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HABITAT CHARACTERIZATION OF CULICIDAE MOSQUITOES IN TWO LOCAL GOVERNMENT AREAS OF NASARAWA STATE, NORTH CENTRAL, NIGERIA

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ABSTRACT
Mosquitoes are major vectors of disease, with their abundance influenced by ecological and environmental factors. This study assessed the habitat characterization and abundance of mosquito species in Awe and Nasarawa Eggon LGAs, Nasarawa State, Nigeria. Larvae were sampled monthly from July 2023 to June 2024 using standard dipping techniques, and physicochemical parameters of breeding sites were analyzed. A total of 2,158 mosquito larvae were collected, with culicines significantly ($P < 0.001$) accounting for 90.08% while anophelines accounted for 9.92% of the population. Among the emerged adult culicines, *Culex quinquefasciatus* (76.67%) was significantly ($P < 0.001$) more abundant followed by *Anopheles gambiae* (13.40%), while *An. funestus* had the lowest emergence rate at 1.97%. Puddle habitats (47.21%) supported the highest mosquito abundance, followed by rice fields (34.99%), while animal hoof prints (0.79%) had the least mosquito abundance. Therefore, habitat type significantly ($P = 0.037$) influenced mosquito abundance in both LGAs. The highest larval abundance was recorded at a 351–400 m (36.52%) gradient from human dwellings, but distance significantly ($P = 0.625$) influence larval abundance. Physicochemical parameters such as temperature, pH, total dissolved solids, and dissolved oxygen exhibited varied correlations with mosquito abundance, with significant effects in some habitats. These findings highlight the need for targeted vector control strategies, particularly habitat modification and public health interventions, to reduce mosquito proliferation and mitigate disease transmission risks in the study area.

Keywords: *Anopheles*, *Aedes*, *Culex*, habitat characterization, Nasarawa State

INTRODUCTION

Culicine and *Anopheles* mosquitoes are significant vectors of various mosquito-borne diseases, contributing to substantial public health challenges globally. While culicine species such as *Culex* and *Aedes* are known for transmitting arboviral diseases, including dengue, chikungunya, yellow fever, and lymphatic filariasis, *Anopheles* mosquitoes are the primary vectors of malaria, a major cause of morbidity and mortality in tropical and subtropical regions (Balthazar *et al.*, 2021). The distribution and abundance of these mosquitoes are influenced by several environmental and ecological factors, including water quality, temperature, vegetation cover, and urbanization (Radl *et al.*, 2024). Understanding these determinants is crucial for effective vector surveillance and control strategies.

Nigeria bears a high burden of mosquito-borne diseases due to the widespread presence of vector breeding habitats and favorable climatic conditions (Oforka *et al.*, 2024). *Culex quinquefasciatus* thrives in polluted water bodies, whereas *Aedes aegypti* prefers artificial containers and urban environments (Juache-Villagrana *et al.*, 2020; Chura *et al.*, 2023; Garba, 2023). Similarly, *Anopheles* species are commonly associated with stagnant, sunlit water bodies, such as puddles, rice fields, and ditches, which serve as breeding sites for malaria vectors (Kweka *et al.*, 2022). In Nasarawa State, rapid urbanization and agricultural expansion have altered mosquito breeding patterns, increasing the risk of both malaria and other vector-borne diseases. However, limited research has been conducted on the habitat characterization of both culicine and *Anopheles* mosquitoes in Awe and Nasarawa Eggon LGAs, necessitating a comprehensive study to bridge this knowledge gap.

This study aims to assess the breeding habitats and environmental determinants of both culicine and *Anopheles* mosquito abundance in these LGAs. By analyzing physicochemical parameters such as pH, dissolved oxygen, turbidity, and total dissolved solids, this research will provide critical insights into habitat suitability for mosquito larvae. Furthermore, spatial analysis will be employed to identify high-risk breeding areas. The findings will support targeted mosquito control interventions, contributing to improved public health strategies in Nasarawa State and similar ecological regions.

MATERIALS AND METHODS

Study location

This study, which is cross-sectional in nature, looks at two particular localities in Nasarawa State—Awe and Nassarawa Eggon. Nasarawa State is located in Nigeria's Middle Benue Trough, which spans latitudes of 7°45' and 9°25'N and longitudes of 7° and 9°37'E of the Greenwich Meridian (Bimbol & Marcus, 2010).

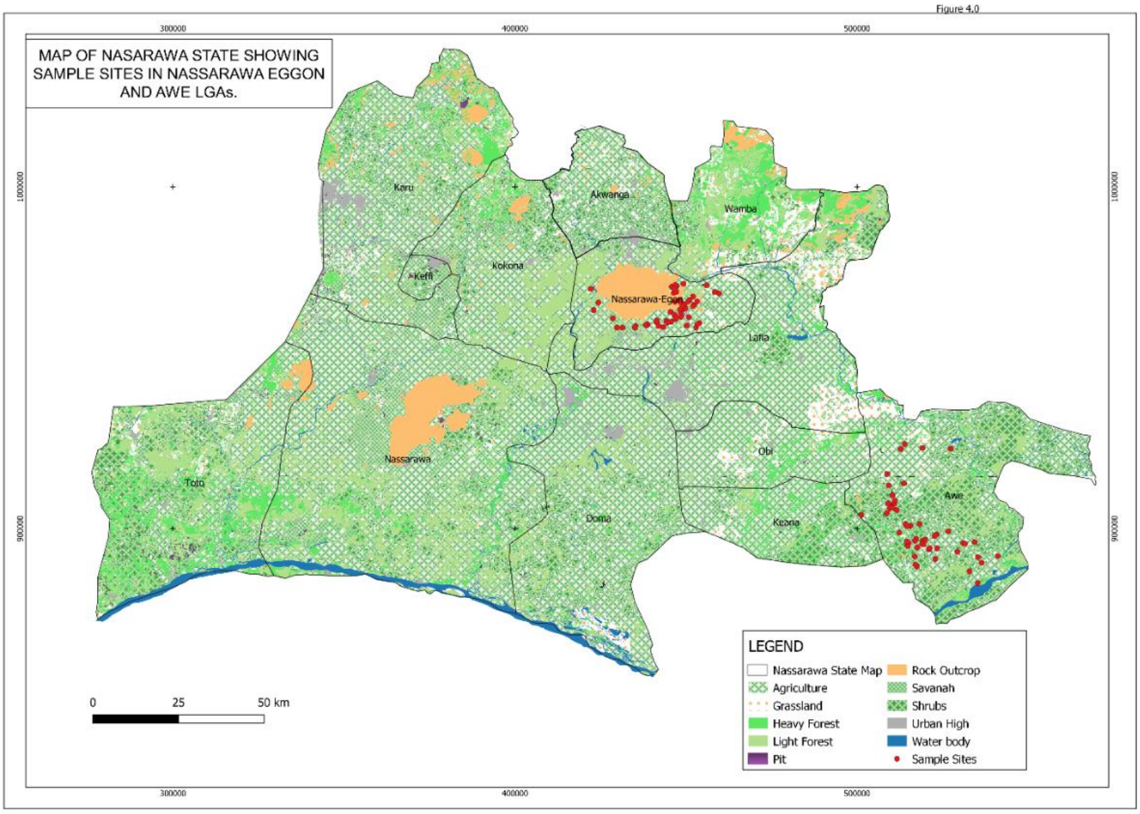

Figure 1: Map of Nasarawa State showing sample sites in Nasarawa Eggon and Awe LGAs

Characterization of breeding sites

A reconnaissance survey was conducted to identify potential mosquito breeding sites before field sampling. A Garmin GPS navigator (eTrex®10; serial number: 53D020795) was used to record the coordinates of each identified site. The collected coordinates were transferred to QGIS version 3.38.4 for geo-referencing and the development of a GIS database. This database facilitated the mapping of all surveyed breeding sites and the generation of a malaria vector risk map for Awe and Nasarawa Eggon LGAs (Oforka *et al.*, 2024).

The presence of mosquito larvae was visually inspected in all designated water bodies with potential breeding suitability. Larval sampling was conducted monthly from July 2023 to June 2024 across the study locations, with collections carried out between 7:00 AM and 11:00 AM (Egwu *et al.*, 2018).

Sample collection

Larval collections were conducted monthly using a standard dipping technique (Wang *et al.,* 2020; Oforka *et al.*, 2024). Samples were placed in labelled plastic containers to prevent cross-contamination (Rodríguez-Ruano *et al.,* 2020) and transported under controlled conditions to the Muhammadu Buhari Institute of Research and Training (MBIRT), Federal University of Lafia. In the laboratory, larvae were reared under controlled conditions and fed finely ground fish food until adulthood for species identification, ensuring a systematic assessment of *Anopheles* species distribution and vector ecology.

Determination of physicochemical parameters

Water samples were collected alongside larvae from breeding sites and study locations, stored in labelled one-liter polyethylene bottles, and transported in an ice chest to the Fisheries and Aquaculture Laboratory, College of Agriculture, Science and Technology, Lafia, for physicochemical analysis. Temperature, pH, electrical conductivity, salinity, and total dissolved solids were measured in situ using an Oakton Multi-Parameter PCSTestr®35WP (serial number: 35425-10). Alkalinity, carbon dioxide, dissolved oxygen, nitrate, nitrogen dioxide, and phosphate were analyzed in the laboratory following APHA (1998) and Seal and Chatterjee (2023) protocols.

Development of *Anopheles* mosquito larvae to adult

The development of mosquitoes from larvae to adulthood was closely monitored. Larvae were identified to species level based on morphological traits (Gillies & Coetzee, 1987). They were reared in plastic trays (30 × 25 × 5 cm) at a density of 30 larvae per bowl, using water from their natural habitats (Hunt *et al.*, 2020). Newly hatched larvae were fed daily with 0.36 g of a 3:1 mix of finely crushed dog biscuits and brewer's yeast (Van Schoor *et al.*, 2020).

Data analysis

Data analysis was conducted using R statistical software version 3.6.1. Mean values was estimated for abundance and distribution of mosquito species and physicochemical parameters.Analysis of Variance (ANOVA) was used to test for the variation in the effect of physicochemical parameters.

RESULTS AND DISCUSSION

Checklist of field collected mosquito larvae in Awe and Nassarawa Eggon LGAs, Nasarawa State, Nigeria

A total of 2,158 mosquito larvae were collected from various habitats in Awe 1798(83.32%) and Nasarawa Eggon 360(16.68%) LGAs. Of all the field collected larvae, 1944(90.08%) were culicines while 214(9.92%) were anophelines (Figure 2). Consequently, there was a very high significant difference (R^2 = 16.147, df = 1, P<0.001) in the abundance of mosquito larvae collected from Awe and Nassarawa Eggon LGAs.

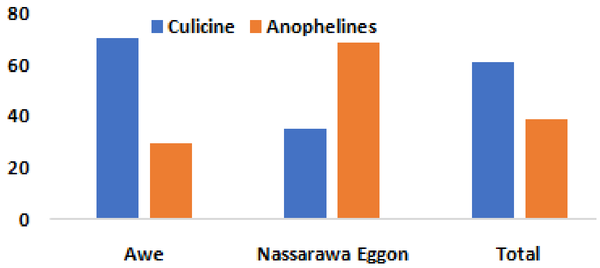

Figure 2: Checklist of field collected mosquito larvae in Awe and Nassarawa Eggon LGAs, Nasarawa State, Nigeria

Composition of emerged adult mosquito species in Awe and Nassarawa Eggon LGAs, Nasarawa State, Nigeria

A total of 1,067 (49.44%) mosquitoes successfully emerged into adulthood (Table 1). *Culex quinquefasciatus* was the most dominant species, accounting for 818 (76.67%) of the emerged adults, with a highly significant difference (R^2 = 30.986, df = 1, P < 0.001). This was followed by *Anopheles gambiae*, which constituted 143 (13.40%) of the emergent mosquitoes, while *Anopheles funestus* had the lowest emergence rate at 21 (1.97%).

Table 1: Composition of emerged adult mosquitoes in Awe and Nassarawa Eggon LGAs, Nasarawa State, Nigeria

LGA	Emerged Mosquito Species (%)						Total (%)
	C. quinquefasciatus (%)	*Aedes aegypti (%)*	Sub-Total	*Anopheles gambiae*	*A. funestus*	Sub-Total	
Awe	735(92.22)	62(7.78)	797(87.20)	106(90.60)	11(9.40)	117(12.80)	914(85.66)
Nassarawa Eggon	83(78.30)	23(21.70)	106(69.28)	37(78.72)	10(21.28)	47(30.72)	153(14.34)
Total (%)	**818(76.67)**	**85(7.97)**	**903(84.63)**	**143(13.40)**	**21(1.97)**	**164(15.37)**	**1067(49.44)**

Composition of emerged adultmosquitoes collected from Awe and Nassarawa Eggon LGA: R^2 = 30.986, df = 1, P< 0.001.

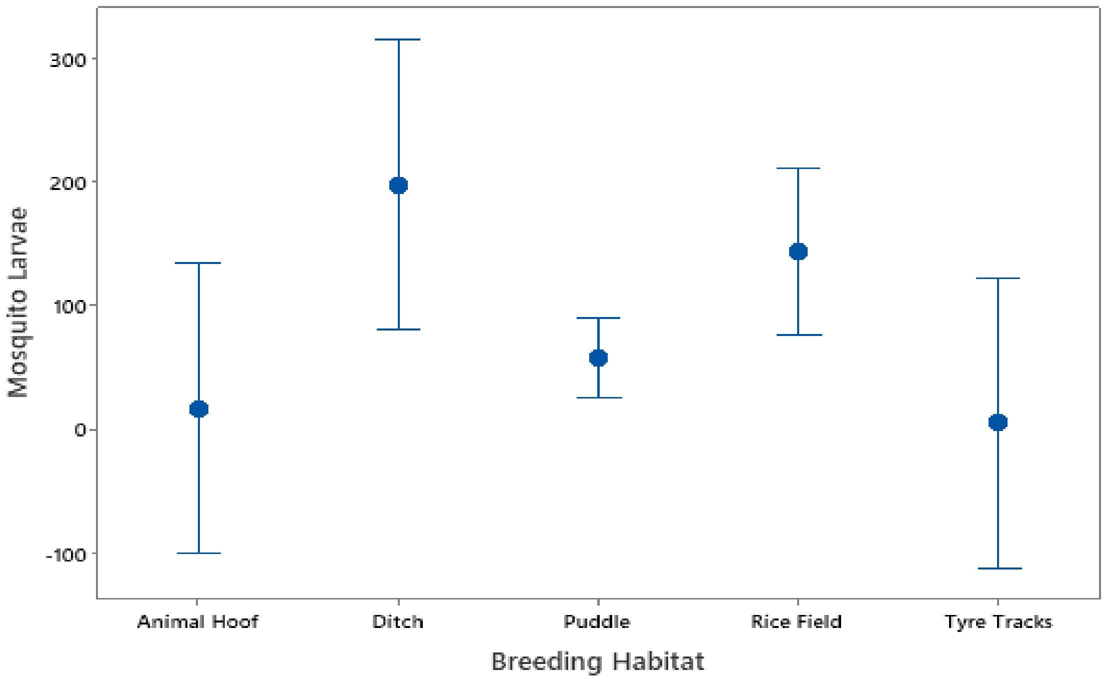

Figure 3: Mean Abundance of Culicine Mosquitoes Larvae in Relation to Breeding Habitats

Mean abundance of mosquitoes larvae in relation to breeding habitats

Mosquito larvae were most abundant in puddle habitat 1019(47.21%) followed by rice field habitat 755(34.99%), while animal hoof prints17(0.79%) accounted for the least population. Therefore, there was a significant difference (F=3.46, df=4, Adj.R^2=35.32%, P=0.037) in the mean abundance of mosquito larvae in relation to habitats as shown in Figure 3.

Mean abundance of mosquito larvae collected in relation to distance to the nearest house

The gradient 351-400m 788(36.52%) had the highest population of mosquito larvae, followed by the gradient 0-50m 532(24.65%), while gradient 451-500m 75(3.48%) had the least abundance of anopheline larvae (Figure 4). However, the mean abundance of mosquito larvae in relation to distance to nearest house showed no significant difference (F=0.80, df=9, Adj.R^2=0.00%, P=0.625).

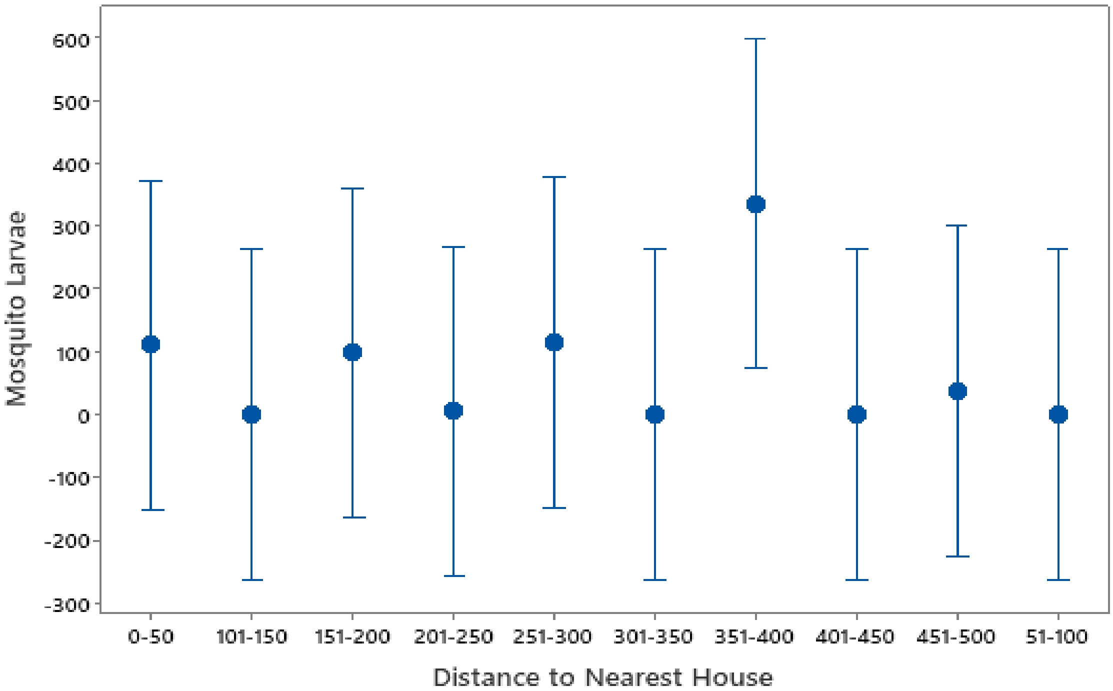

Figure 4: Mean abundance of culicine mosquito larvae collected in relation to distance to the nearest house

Table 2: Effect of physicochemical parameters on mosquito abundance across breeding habitats in Awe and Nassarawa Eggon LGAs, Nasarawa State

Physicochemical Parameters	Puddle		Rice Field		Animal Hoof		Ditch		Tyre Track	
	r	p	r	p	R	p	R	p	r	p
Temperature	0.69	0.009	0.977	0.138	0.416	0.076	0.41	0.361	-0.563	0.006
pH	0.326	0.277	0.063	0.96	-0.097	0.694	-0.371	0.412	0.043	0.849
Electrical Conductivity	-0.605	0.028	-0.997	0.046	0.339	0.155	-0.303	0.508	-0.484	0.023
Salinity	-0.506	0.077	-0.991	0.084	0.445	0.056	-0.368	0.417	-0.334	0.129
Total Dissolved Solids	-0.266	0.38	0.999	0.033	0.365	0.124	-0.58	0.172	-0.196	0.381
Alkalinity	0.189	0.536	0.821	0.386	-0.097	0.692	-0.416	0.353	-0.045	0.842
Carbon Dioxide	-0.373	0.209	-0.059	0.962	-0.054	0.825	0.029	0.95	-0.162	0.47
Dissolved Oxygen	0.558	0.048	-0.735	0.474	-0.049	0.842	0.011	0.981	0.343	0.119

Effect of physicochemical parameters on mosquito abundance across breeding habitats in Awe and Nassarawa Eggon LGAs, Nasarawa State

Asides from tyre track habitat (r=-0.563), temperature showed a positive correlation with mosquito abundance in puddle, rice field, animal hoof and ditch habitats (Table 2). However, temperature only showed a significant difference (P=0.009) in mosquito abundance in the puddle habitat. pH showed a positive correlation with mosquito larvae abundance in puddle, rice field and tyre track habitats (Table 2). However, in animal hoof (r=-0.097) and ditch (r=-0.371) habitats, a negative correlation was observed pH. Electrical conductivity showed a positive correlation with mosquito abundance only in animal hoof habitat (r=0.339) (Table 2). Notably, mosquito abundance showed significant difference in puddle (P=0.028), rice field (P=0.046), and tyre track (P=0.023) habitats respectively.

There was a positive correlation between salinity and mosquito larvae abundance only in animal hoof (Table 2). There was no significant difference recorded across the breeding habitats. Rice field and animal hoof habitats were positively correlated with total dissolved solids (Table 2). However, there was a significant difference in mosquito abundance in rice fields (P=0.033). Alkalinity showed a positive correlation with mosquito abundance only in puddle (r=0.189) and rice field (r=0.821) habitats (Table 2). There were no significant differences in the abundance of mosquito larvae across the breeding habitats. Carbon dioxide exhibited a positive correlation to the abundance of mosquito larvae only in ditch habitat (r=0.029) (Table 2). There were no significantt differences in the abundance of larvae across the breeding habitats. Dissolved oxygen showed a negative correlation to the abundance of mosquito larvae in rice field (r=-0.735), animal hoof (r=-0.049) habitats respectively (Table 2). Notably, there was a significantly (P=0.048) positive correlation with mosquito larvae abundance and puddle habitat (r=0.558).

The overwhelming dominance of culicine larvae (90.08%) compared to anopheline larvae (9.92%) aligns with the ecological adaptability of culicines to diverse breeding habitats. Culicines, particularly *Culex* and *Aedes* species, thrive in a broad range of stagnant water sources, including polluted and artificial water bodies often found in urban and semi-urban areas. In contrast, anophelines, the primary vectors of malaria, prefer transient, unpolluted, and sunlit water bodies with minimal organic contamination (Nambunga *et al.,* 2020). The significantly higher abundance of culicine larvae suggests an increased risk of arboviral diseases, including lymphatic filariasis and dengue, while the presence of anopheline larvae indicates a sustained malaria transmission risk in the study area.This finding is consistent with studies by Hinne *et al.* (2021) and DeSiervo *et al.* (2022), theyreported that culicines are more adaptable to anthropogenic habitats and tolerate a wider range of environmental conditions than anophelines. Additionally, Kinga *et al.* (2022) highlighted that *Anopheles* species typically require cleaner and more sunlit pools, which may be less common in highly disturbed environments. However, the current result differs from Osidoma *et al.* (2023) and Abdullaahi *et al.* (2020), who observed a higher occurrence of anophelines in Nasarawa and Sokoto States, respectively. This disparity could be attributed to differences in study locations, seasonal variations, and habitat availability. The significant variation in mosquito larval abundance between Awe and Nassarawa Eggon suggests spatial heterogeneity in breeding site availability. Awe, with its extensive agricultural activities, likely provides more stable and nutrient-rich breeding grounds favorable to mosquito proliferation. In contrast, the undulating terrain of Nassarawa Eggon may contribute to reduced standing water availability, limiting suitable breeding sites for both culicine and anopheline mosquitoes.

The successful emergence of 49.44% of collected mosquito larvae into adulthood highlights the favorable rearing conditions and species-specific survival rates under laboratory settings. The dominance of *Culex quinquefasciatus* (76.67%) aligns with previous findings (Omar *et al.,* 2022; Fagbohun *et al.,* 2020), which identified this species as the most prevalent culicine in urban and semi-urban environments. Its high emergence rate may be attributed to its ecological adaptability, rapid reproductive cycle, and strong tolerance to polluted breeding sites, including drainage ditches, septic tanks, and stagnant pools rich in organic matter (Jeanrenraud *et al.,* 2023; Busari *et al.,* 2023). This species' ability to thrive in various environmental conditions, along with its nocturnal feeding behavior, contributes to its widespread distribution and persistence as a dominant culicine species.The emergence of *Anopheles gambiae* and *Anopheles funestus* reinforces the ongoing malaria transmission risk in the study area. *An. gambiae,* a primary malaria vector, is well known for its preference for transient, sunlit, and unpolluted water bodies, while *An. funestus* is often associated with more permanent water sources with vegetation (Badolo *et al.,* 2022). The lower emergence rate of *An. funestus* compared to *An. gambiae* may indicate fewer suitable breeding sites for this species in the sampled locations. However, their presence suggests that malaria transmission remains a potential public health concern, particularly in areas with conducive breeding conditions.The significant difference in species composition highlights the ecological preferences and adaptability of the different mosquito genera. While culicines, particularly *C. quinquefasciatus*, dominate urban and polluted environments, anophelines thrive in cleaner, more natural habitats.

The high abundance of mosquito larvae in puddle habitats aligns with previous findings (Ekedo *et al.,* 2020), which reported that temporary water bodies provide optimal breeding conditions due to reduced predation pressure and high organic content. Puddles often accumulate nutrient-rich debris, supporting microbial growth, which serves as a crucial food source for mosquito larvae. This preference is particularly evident among *Culex* and *Aedes* species, which are well-documented to thrive in ephemeral aquatic habitats with varying organic loads (Busari *et al.,* 2023). The significant presence of mosquito larvae in rice field habitats suggests that agricultural activities contribute substantially to mosquito proliferation. *Anopheles* species, particularly *An. gambiae*, have been reported to favor rice fields due to their shallow, sunlit, and relatively unpolluted waters (Weidig *et al.,* 2022). The irrigation practices in rice cultivation create ideal conditions for *Anopheles* larvae to develop, thereby sustaining malaria vector populations in agricultural areas (Kameke *et al.,* 2021). This result agrees with studies by Oduwole *et al.* (2020), which highlighted the role of agricultural landscapes in shaping mosquito breeding patterns. The relatively low abundance of larvae in animal hoof prints suggests that while these microhabitats can retain water, they may be less stable for prolonged mosquito development. However, their role as temporary breeding sites for both culicines and anophelines has been documented, especially in rural settings where livestock presence influences water retention dynamics (Oduwole *et al.,* 2020). The significant difference in larval abundance across habitat types underscores the importance of habitat-specific mosquito control strategies. While culicines exhibit broad habitat plasticity, *Anopheles* species demonstrate a more selective preference for clean, sunlit environments.

The highest abundance of mosquito larvae at the 351–400 m gradient suggests that breeding sites farther from human settlements may provide optimal ecological conditions, such as reduced anthropogenic disturbances, stable water retention, and lower exposure to domestic water management practices. This observation aligns with the findings of Munyao *et al*. (2020), who reported that *Culex* species prefer semi-permanent water bodies with high organic content, often found in peri-domestic and rural areas. Moreover, *Anopheles* mosquitoes, particularly *An. gambiae*, tend to thrive in open, sunlit breeding sites with limited human activity, which could explain their occurrence in these distant habitats (Kinga *et al.,* 2022). The relatively high abundance of mosquito larvae at the 0–50 m gradient supports the findings of Ngadjeu *et al.* (2020), who noted that *Culex* and *Aedes* mosquitoes readily breed close to human habitation, particularly in areas with wastewater accumulation and stagnant pools. The presence of *Anopheles* species in these environments suggests that some members of this genus may also exploit peri-domestic water bodies, especially when unpolluted breeding sites are scarce (Weidig *et al.,* 2022). However, *Anopheles* larvae are generally more sensitive to water pollution and may be less dominant in areas with high organic contamination compared to *Culex* species (Amao *et al.,* 2022). The significantly lower larval abundance at the 451–500 m gradient contrasts with the study by Weidig *et al.* (2022), who reported that *Culex* mosquitoes exhibit high adaptability and can breed even at greater distances from human habitation, provided suitable water conditions exist. The lower abundance at this gradient may be attributed to habitat limitations, such as insufficient water accumulation or increased predation pressures in more remote locations. The lack of a significant difference in mosquito larval abundance across distance gradients suggests that both *Culex* and *Anopheles* species exhibit spatial adaptability, utilizing breeding habitats irrespective of their proximity to human dwellings. This finding differs from Amao *et al.* (2022), who found a strong correlation between culicine larval abundance and household proximity due to the preference of *Culex* mosquitoes for polluted domestic water sources. The presence of *Anopheles* mosquitoes across different gradients further highlights their ability to exploit both peri-domestic and semi-rural habitats, emphasizing the need for comprehensive vector control strategies that address multiple breeding site types.

The relationship between physicochemical parameters and mosquito larval abundance varied across habitats, highlighting the role of environmental factors in shaping breeding conditions. Temperature exhibited a positive correlation with mosquito abundance in most habitats, except tyre tracks, with a significant effect in puddles. This supports findings by Nwonumara and Nwere (2021), who reported that higher temperatures accelerate mosquito development. Similarly, pH showed mixed effects, displaying positive correlations in puddles, rice fields, and tyre tracks, while negative correlations were observed in animal hoof and ditch habitats. These results align with Obi *et al.* (2019), who found that mosquito larvae generally thrive in slightly alkaline environments. Electrical conductivity positively influenced mosquito abundance in animal hoof habitats, consistent with Sossou *et al.* (2022), who reported that higher ionic concentrations favor mosquito larval development. Total dissolved solids (TDS) were significantly associated with mosquito abundance in rice fields, corroborating the findings of Oforka *et al.* (2024), who noted that nutrient-rich water bodies enhance mosquito breeding. Dissolved oxygen had varying effects, showing a positive correlation in puddles but a negative correlation in rice fields and animal hoof habitats. This aligns with the observations of Kinga *et al.* (2022) and Oforka *et al.* (2024), who reported that some mosquito species, particularly culicines, can thrive in low-oxygen environments. These findings underscore the importance of targeted vector control strategies, including environmental modifications to regulate temperature, pH, and nutrient levels, thereby limiting mosquito breeding and reducing the risk of vector-borne diseases.

CONCLUSION

This study provides valuable insights into the ecological determinants of mosquito abundance in Awe and Nasarawa Eggon LGAs, emphasizing the significance of habitat characteristics and physicochemical factors in shaping mosquito distribution. The high abundance of mosquito larvae in puddles and rice fields underscores the importance of temporary water bodies as key breeding sites, while the relatively low abundance in animal hoof prints suggests that smaller, ephemeral water bodies may contribute less to overall mosquito proliferation. The significant correlation between mosquito abundance and environmental variables such as temperature, pH, and dissolved oxygen highlights the role of water quality in influencing larval survival and development. However, the lack of a consistent relationship across all physicochemical parameters suggests that mosquito breeding is influenced by a combination of biotic and abiotic factors. The dominance of *Culex quinquefasciatus* among the emerged adults raises concerns about the potential risk of arboviral and filarial disease transmission in the study areas.

Furthermore, the study demonstrates that mosquito abundance does not significantly vary with distance from human habitation, reinforcing the notion that diverse ecological gradients can sustain mosquito populations irrespective of proximity to households. These findings align with previous studies that have identified environmental suitability as a key driver of mosquito distribution.

Recommendations

Effective control of mosquito populations in Awe and Nasarawa Eggon LGAs requires an integrated approach that combines environmental management, community participation, scientific research, and policy enforcement. Given that puddles and rice fields were identified as the most productive breeding habitats, targeted larval source management should be prioritized. Environmental modifications, including draining stagnant water, filling puddles, and applying larvicides, can significantly reduce mosquito proliferation. Additionally, promoting land use practices that minimize the creation of artificial breeding sites is essential for long-term vector control.

Community engagement remains a cornerstone of sustainable mosquito management. Public awareness campaigns should educate residents on eliminating potential breeding sites, particularly in rural and peri-urban areas where mosquito proliferation is prevalent. Strengthening community participation in surveillance and control activities, such as reporting mosquito hotspots and participating in environmental sanitation, will enhance the effectiveness of vector management strategies. Continuous monitoring of mosquito populations and their habitat characteristics is essential for understanding seasonal variations and improving control interventions. Since physicochemical parameters such as temperature, pH, and dissolved oxygen influence mosquito abundance, integrating environmental and climatic data into predictive models can aid in the early detection of potential disease outbreaks.

Further research should assess the vectorial capacity of *Culex quinquefasciatus* for arboviral and filarial pathogens and evaluate its resistance to commonly used insecticides. This will provide valuable insights for refining control strategies and ensuring the efficacy of vector management programs. Policy implementation and government support are critical to sustaining mosquito control efforts. Urban planning and infrastructure development should incorporate measures to minimize artificial breeding sites, such as proper drainage systems and waste management strategies. Strengthening regulations on water storage practices and promoting the use of insecticide-treated materials can further reduce mosquito-borne disease transmission. By integrating scientific research, community involvement, and policy-driven interventions, a comprehensive and sustainable approach to mosquito control can be established to mitigate the public health risks associated with mosquito vectors in Nasarawa State.

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