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ORIGINAL RESEARCH ARTICLE

Ecological Characterization of Malaria Vector Habitats in Awe and Nassarawa Eggon Local Government Areas, Nasarawa State, Nigeria

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ABSTRACT

Malaria remains a significant global health concern due to *Anopheles* mosquitoes. This study assessed malaria vector populations in Awe and Nassarawa Eggon LGAs of Nasarawa State, Nigeria. Mosquito larvae were collected employing standard dipping methods, while physicochemical parameters were analyzed in-situ and in the laboratory using standard methods. A total of 1,405 mosquito larvae were collected, with a higher abundance in Awe (95.2%) than in Nassarawa Eggon (4.8%). Culicines comprised 84.8% of the total larvae, while anophelines accounted for 15.2%. Although habitat type did not significantly influence *Anopheles* abundance (P = 0.364), puddles (52.5%) and rice fields (28.6%) supported the highest larval populations. The highest mosquito abundance was recorded at a 351–400m gradient (47.8%). No significant association (P = 0.65) was found between larval abundance and proximity to human dwellings. Temperature (r = 0.395), electrical conductivity (r = 0.303), salinity (r = 0.407), total dissolved solids (r = 0.390), and carbon dioxide (r = 0.015) positively influenced *Anopheles* abundance, while pH (r = -0.039), alkalinity (r = -0.024), and dissolved oxygen (r = -0.067) had negative correlations. *Anopheles gambiae* (87.2%) was more abundant than *An. funestus* (12.8%), with no significant difference (P = 0.0881) between species in both LGAs. Continued mosquito surveillance in Awe and Nassarawa Eggon is necessary to enhance vector control strategies and malaria prevention efforts.

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Anopheles, Habitat, Malaria, Mosquito, Nasarawa

INTRODUCTION

Anopheles species have plagued the world with malaria for centuries. In 2021, approximately 247 million malaria cases were reported across 84 malaria-endemic countries, marking an increase from 245 million cases in 2020 (WHO, 2022). Twenty-nine countries accounted for 96% of malaria cases globally, and four countries – Nigeria (30.9%), the Democratic Republic of Congo (11.3%), Niger (5.9%), and United Republic of Tanzania (4.3%) – accounted for almost half of all cases globally (WHO, 2022, 2024).

The distribution and population size of adult *Anopheles* mosquitoes depend on the availability and productivity of their larval breeding sites (Lapang *et al.,* 2019; Oniya *et al.,* 2019). The productivity of such habitats influences the conditions of larval development and plays a major role in the eventual size of adult mosquitoes, which in turn affects factors such as longevity, abundance, morphology, and blood meal volume (Ukubuiwe *et al.,* 2018; Hassan *et al.,* 2021; Njila *et al.,* 2023). While previous studies, such as Lapang *et al.* (2019) and Hassan *et al.* (2021), have explored habitat productivity and vector abundance, their findings were limited to specific ecological zones, leaving gaps in understanding how varying environmental conditions influence vector populations across different landscapes. Similarly, Oguche *et al.* (2022) assessed malaria vector ecology but did not comprehensively incorporate spatial mapping techniques to visualize habitat distribution and vector density.

Building spatial models of disease incidence and risk, such as maps for the possible spread of infectious diseases like malaria, is a key theoretical objective of epidemiology. In particular, Ryan et al. (2020) emphasize risk maps for malaria in Africa. Unfortunately, there is little information on the availability of risk maps for malaria vectors, particularly *Anopheles* species, in or around Awe and Nasarawa Eggon LGAs, Nasarawa State, Nigeria. This study addresses these gaps by integrating ecological characterization with geospatial mapping to provide a more comprehensive understanding of malaria vector habitats in the study areas.

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MATERIALS AND METHODS

Study Area

The study was carried out in Awe and Nassarawa Eggon LGAs, respectively, in Nasarawa State, Nigeria (Figure 1).

Identification and Characterization of Anopheles Breeding Habitat

A preliminary survey was carried out prior to the fieldwork to identify potential *Anopheles* mosquito breeding habitats. The respective coordinates of identified breeding habitats were obtained with the aid of a Garmin GPS navigator (Garmin Inc., Kansas, USA) and exported to ArcGIS version 9.3, which was then used to generate a map of the study areas (Egwu *et al.,* 2018; Njila *et al.,* 2023).

Sampling was conducted between 7:00 am and 11:00 am (Egwu *et al.,* 2018; Lapang *et al.,* 2019). All potential mosquito breeding sites were carefully inspected for the presence of *Anopheles* larvae through direct visual observation (Mattah *et al.,* 2017; Lapang *et al.,* 2019). Habitats of the *Anopheles* mosquito species were categorized with respect to whether they are man-made or natural (Owolabi & Bagbe, 2020).

Sample Collection

Anopheles mosquito larvae were sampled using the standard dipping technique as described by Oniya *et al.* (2019). At each identified breeding site, a 350 mL standard dipper was used to collect larvae by submerging it at a 45-degree angle into the water. In shallow or vegetated habitats, the dipper was skimmed gently along the surface to avoid disturbing the larvae. A total of 10 dips were taken per site. Collected larvae were transferred into labelled plastic containers filled with site water and covered with fine mesh netting for transport to the laboratory.

Determination of Physicochemical Parameters

Temperature, pH, electrical conductivity (EC), salinity, and total dissolved solids (TDS) were measured in situ using a well-calibrated Oakton Multi-Parameter (Oakton, USA), following the protocol described by Lin *et al.* (2021). Measurements were taken directly at each sampling site by immersing the probe into the water, allowing for real-time readings.

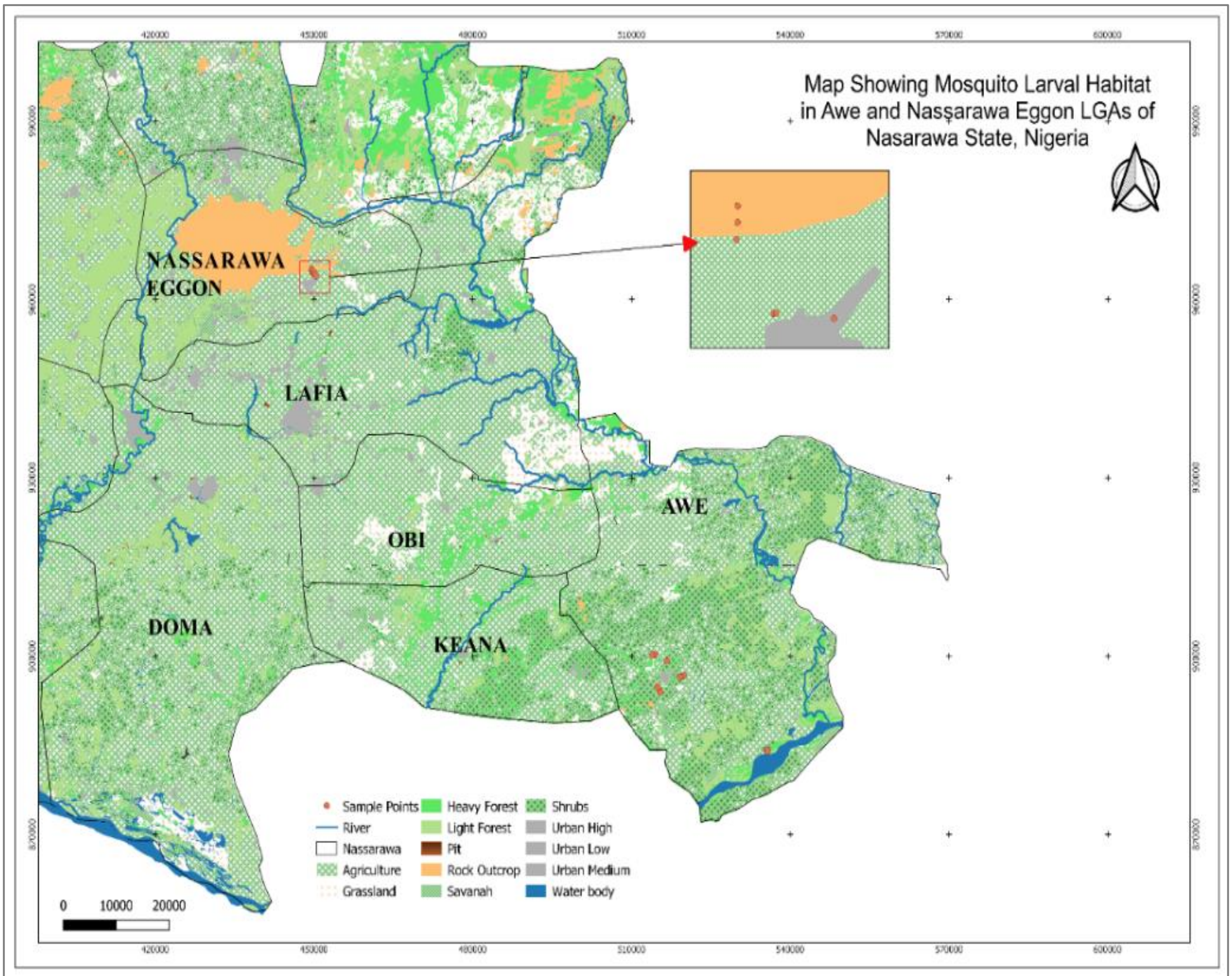

Figure 1: Map of Awe and Nassarawa Eggon LGAs Showing Mosquito Larvae Sample Points

Alkalinity (mg/L $CaCO_3$), carbon dioxide (CO_2), and dissolved oxygen (DO_2) were determined in the laboratory following standard titrimetric and electrochemical methods as described by Pimenta *et al.*

(2023). Water samples were collected in airtight polyethylene bottles to minimize gas exchange and contamination. Samples were transported in cool, insulated containers to maintain stability and prevent alterations in chemical composition. Alkalinity was measured using acid-base titration, CO_2 levels were determined by acidification followed by titration, and DO_2 was quantified using the Winkler method (Hu *et al.,* 2024). All analyses were conducted immediately upon arrival at the laboratory to ensure accuracy and reliability of results.

Anopheles Mosquito Rearing

The larvae were identified based on their morphological characteristics (Gillies & Coetzee, 1987; Sallum *et al.,* 2020). All larvae morphologically confirmed as belonging to *Anopheles* species were used for this study. The larvae were reared under controlled conditions following standard procedures (Zengenene *et al.,* 2022). They were housed in plastic rearing cages (30 cm × 25 cm × 5 cm) and maintained in larval bowls filled with water sourced from their respective natural habitats to preserve their native environmental conditions. This setup ensured optimal development by minimizing stress and maintaining natural microbial communities essential for larval growth. Water levels were monitored and replenished as needed to prevent desiccation, while environmental factors such as temperature and light exposure were kept stable to support normal larval development (Wohl & McMeniman, 2022).

Emerged adult *Anopheles* mosquitoes were fed with 10% sucrose solution (Ukubuiwe *et al.*, 2018; Lapang *et al.,* 2019; Ngowo *et al.,* 2021), knocked down in a -20°C freezer for 10 minutes, and then further identified under a dissecting microscope using identification keys by Ukubuiwe *et al.,* (2018) and Coetzee (2020).

Data Analysis

The data was analysed using R statistical software (version 3.6.1). One-Way ANOVA was applied to compare larval abundance across different breeding habitats and distances from the nearest houses. A Chi-Square test was used to assess differences in *Anopheles* mosquito larvae between the two LGAs. Descriptive statistics provided mean values and percentages of larval abundance in the study sites. Pearson's Correlation Coefficient measured the relationship between larval abundance and physicochemical parameters, while another Chi-Square test examined the association between emerged adult *Anopheles* species in both LGAs. A P-value below 0.05 was considered statistically significant.

RESULTS AND DISCUSSION

Association between Physicochemical Parameters and Anopheline Larval Abundance in Awe and Nassarawa Eggon, Nigeria

There was a positive relationship between temperature ($r = 0.395$), electrical conductivity ($r = 0.303$), salinity ($r = 0.407$), total dissolved solid ($r = 0.390$), and carbon dioxide ($r = 0.015$) and the abundance of anopheline mosquito larvae in their breeding habitats at Awe and Nassarawa Eggon LGA, Nasarawa State, Nigeria. Conversely, pH ($r = -0.039$), alkalinity ($r = -0.024$), and dissolved oxygen ($r = -0.067$) all recorded a negative relationship with the abundance of anopheline mosquito larvae in their breeding habitats at Awe and Nassarawa Eggon LGA, Nasarawa State, Nigeria (Table 1).

Table 1: Association between Physicochemical Parameters and Anopheline Larval Abundance in Awe and Nassarawa Eggon, Nigeria

Physicochemical Parameters	P	r	Coefficient of Determination (r^2)
Temperature	0.094	0.395	0.156025
pH	0.874	-0.039	0.001521
Electrical Conductivity	0.207	0.303	0.091809
Salinity	0.084	0.407	0.165649
Total Dissolved Solids	0.098	0.390	0.15210
Alkalinity	0.921	-0.024	0.000576
Carbon Dioxide	0.952	0.015	0.000225
Dissolved Oxygen	0.785	-0.067	0.004489

The negative correlation observed in the relationship between anopheline mosquito larvae abundance and pH, alkalinity, and dissolved oxygen possibly suggests that they do not influence the abundance of anopheline larvae in habitats sampled in Awe and Nassarawa Eggon LGA, Nasarawa State, Nigeria. This result is consistent with that of Obi *et al.* (2019), Akeju *et al.* (2022), and Seal and Chatterjee (2023), who all recorded a negative correlation in the relationship between anopheline mosquito larvae abundance and pH, alkalinity, and dissolved oxygen in their respective study sites.

The positive correlation observed between Electrical conductivity (EC), salinity, total dissolved solid (TDS), and carbon dioxide (CO_2) contents of the water from larval habitats and anopheline larval abundance at the study locations suggests that these parameters influence the abundance of these anophelines. Oguche *et al.* (2022) and Omondi *et al.* (2023) reported similar associations with EC, salinity, TDS, CO_2 and DO_2 content with anophelines and culicines in their study in Kaduna State, Nigeria, and Kwale County, Kenya, respectively.

Checklist of Field Collected Larvae in Awe and Nassarawa Eggon LGAs of Nasarawa State, Nigeria

A total of 1,405 mosquito larvae belonging to the anopheline and culicine groups were collected from various habitats in Awe (95.2%) and Nassarawa Eggon

(4.8%) LGAs, respectively. Culicine larvae (84.7%) were the predominant group encountered, while the anophelines accounted for 15.2% of the total larval population collected from the field (Table 2). The abundance of mosquito larvae species differed significantly (χ^2 = 265.81, df = 1, P < 0.0001) between Awe and Nasarawa Eggon LGAs, Nasarawa State, Nigeria, indicating a notable variation in species distribution across the study locations. This study revealed high larval heterogeneity, suggesting that environmental factors such as habitat type and water quality influence mosquito breeding site selection. The observed differences may also be attributed to ecological variations between the two LGAs, such as differences in vegetation cover, human activities, and climatic conditions, which create distinct microhabitats that support varying mosquito species compositions. These results are consistent with studies by Lapang *et al.* (2019) in Shendam, Ekedo *et al.* (2020) in Umudike, Nigeria, and Oforka *et al.* (2024) in Lagos State, Nigeria. Conversely, Surendran *et al.* (2021) reported mosquito larvae productivity as a habitat species specific in Jaffna Peninsula, Sri Lanka.

The great variation observed in larval abundance between anopheline and culicine mosquitoes could indicate that the habitat types studied possibly support more of the growth of culicines than the anophelines. This result is in tandem with that of Alkhayat *et al.* (2020) in Qatar, Gowelo *et al.* (2020) in Malawi, and Onen *et al.* (2021) in Central Uganda. However, the result did not agree with that of Lapang *et al.* (2019) and Kinga *et al.* (2022), who recorded no variation in larval abundance between anophelines and culicines in their study.

Table 2: Checklist of Field Collected Larvae in Awe and Nassarawa Eggon LGAs of Nasarawa State, Nigeria

Group	Awe LGA (%)		Nassarawa Eggon LGA (%)		Total	
	Number	(%)	Number	(%)	Number	(%)
Anopheline	157	11.7	57	85.1	214	15.2
Culicine	1181	88.3	10	14.9	1191	84.8
	1338	**95.2**	**67**	**4.8**	**1405**	

Emerged Adult Anopheles Mosquitoes

Only 164 of the 214 *Anopheles* mosquito species collected from their natural habitats emerged. Of this number, *Anopheles gambiae* (87.2%) was most abundant, while *An. funestus* accounted for 12.8% of the population (Table 3). The distribution of emerged *Anopheles* mosquito species between Awe and Nasarawa Eggon LGAs, Nasarawa State, Nigeria, showed no statistically significant variation (χ^2 = 2.9086, df = 1, P = 0.0881). This indicates that the observed differences in species composition between the two LGAs could be due to random variation rather than distinct ecological or environmental factors. The relatively high *P*-value suggests that *Anopheles* species are likely distributed uniformly across both locations, potentially influenced by similar habitat characteristics, breeding site availability, and climatic conditions. The consistent presence of *Anopheles* mosquitoes in this study suggests an ongoing risk of malaria transmission in the area. The dominance of *An. gambiae* may be due to its remarkable adaptability, allowing it to thrive even in challenging environments. This aligns with findings by Hassan *et al.* (2021) and Li *et al.* (2021), who also observed its resilience in adverse conditions. This result is consistent with that of Lapang *et al.* (2019) and Osidoma *et al.* (2023), where they had more emergence of *An. gambiae* than other mosquito species reared.

Table 3: Emerged Adult *Anopheles* Mosquitoes

LGA	No. of Emerged Adult Mosquitoes						Overall Emerged (%)
	A. gambiae s. l.		**Total (%)**	***A. funestus***		**Total (%)**	
	Male	**Female**		**Male**	**Female**		
Awe	27(25.5)	79(74.5)	**106(74.1)**	5(45.5)	6(54.5)	**11(52.4)**	**117(71.3)**
Nassarawa Eggon	7(18.9)	30(81.1)	**37(25.9)**	3(27.3)	7(70.0)	**10(47.6)**	**47(28.7)**
Total (%)	**34(23.8)**	**109(76.2)**	**143(87.2)**	**8(38.1)**	**13(61.9)**	**21(12.8)**	**164**

Distribution of Anopheline Mosquito Larvae Across Different Habitat Types in Awe and Nasarawa Eggon LGAs, Nasarawa State

Anopheline Mosquito larvae were most abundant in puddle habitat (52.5%) habitat followed by rice field (28.6%), while the animal hoofs (0.2%) accounted for the least population (Figure 2). However, there was no significant difference (F = 1.37, df = 4, Adj.R^2 = 13.98%, P = 0.364) in the abundance of anopheline mosquito larvae in Awe and Nassarawa Eggon LGA, Nasarawa State, Nigeria. The absence of significant variations in the abundance of anopheline mosquito larvae across different habitat types in Awe and Nassarawa Eggon LGA of Nasarawa State, Nigeria, strongly indicates that both locations provide favorable conditions for breeding this disease-carrying vector. The abundance of mosquito larvae in puddle habitats can be attributed to the rainy season, which creates numerous pockets of puddle habitats favorable for mosquitoes.

This finding aligns with the research conducted by Ekedo *et al.* (2020), and Getachew *et al.* (2020). It did not agree with the results of Lapang *et al.* (2019), who collected more mosquito larvae in rice fields at Shendam, and Oguche *et al.* (2022), who collected more mosquito larvae from abandoned tyres in Kaduna metropolis.

Distribution of Anopheline Mosquito Larvae Based on Proximity of Breeding Sites to Residential Areas in Awe and Nasarawa Eggon LGAs, Nasarawa State, Nigeria

The gradient 351–400 m recorded the highest population of *Anopheles* mosquito larvae (47.8%), followed by the 251–300 m gradient (14.3%), while the 451–500 m gradient had the least abundance (0.4%) (Figure 3). This pattern suggests that *Anopheles* mosquitoes preferentially breed within specific elevation ranges, possibly due to favorable environmental conditions such as water availability, vegetation cover, and reduced disturbance. However, statistical analysis showed no significant difference in larval abundance relative to the proximity of breeding habitats to human dwellings ($F = 0.76$, $df = 9$, Adj. $R^2 = 0.000\%$, $P = 0.65$). This indicates that the distance between breeding sites and human settlements does not directly influence *Anopheles* larval density. The high abundance observed at 351–400 m suggests that *Anopheles* mosquitoes are well adapted to breeding even at moderate distances from human habitations, reinforcing the need for vector control strategies that extend beyond immediate residential areas.

These findings align with the observations made by Lapang *et al.* (2019) and Zogo *et al.* (2019), who reported greater larval abundance in habitats surrounded by fewer houses and more green areas compared to habitats densely populated by human inhabitants. However, the result is in contrast with that of Mathania *et al.* (2020), who recorded more abundance of anopheline larvae in habitats along gradients ranging between 51-100m in Tanzania.

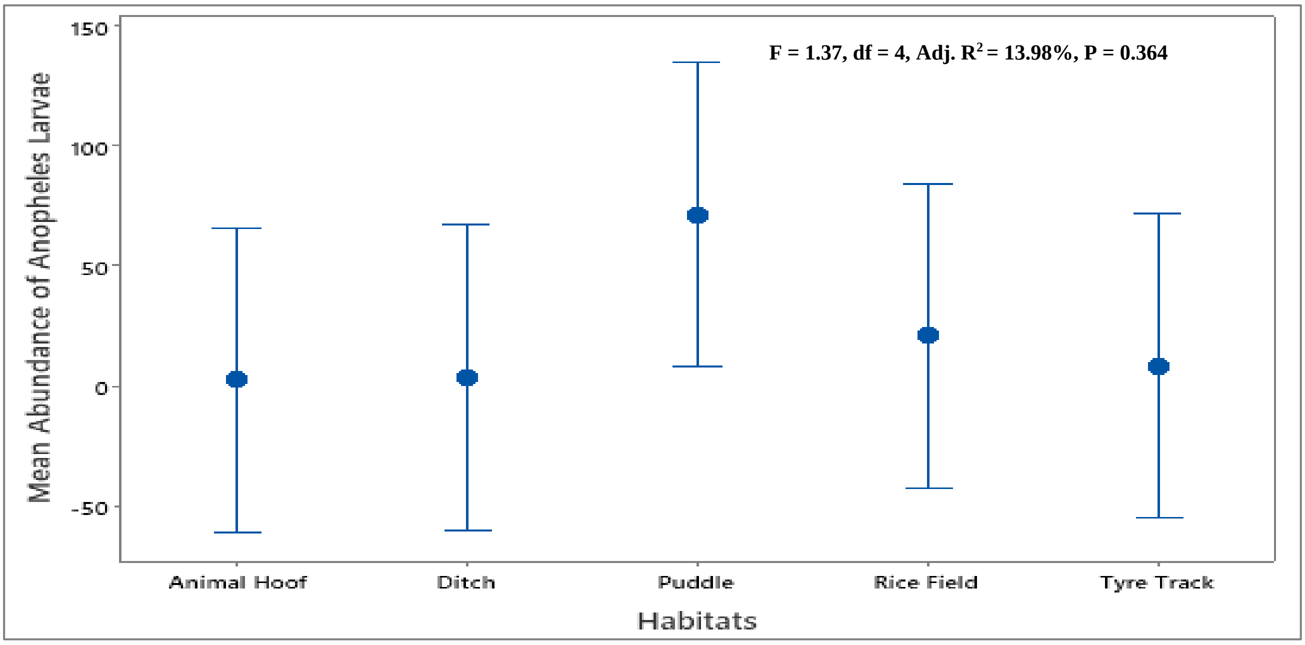

Figure 2: Distribution of Anopheline Mosquito Larvae Across Different Habitat Types in Awe and Nasarawa Eggon LGAs, Nasarawa State

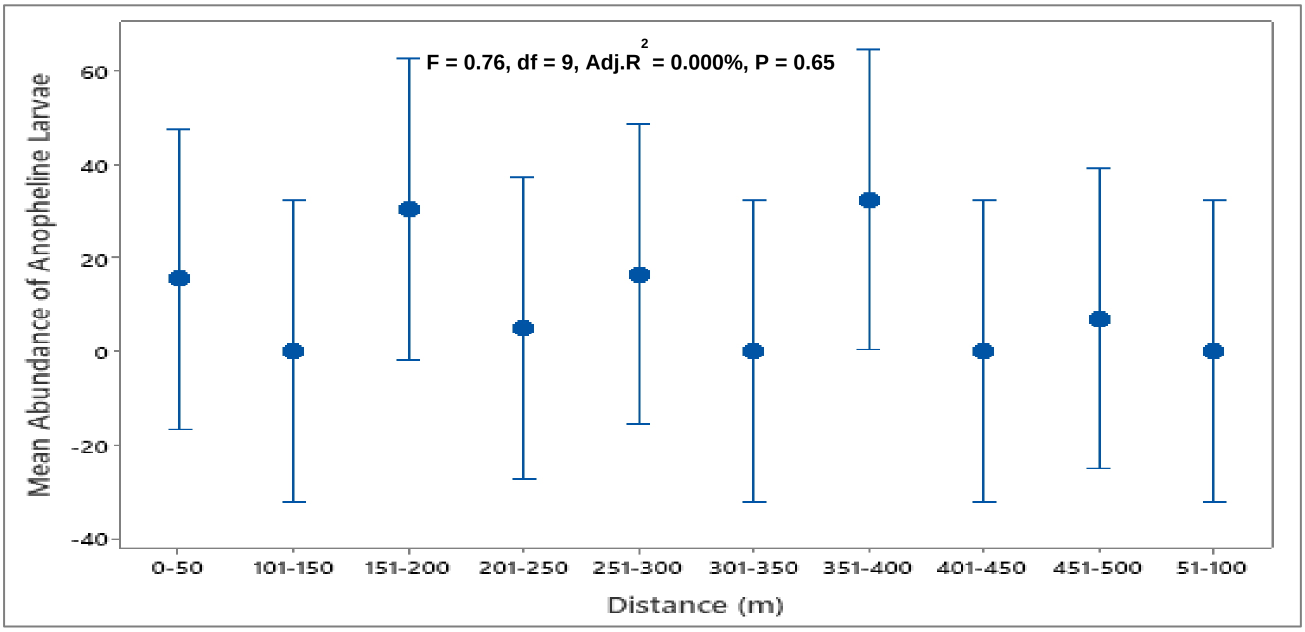

Figure 3: Distribution of Anopheline Mosquito Larvae Based on Proximity of Breeding Sites to Residential Areas in Awe and Nasarawa Eggon LGAs, Nasarawa State, Nigeria

Breeding Index (BI) of Anopheline Larvae Across Different Habitat Types in Awe and Nasarawa Eggon LGAs, Nasarawa State, Nigeria

The puddle habitat proved to be the most favorable breeding ground, recording a breeding index (BI) of 31.7, followed by the rice field (6.6), while the ditches (0.7) had the least BI (Table 4). The animal hoof prints had a BI of 0.0, indicating that they did not contribute to mosquito breeding in the study area. The consistently high BI observed in puddles suggests that these habitats provide ideal conditions for *Anopheles* larvae, possibly due to factors such as stagnant water, suitable temperature, and organic matter availability, which enhance larval survival and development. With an overall breeding index of 8.2, which exceeds the 5.0 threshold for high mosquito productivity, the *Anopheles* population in Awe and Nasarawa Eggon LGAs presents a serious public health risk. The elevated BI suggests an increased likelihood of multiple mosquito-borne disease outbreaks among residents, necessitating urgent vector control interventions. These findings align with the studies of Doumbe-Belisse *et al.* (2021) and Chan *et al.* (2022), who reported even higher breeding indices of 20.0 and 48.8, respectively, reinforcing the idea that high BI values correspond to greater malaria transmission potential. The observed differences in BI across habitats further emphasize the need for targeted control measures to mitigate malaria transmission in the study area, focusing on high-risk breeding sites such as puddles.

Table 4: Breeding Index (BI) of Anopheline Larvae Across Different Habitat Types in Awe and Nasarawa Eggon LGAs, Nasarawa State, Nigeria

Habitats	Communities									Total BI
	Awe LGA						Nasarawa Eggon LGA			
	KA	MG	MSM	KKR	TG	Sub-Total	NEQM	NEM	Sub-Total	
Puddle	0.4	0.0	8.7	9.6	9.3	**28**	1	2.7	**3.7**	**31.7**
Rice Field	0.0	4.8	0.0	0.0	0.0	**4.8**	1.8	0.0	**1.8**	**6.6**
Ditch	0.0	0.0	0.0	0.7	0.0	**0.7**	0.0	0.0	**0.0**	**0.7**
Animal Hoof	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	**0.0**	**0.0**
Tyre Track	0.0	0.0	0.0	0.0	0.0	**0.0**	0.5	1.7	**2.2**	**2.2**
Average BI	**0.1**	**1**	**1.7**	**2.1**	**1.9**	**6.7**	**0.7**	**0.9**	**1.5**	**8.2**

KA: Kauje-Aburi, MG: Manga-Galadima, MSM: Madiki Salt Mine, KKR: Kekura, TG: Tunga, NEQM: Nasarawa Eggon Quarry Mine, NEM: Nasarawa Eggon Market

CONCLUSION

This study clearly shows the presence of heterogenous association between mosquito larval groups (anopheline and culicine) across breeding habitats in Awe and Nassarawa Eggon LGAs, Nasarawa State, Nigeria. Emerged adult *Anopheles gambiae* complex had a higher abundance than *A. funestus.* All the mosquito larvae collected utilized five habitat types: animal hoof, ditch, puddle, rice fields, and tyre tracks.

Also, this research shows that mosquitoes have no preferred gradient from houses. However, on average, they preferred to breed farther away from human settlements. Furthermore, it was observed that physicochemical parameters (temperature, EC, salinity, TDS & CO_2) positively influence larval abundance in the study areas with the exception of pH, alkalinity, and DO_2. The observed high breeding index (8.2) recorded in this study suggests that the inhabitants of Awe and Nassarawa Eggon LGA are at risk of the transmission of mosquito-borne diseases.

Mosquito surveys should be carried out all year round in Awe and Nassarawa Eggon LGAs. This will provide additional information on their distribution within these areas. Inhabitants in these areas should always clear stagnant water bodies so as to interrupt mosquito breeding success. Residents of the two LGAs should sleep under insecticide-treated bed nets in order to avoid human-vector contact.

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