |
| COD          | Crud odd ratio                        |
| AOD          | Adjusted odd ratio                    |
| SE           | Standard error                        |
| PCR          | Polymerase chain reaction             |

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### Authors' contributions

MT, HT, YW and SD designed the study. HT, YW and SD supervised the field work, rearing and identification experiments. MT conducted the statistical analyses. MT developed the first draft, HT, YW and SD revised the manuscript. All authors read and approved the final manuscript.

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### Availability of data and materials

The data sets supporting the conclusions of this article are provided in the manuscript.

### Declarations

#### Ethics approval

Not applicable.

#### Consent to participate

Not applicable.

#### Consent for publication

Not applicable.

#### Conflicts of interest/Competing interests

The authors declare that there is no conflict of interest.

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