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ORIGINAL RESEARCH ARTICLE

Occurrence and distribution of *Culex* mosquito larvae in relation to breeding habitat characteristics in four communities in Minna, North-Central, Nigeria

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Abstract

This study was designed to examine the influence of the features of selected conventional mosquito breeding habitats on the abundance of *Culex* mosquitoes in selected communities in Minna, Nigeria. This approach is crucial for analysing potential risks associated with these habitats and implementing effective and long-term larval source management interventions in the area. The larval stages of the mosquitoes were collected systematically using the dipping method from five breeding habitat types (rain pools, septic tanks, rice fields, drainages and large water bodies) at four study sites in the study area. The physical, chemical, and biological characteristics of the selected habitats were established using specific criteria. Mosquito abundance, habitat productivity, and similarities were all estimated. Five *Culex* mosquito species were encountered in the following decreasing order of abundance: *Cx. quinquefasciatus* (59.85 ± 19.24 larvae/dip) > *Cx. salinarius* (31.21 ± 22.23 larvae/dip) > *Cx. restuans* (23.57 ± 19.24 larvae/dip) > *Cx. nigripalpus* (20.56 ± 17.72 larvae/dip) > *Cx. tarsalis* (14.29 ± 16.99 larvae/dip). Rain pools had the lowest productivity (33.48 ± 14.81 larvae per dip), while drainages produced the most (41.48 ± 17.37 larvae per dip). No mosquito larvae were found in large water bodies. The larval habitat types exhibited various degrees of similarities and differences in their characteristics. Similarly, the abundance of mosquito species showed various degrees of similarities with numerous physicochemical factors. Thus, the study revealed that the productive mosquito habitat types have characteristics that promote mosquito proliferation. This poses epidemiological risks to the population in the study area. The information generated in this study will be vital for an effective and sustainable vector control intervention in the study area.

Keywords Disease risk · Lymphatic filariasis · Productivity · Urbanization

Introduction

Mosquitoes transmit disease pathogens that cause human diseases such as malaria, yellow fever, and lymphatic filariasis (Deribe et al. 2021). *Culex* mosquitoes are among the most dreaded mosquito vector species. Typically, the *Culex* mosquito has four life stages: three aquatic (egg, larva, and pupa) and one terrestrial (adult or imago). The genera have been shown to reproduce in nearly any suitable water-containing vessel or -retaining structure (Krol et al. 2024). These species flourish in tropical and subtropical regions of the world, including Nigeria, and are known for transmitting filarial worms that cause lymphatic filariasis (LF) (Elkanah et al. 2017).

Minna is a developing city in North Central Nigeria with many potential mosquito breeding sites. This is due in part to the city's extensive agricultural activity, increasing urbanisation, and other man-made activities. These activities promote mosquito proliferation and increase the risk of disease outbreaks.

Lymphatic filariasis is a neglected tropical disease (NTD) with an overwhelming burden, threatening about

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863 million people in 47 countries globally, and with an estimated more than 120 million infected with the causal parasite. As a disease, LF has rendered more than 40 million individuals disabled and deformed (World Health Organisation WHO 2022). The disease is widespread in Nigeria (Adamu et al., 2020).

The primary focus of mosquito-borne disease control has been vector control with the use of insecticides. Although this method is successful, it has not produced the desired results. This is partly due to increased insecticide resistance occasioned by the long-term usage of insecticides (Talipouo et al. 2021). These difficulties necessitate the use of other vector control tactics, such as larval source management (LSM). However, for any larval control technique to be effective and sustainable, an understanding of the biology of the local vector species is required, which sadly differs from one place or habitat to the next (McCann et al. 2017).

As a result, gathering location- and habitat-specific data on the bionomics of juvenile mosquito vector life stages, as well as characterising larval breeding sites, is critical for generating sufficient data for effective LSM intervention. The purpose of this study was to elucidate the biological, physical, and chemical properties of *Culex* mosquito breeding sites in Minna, as well as the occurrence and relative abundance of vector species, for effective and sustainable application of larval source control strategy.

Materials and methods

Study period, area and sites

This study was conducted in Minna, Niger State, Nigeria, during the late rainy season in 2018 (August to November 2018) and the early rainy season in 2020 (April to July 2020). Minna, the capital city of Niger State, is at latitude 9° 35′ 0.7980′ N and longitude 6° 32′ 46.7376′ E, with a land area of 88 km2 (Fig. 1). The city is home to an estimated 1.2 million people and has a tropical climate with average annual temperatures of 30.20 °C, relative humidity of 61.00%, and rainfall of 1334.00 mm. The research area has two different seasons: rainy (May–October) and dry (November–April). The vegetation of Minna is typically grass-dominated savannah with scattered trees.

Minna, as a quickly developing community, has seen an increase in human population, resulting in increased anthropogenic activities such as agricultural input-intensive farming and indiscriminate solid waste deposition, which clogs water drainage systems. These have contributed to the creation of habitats and conditions that promote mosquito breeding.

The study was conducted at four study sites: Bosso, Maikunkele, Chanchaga, and Gidan Kwano, as previously described (Ukubuiwe et al. 2022). Five mosquito larval habitat types were chosen for sampling at each study location (rice fields, rain pools, septic tanks, drainages, and large water bodies). These habitat types were chosen based on their size, length of existence, degree of anthropogenic activity, source, and level of organic pollution.

Collection, preservation, and identification of larval mosquito species

Mosquito larvae were collected from all the selected habitats in the morning (0700 to 0900 local time) monthly from August 2018 to July 2020. Mosquito larvae were collected using the dipping method as reported by Ukubuiwe et al. (2022). The process involves immersing a 350 mL-capacity white plastic-cup larval dipper into a habitat twenty (20) times while ensuring that none of the collected larvae overflow.

The collected mosquito samples were divided into Culicine and Anopheline species and preserved in a 4% formaldehyde solution. Larvae were identified with a light microscope using the taxonomic and morphological keys of Hopkins (1952) and Gillies and De Meillon (1968) for Culicine and Anopheline mosquito species, respectively.

Characterization of *Culex* mosquito breeding habitats

Biological characterization

A qualitative biological description of larval environments was conducted at all study locations and habitat categories. This included the presence or absence of conspecifics (Anopheline and Culicine mosquito larvae and pupae), aquatic plants in the middle, floating or near the edge, and predators as described by Sattler et al. (2005).

Physical characterization

These traits were quantified and then expressed qualitatively using categories. The distances between habitats and the next human-inhabited dwelling and prospective breeding site were measured using a tape rule and classified as less than 10 m, 10 to 100 m, and more than 100 m. Habitat depths were measured using a calibrated metre rule and classified into three categories: less than 0.5 m, between 0.5 and 1 m, and greater than 1 m. Habitat perimeters were divided into three categories: less than one metre, one to ten metres, and more than ten metres.

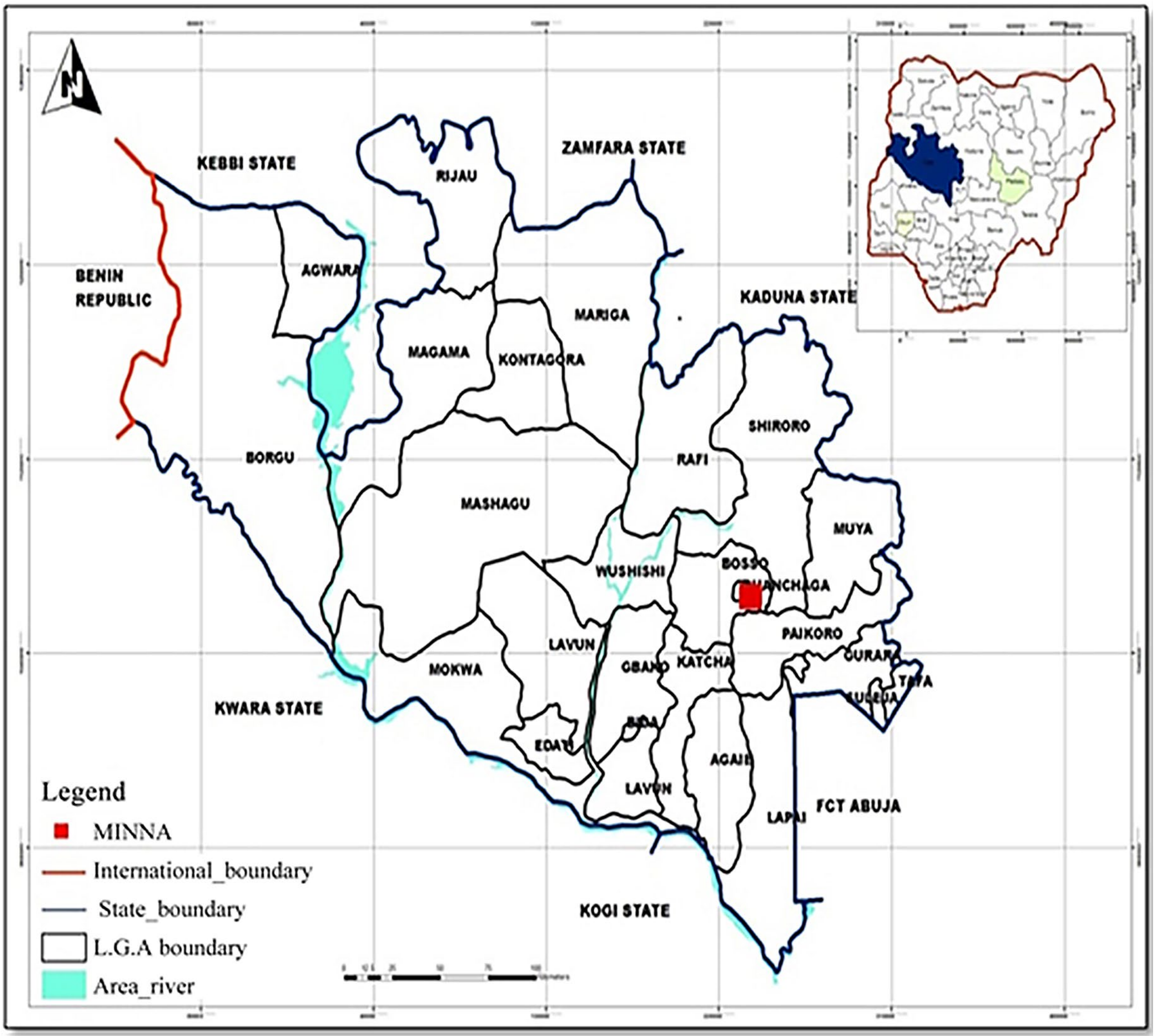


Fig. 1 Map Nigeria and Niger state showing Minna city

The turbidity of the mosquito habitats was classified as clear, turbid, or very turbid based on the ability to view the floor. The percentage of shade cover was defined as quarterly (0–25%), semi (26–50%), three-quarters (51–75%), or entirely covered (76–100%), depending on the shade provided by the tree covers or structures. Temperature was measured in situ with a mercury-in-glass thermometer and classified into intervals of 25–26, 27–28, 29–30, 31–32, 33–34, 35–36, 37–38, and 39–40 °C, according to the methods by Sattler et al. (2005).

Chemical characterization

Water samples were collected monthly (during larval collection) from the selected breeding habitats at all study sites between 0700 and 0900 h using 250 mL bottles (for Biochemical Oxygen Demand, BOD) and 1-L capacity rubber containers (for other chemical analyses). The containers were carefully tagged and transported to the Department of Water, Aquaculture, and Fisheries Technology's (WAFT) laboratory at the Federal University of Technology, Minna, Nigeria for analysis. During larval collection, a digital water quality tester (model EZ-9908) was used to measure temperature (°C), pH, TDS (mg/L), and EC (µS/cm). Dissolved oxygen (DO) was determined in mg/L using an AMTAST DO meter.

Other chemical parameters (biochemical oxygen demand, BOD, chemical oxygen demand, COD, alkalinity, nitrate, and phosphate contents) were determined using standard procedures for water and wastewater examination (American Public Health Association, APHA 1998) and expressed in mg/L.

Table 1 Species composition and relative abundance (aggregate) of *Culex* mosquitoes larvae in Minna during the study period

Mosquito Species	Aggregate (Mosquito larvae per dip)	Range (Mosquito larvae per dip)	Percentage Relative Abundance	Heydemann's Dominance Structure
Culex salinarius	$31.21 \pm 22.23^{c*}$	8.98–53.44	20.82	Dominant
Cx. tarsalis	14.29 ± 16.99^{a}	2.70–31.28	9.53	Subdominant
Cx. restuans	23.57 ± 19.24^{b}	4.33–41.29	15.73	Dominant
Cx. nigripalpus	20.56 ± 17.72^{b}	2.84–38.28	13.72	Dominant
Cx. quinquefasciatus	59.85 ± 35.76^{d}	24.09–95.61	39.93	Eudominant
Total	149.88 ± 64.36	85.52–214.24	100.00	

*Values followed by the same subscript alphabet in a column are not significantly different ($p > 0.05$)

Data analysis

All data collected were recorded and cleaned using Excel (Microsoft Excel, 2019 Office). The analyses were done using R software (RCore Team 2022). The number of mosquitoes collected was given as larvae per dip. Descriptive statistics (mean, standard deviation, and range) for entomological variables were calculated using the *BiodiversityR* package (Kindt and Coe 2005). Means, medians, and ranges of physicochemical variables were calculated using the *dplyr* package (Wickham et al. 2022).

The Kolmogorov-Smirnov test was employed to determine data normality. To assess differences in mosquito species abundance, the Kruskal-Wallis's test was employed for nonnormally distributed data and ANOVAs for normally distributed data. Statistical differences between means were separated using post hoc tests (Ferroni test for nonnormally distributed data and Dunn-Bonferroni adjustment for normally distributed data). The statistical comparison of means was done at a p-value of 0.05. Heydemann's classification was used to evaluate species dominance (eudominant = > 30%, dominant = 11–30%, subdominant = 6–10%, uncommon = 1–5%, and subrare = < 1%) (Amao et al. 2018).

The *corrplot* package was used to perform Spearman's rank correlations. A correlation matrix was utilised to calculate the coefficient of rank correlation, which indicates whether correlations are positive or negative. The relationships between *Culex* mosquito species abundance and physicochemical factors were investigated. Focused principal component analysis (FPCA) was performed to determine the factors' particular effect on individual mosquito species (Falissard 2022). Using the *Factoshiny* package, the habitats at the sampling sites were classified using cluster analysis based on similarities in biological, physical, and chemical properties (Vaissie et al. 2021).

Table 2 Habitat-wise aggregate of *Culex* mosquito larvae in Minna during the study period

Habitat	Aggregate (Mosquito larvae per dip)	Range (Mosquito larvae per dip)	Percentage Habitat Contribution
Rice Fields	$36.35 \pm 17.75^{b*}$	18.60–54.10	24.25
Rain pools	33.48 ± 14.81^{b}	18.67–48.29	22.34
Septic tanks	38.58 ± 14.42^{b}	24.16–53.00	25.74
Drainages	41.48 ± 17.37^{b}	24.11–58.85	27.67
Large Water Bodies	0.00 ± 0.00^{a}	0.00–0.00	0.00
Total	149.88 ± 64.36	85.52–214.24	100.00

*Values followed by the same subscript alphabet in a column are not significantly different ($p > 0.05$)

Results

Species composition, relative abundance, and dominance status of *Culex* mosquitoes larval in Minna during the study period

The composition and relative abundance of *Culex* mosquito species encountered in breeding habitats in Minna are shown in Tables 1 and 2; Fig. 2. Five species of *Culex* mosquitoes were encountered during the study period: these included *Cx. salinarius*, *Cx. tarsalis*, *Cx. restuans*, *Cx. nigripalpus*, and *Cx. quinquefasciatus* (Table 1). However, their presence was limited to four habitats (rice fields, rain pools, septic tanks, and drainages) out of the five sampled habitats (Table 2). Large water bodies were devoid of *Cx.* Mosquito species.

The relative number of mosquito species differed significantly across the investigated habitats ($p < 0.001$). *Culex quinquefasciatus* was the most abundant, followed by *Cx. salinarius*, and then *Cx. restuans* and *Cx. nigripalpus*. *Culex tarsalis* was the least abundant (Table 1). According to Heydemann's classification, the study area's *Culex* mosquito population consisted of one eudominant species (*Cx. quinquefasciatus*), three dominant species (*Cx. salinarius*, *Cx. restuans*, and *Cx. nigripalpus*), and one subdominant species (*Cx. tarsalis*) (Table 1).

There was no significant variation ($p = 0.08$) in the number of mosquito species encountered in larval habitats. The

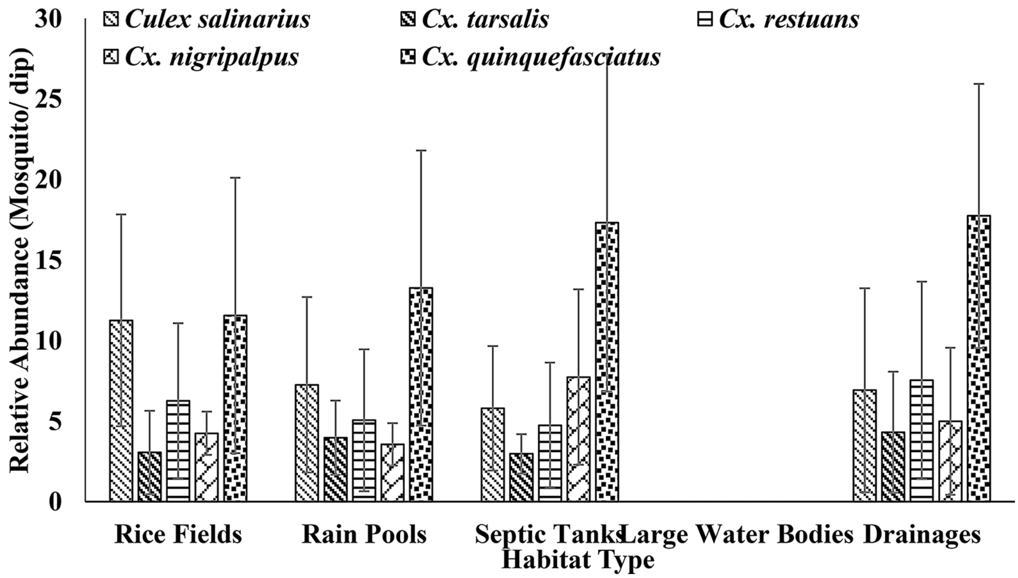


Fig. 2 Relative abundance of *Culex* mosquito larvae in Minna during the study period

Table 3 Biological Characterisation of *Culex* mosquitoes breeding habitats in Minna

Biological Character	Mean Percentage Distribution (Minna)	Range (%)
Anopheles larvae	42.00 ± 40.40	0.00–90.00
Culicine larvae	80.00 ± 44.72	0.00–100.00
Anopheles and Culicine pupae	68.00 ± 39.93	0.00–65.00
Vegetation in the middle of the habitat	45.62 ± 39.94	0.00–100.00
Vegetation along the edge of the habitat	69.00 ± 39.54	15.00–100.00
Presence of floating plants	48.31 ± 37.14	0.00–100.00
Presence of predators	70.00 ± 39.37	10.00–100.00

Total Numbers of Habitats sampled = 93; RF = Rice Fields, RP = Rain Pools, ST = Septic Tanks, DR = Drainages, LWB = Large water bodies*Values expressed as Mean ± SD of mean; **Values expressed as percentage distribution

percentage contribution of habitats to the mosquito population was nearly identical (range = 22.34 to 27.67%). Drainages were the most productive habitat type, whereas rain pools were the least productive (Table 2).

Biological characterization of *Culex* mosquitoes breeding habitats in Minna

Presence of *Anopheles* larvae

All the *Culex* mosquito-productive habitats examined during the study were positive for *Anopheles* larvae. Less than 25% of the septic tanks and drainages were positive for Anopheline larvae, whereas over 75% of the rice fields and rain pools had Anopheline larvae present (Table 3). No Anopheline mosquito was encountered in large water bodies.

Presence of culicine larvae

Most of the habitats studied (more than 80%) had Culicine larvae (Fig. 3).

Presence of mosquito pupal life stages

Not every habitat productive with the larval stages of mosquitoes was positive for mosquito pupae. A higher percentage (65%) of the drainages studied and the majority (over 80%) of the rice fields, rain pools, and septic tanks were positive for mosquito pupae (Fig. 3).

The presence of vegetation in the middle or edge of the habitat or floating

The distribution of aquatic vegetation within habitats was 45.62 ± 39.94, 69.00 ± 39.54, and 48.31 ± 37.14% for floral species in the middle, borders, and floating areas, respectively (Table 3). All rice fields sampled were positive for these vegetation-type distributions. Most rain pools featured vegetation in the centre (70%), along the borders (80%), and as floating plants (50%). The septic tanks contained no floating plants in the middle. Furthermore, all the big water bodies studied had floral species growing along their edges (Fig. 3).

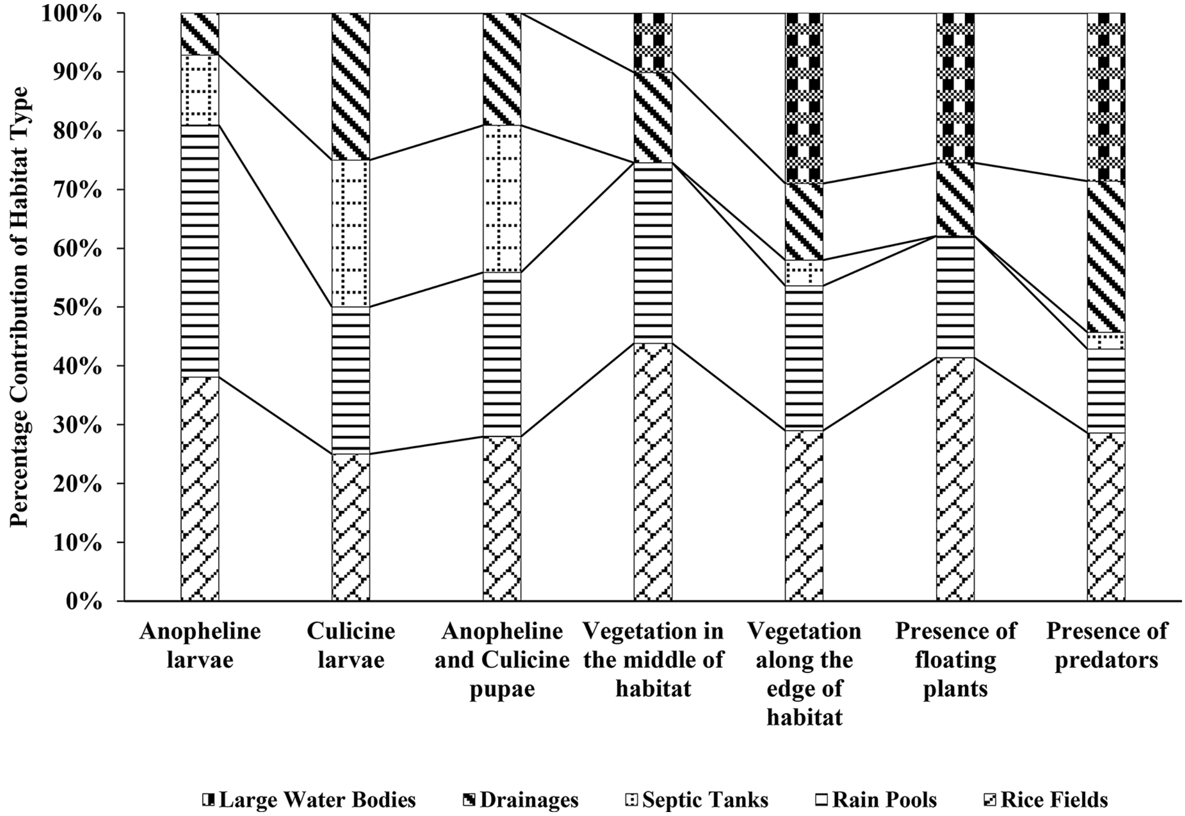


Fig. 3 Percentage contribution of habitat types to biological characteristics of *Culex* mosquitoes breeding habitats in Minna

Presence of potential predators

Potential mosquito larvae predators were found in a higher proportion in the habitats studied (more than 70%). All rice fields and large water bodies sampled were positive for predators. Predators were found in 90% of the drainages and 50% of the rain pools studied, with only 10% of septic tanks sampled being positive for predators (Fig. 3).

Similarities in biological features of *Culex* mosquitoes breeding habitats in Minna during the study period

Cluster analysis indicated varying degrees of similarity and dissimilarity in the biological parameters of the selected mosquito breeding habitats in Minna during the study period (Fig. 4). Except for the rice fields at Gidan Kwano and Maikunkele sampling location, the rice fields were similar in their biological features. Rain pools and septic tanks in Gidan Kwano and Maikunkele shared similar characteristics. The drainage systems in Bosso and Chanchaga were similar but different from those in Maikunkele and Gidan Kwano. However, the rain pools in Bosso were biologically similar to the drainages in Gidan Kwano (Fig. 4).

Physical characterization of *Culex* mosquitoes breeding habitats in Minna

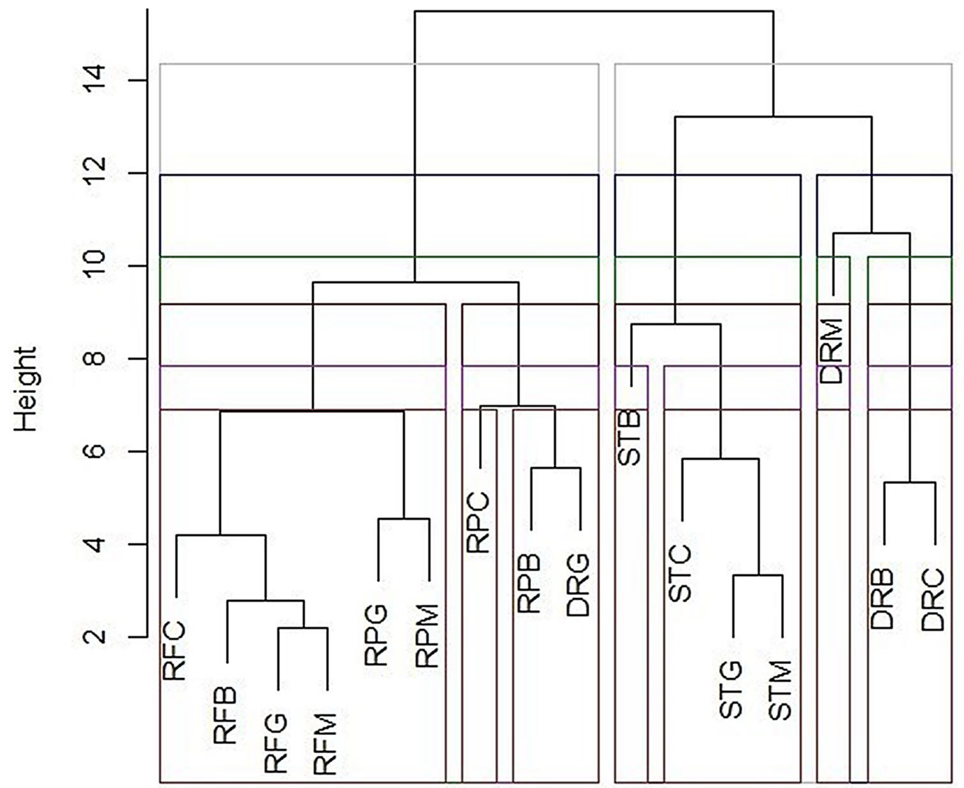
Distance from nearest human habitation

The Kruskal-Wallis test revealed that over 40% of mosquito larval habitats were within 10 m of human settlement. Less than half of the large water bodies and a very small proportion (10%) of the rain pools sampled were within 10 to 100 m of residential homes. Similarly, only 10% of the septic tanks were situated at distances of more than 100 m (Fig. 5).

Distance from nearest adult-stage resting sites

Half of the septic tanks studied ($n=20$) were less than 10 m away from an adult-stage resting site, while fewer than half (45%; $n=20$) of the rain pools observed were 10 to 100 m away from the nearest adult resting sites. Less than half of the rice fields ($n=20$; 40%) and large water bodies (46.15%) sampled were more than 100 m from the nearest adult resting locations (Fig. 5).

Fig. 4 Cluster of Biological features of *Culex* mosquitoes breeding habitats in Minna. STM–Septic Tanks in Maikunkele, RFM–Rice Fields in Maikunkele, RPM-Rain Pools in Maikunkele, DRM–Drainages in Maikunkele, STC–Septic Tanks in Chanchaga, RFC–Rice Fields in Chanchaga, RPC-Rain Pools in Chanchaga, DRC–Drainages in Chanchaga, STB–Septic Tanks in Bosso, RFB–Rice Fields in Bosso, RPB-Rain Pools in Bosso, DRB–Drainages in Bosso, STG–Septic Tanks in Gidan Kwano, RFG–Rice Fields in Gidan Kwano, RPG-Rain Pools in Gidan Kwano, DRG–Drainages in Gidan Kwano



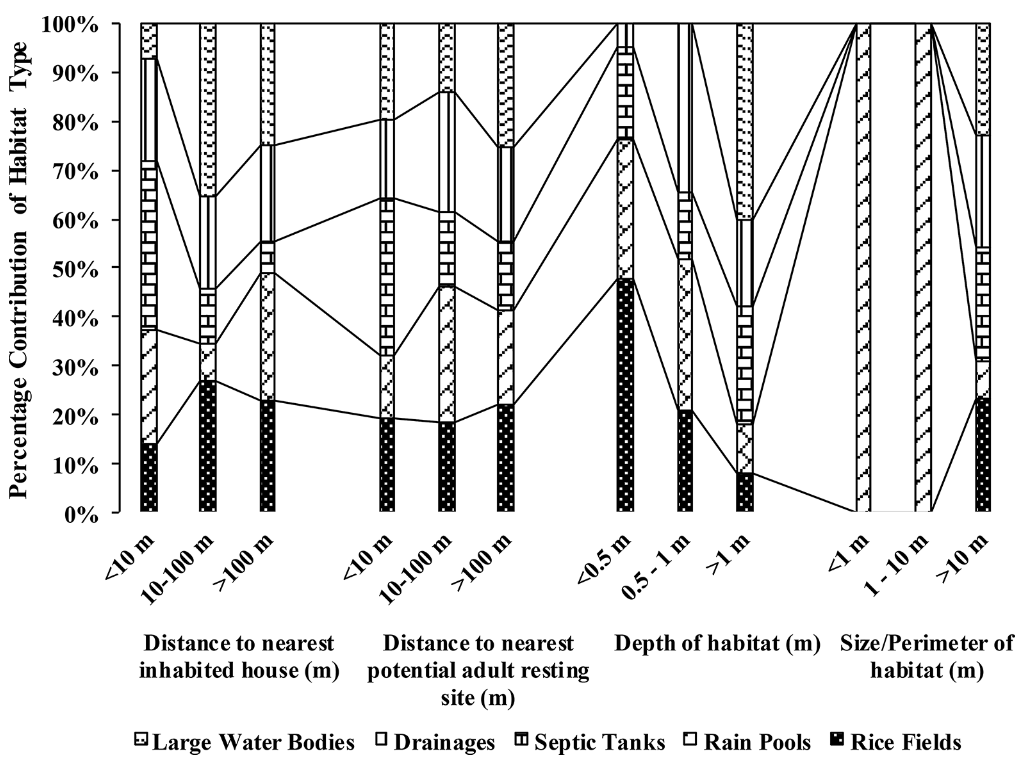


Fig. 5 Percentage contribution of habitat types to physical characteristics of *Culex* mosquitoes breeding habitats in Minna

Table 4 Mean percentage distribution of physical characteristics of *Culex* mosquitoes breeding habitats in Minna

Physical Characteristic	Category	Mean Percentage Distribution	Range (%)
Distance to the nearest inhabited house (m)	< 10	43.08 ± 22.41[b]*	15.38–75.00
	10–100	26.23 ± 14.70[a]	10.00–46.15
	> 100	30.69 ± 12.19[a]	10.00–40.00
Distance to nearest potential adult resting site (m)	< 10	31.15 ± 11.39[a]	20.00–50.00
	10–100	32.62 ± 9.54[a]	23.08–45.00
	> 100	36.23 ± 7.77[a]	25.00–46.15
Depth of habitat (m)	< 0.5	21.00 ± 20.12[a]	0.00–50.00
	0.5-1	29.00 ± 20.12[b]	0.00–50.00
	> 1	50.00 ± 32.21[c]	20.00–100.00
Size/Perimeter of habitat (m)	< 1	8.00 ± 17.89[a]	0.00–40.00
	1–10	5.00 ± 11.18[a]	0.00–25.00
	> 10	87.00 ± 29.07[b]	35.00–100.00

Total Numbers of Habitats sampled = 93; *Values with similar alphabet superscripts in a column for a category of a feature are not significantly different ($p > 0.05$)

Depth of habitat

The Kruskal-Wallis test showed that 50.00 ± 32.21% of the studied habitats were deeper than 1 m (Fig. 5; Table 4). Fifty per cent of the rice fields studied were less than 0.5 m deep. Rain pools (45%) and drainages (50%) were on average within the 0.5–1 m depth category. Most septic tanks (60%, $n = 20$) and all large bodies of water (100%, $n = 13$) were deeper than 1 m.

Size of habitat

Most of the investigated habitats (< 85%) were wider than 10 m. The rice fields, septic tanks, drainages, and large water bodies sampled all had perimeters of more than 10 m. Most of the rain pools (40%, $n = 20$) were smaller than one metre in size (Fig. 5; Table 4).

Degree of turbidity

In terms of clarity, a large proportion of the investigated habitats were murky. Most drainages (60%, $n = 20$), septic tanks (55%, $n = 20$), rice fields (50%, $n = 20$), and rain pools (40%, $n = 20$) were turbid. Neither of the septic tanks was clear. The majority of the large water bodies (more than 80%, $n = 13$) were clear, and none were particularly muddy (Fig. 6; Table 5).

Temperature and pH

Over half (50%) of the habitats sampled throughout the study had temperatures within the 25 to 26 degrees Celsius temperature category. Although most of the rice fields and drainages observed were within the 27–28 °C category, only the rain pools were within the 31–32 and 33–34 °C temperature categories (Fig. 6). The water pH of the examined habitats was commonly between 6.0 and 8.0 (Fig. 6).

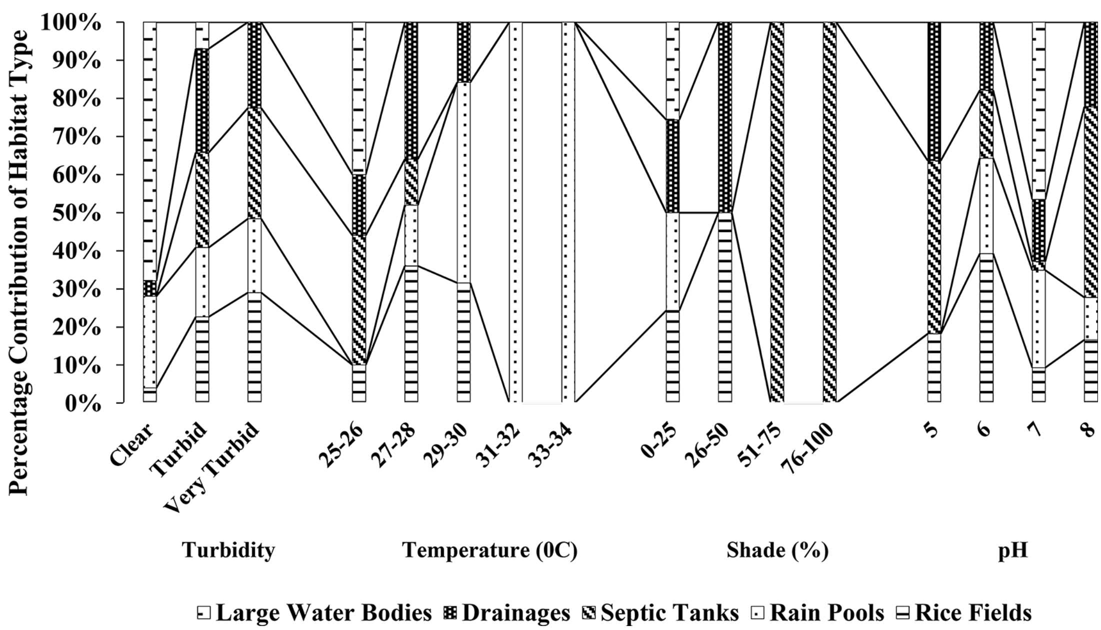


Fig. 6 Percentage contribution of habitat types to physical characteristics of *Culex* mosquitoes breeding habitats in Minna

Table 5 Percentage distribution of physical characteristics of *Culex* mosquitoes breeding habitats in Minna

Physical Characteristic	Category	Mean Percentage Distribution	Range (%)
Turbidity	Clear	$29.92 \pm 35.37^{a*}$	5.00–84.62
	Turbid	44.08 ± 17.66^{b}	15.38–60.00
	Very Turbid	31.00 ± 18.51^{a}	0.00–45.00
Temperature (^{0}C)	25–26	50.00 ± 41.68^{c}	0.00–100.00
	27–28	25.00 ± 19.69^{b}	0.00–45.00
	29–30	19.00 ± 21.33^{b}	0.00–30.00
	31–32	3.00 ± 6.71^{a}	0.00–15.00
	33–34	3.00 ± 6.71^{a}	0.00–15.00
Shade (%)	0–25	78.00 ± 43.67^{c}	0.00–100.00
	26–50	2.00 ± 2.74^{a}	0.00–5.00
	51–75	5.00 ± 11.18^{a}	0.00–25.00
	76–100	15.00 ± 33.54^{b}	0.00–75.00
pH	5**	11.00 ± 11.40^{a}	0.00–25.00
	6	28.00 ± 19.87^{b}	0.00–55.00
	7	43.00 ± 36.84^{c}	5.00–55.00
	8	18.00 ± 16.81^{a}	0.00–45.00

Total Numbers of Habitats sampled = 93; * *Values with similar alphabet superscripts in a column for a category of feature are not significantly different at $p = 0.05$. Values expressed as Mean ± SD of the mean. **Rounded to full numbers

Degree of cover

Most of the habitats studied in Minna had shade cover that ranged from 0 to 25%. These include rice fields (95%, $n = 20$), rain pools (100%, $n = 20$), drainages (95%, $n = 20$), and large bodies of water. The septic tanks were generally (75%) in the 76–100% shade category (Fig. 6).

Similarities in physical features of *Culex* mosquitoes breeding habitats in Minna during the study period

The physical characteristics of the rice fields and rain pools in Bosso and Gidan Kwano sampling stations were similar, while the drainages and septic tanks in Bosso and Maikunkele were similar (Fig. 7). Meanwhile, the rice fields in Chanchaga and Maikunkele were similar (Fig. 7). The septic tanks in Gidan Kwano were physically different from those in the other three study sites.

Chemical characterization of *Culex* mosquitoes breeding habitats in Minna

Dissolved oxygen, biological, and chemical oxygen demand

The study area's habitats' level of dissolved oxygen (DO) ranged from 4.44 ± 1.03 mg/L in septic tanks to 7.38 ± 2.16 mg/L in large water bodies (Fig. 8). The average biological oxygen demand (BOD) and chemical oxygen demand (COD) for the study area were 4.20 ± 1.66 and 8.54 ± 6.31 mg/L, respectively (Table 6). During the study, rice fields exhibited the lowest BOD and COD concentrations (3.75 ± 1.39 and 4.87 ± 1.64 mg/L, respectively), while septic tanks and drainages had the highest values (Fig. 8).

Phosphate, nitrate, and alkalinity

Large water bodies and rice fields had the lowest phosphorus and nitrate levels (0.07 ± 0.02 and 0.38 ± 0.27 mg/L, respectively). Septic tanks had the highest values for the two parameters (82.73 ± 43.83 and 130.42 ± 52.85 mg/L, respectively). Alkalinity levels were lowest in rice

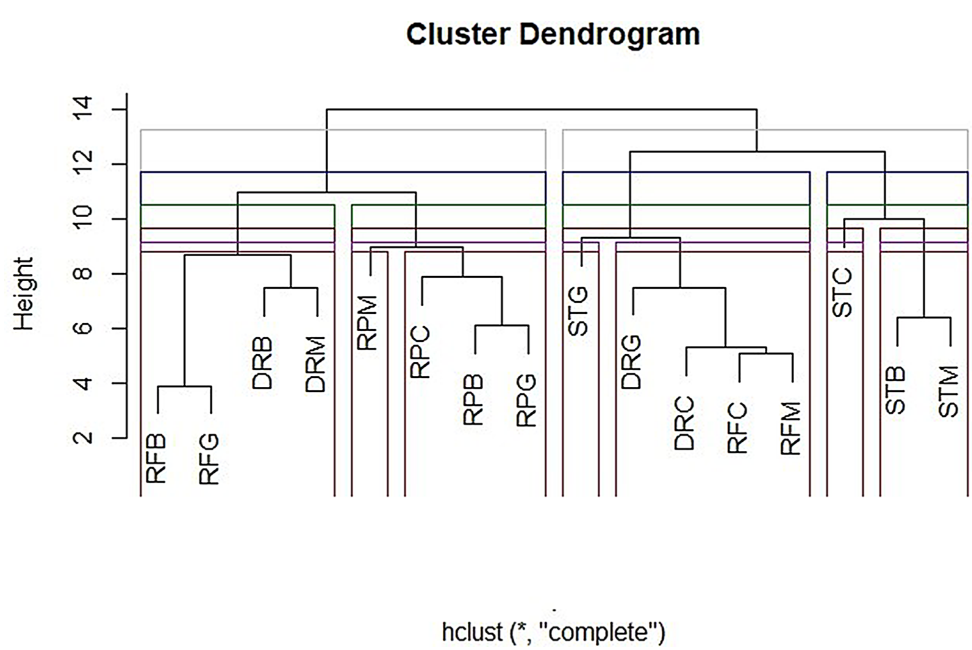


Fig. 7 Cluster of Physical features of *Culex* Mosquitoes habitats in Minna. STM–Septic Tanks in Maikunkele, RFM–Rice Fields in Maikunkele, RPM-Rain Pools in Maikunkele, DRM–Drainages in Maikunkele, STC–Septic Tanks in Chanchaga, RFC–Rice Fields in Chanchaga, RPC-Rain Pools in Chanchaga, DRC–Drainages in Chanchaga, STB–Septic Tanks in Bosso, RFB–Rice Fields in Bosso, RPB-Rain Pools in Bosso, DRB–Drainages in Bosso, STG–Septic Tanks in Gidan Kwano, RFG–Rice Fields in Gidan Kwano, RPG-Rain Pools in Gidan Kwano, DRG–Drainages in Gidan Kwano

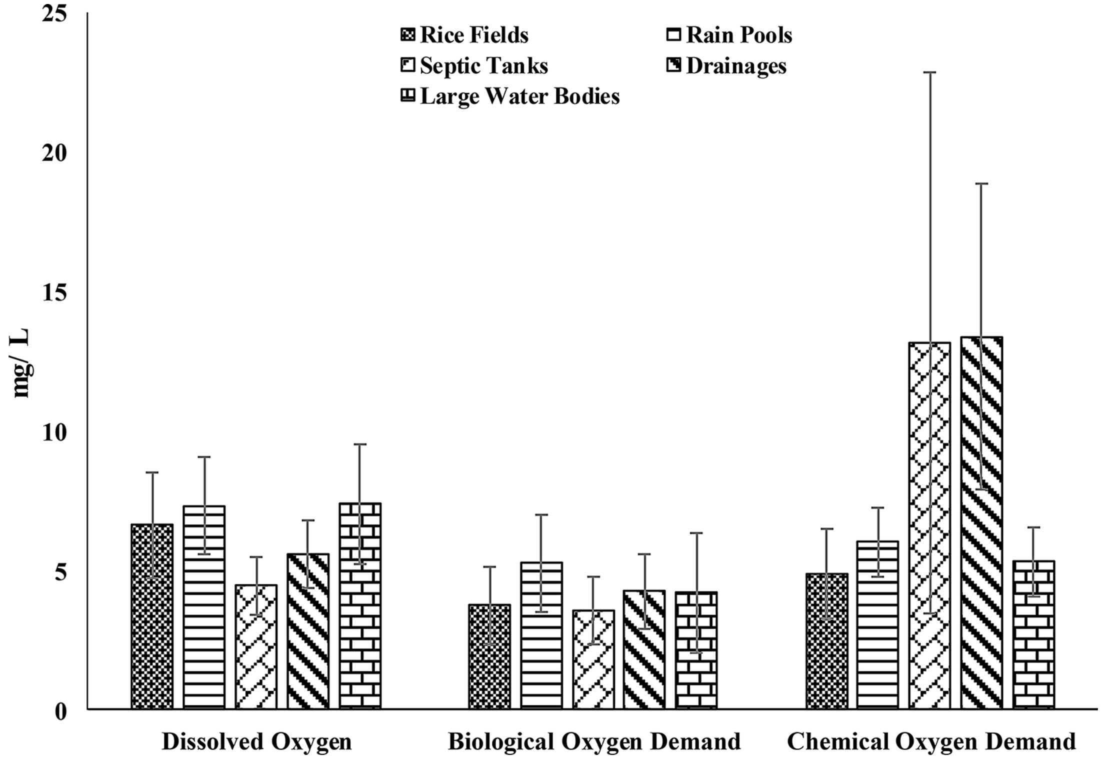


Fig. 8 Habitat-wise variation in dissolved oxygen, biological and chemical oxygen demands of *Culex* Mosquito Larval Breeding Habitats in Minna during the Study period

Table 6 Chemical characterisation of *Culex* mosquito larval habitats in Minna during the study period

Parameters (Unit)	Mean (Minna)*	Range (Minna)
Dissolved Oxygen (mg/L)	6.26 ± 1.97	4.29–8.23
Biological Oxygen Demand (mg/L)	4.20 ± 1.66	2.54–5.86
Chemical Oxygen Demand (mg/L)	8.54 ± 6.31	2.23–14.85
Electrical Conductivity (µS/cm)	303.55 ± 296.67	6.88–600.22
Total Dissolved Solid (mg/L)	77.68 ± 55.61	22.07–133.29
Phosphate (mg/L)	30.96 ± 44.91	13.98–75.84
Nitrate (mg/L)	43.77 ± 61.42	17.65–105.19
Alkalinity (mg/L)	48.01 ± 62.93	14.92–110.94

*All Values Expressed as Mean ± SD

fields (16.31 ± 5.29 mg/L) and highest in septic tanks (127.75 ± 94.89 mg/L) (Table 6, and Fig. 9).

Total dissolved solids (TDS) and electrical conductivity

Minna had an average TDS level of 77.68 ± 55.61 mg/L, ranging from 40.56 ± 15.72 mg/L in rice fields to 135.00 ± 69.06 mg/L in septic tanks (Table 6; Fig. 9). The electrical conductivity of the sampled habitats in the study area (Minna) averaged 303.55 ± 296.67 µS/cm, ranging from 159.86 ± 65.52 (in large water bodies) to 723.06 ± 389.87 µS/cm in septic tanks (Table 6; Fig. 10).

Similarities in the chemical features of *Culex* mosquitoes breeding habitats in Minna during the study period

The chemical characteristics of the septic tanks in Maikunkele were distinct from those of all other locations (Fig. 11). The septic tanks in Gidan Kwano and Chanchaga, as well as the drainages in Chanchaga and Maikunkele, had similar chemical properties. Interestingly, the rice fields and rain pools in Gidan Kwano were chemically similar to those found in Maikunkele. Furthermore, the chemical characteristics of rice fields in Bosso and Chanchaga were similar (Fig. 11).

Relationships between the physicochemical parameters of *Culex* mosquito breeding habitats in Minna

There were significant positive relationships between biological oxygen demand (BOD) and dissolved oxygen (DO), temperature and DO, phosphate and alkalinity, and electrical conductivity (EC) and alkalinity (Fig. 12). Further, analyses revealed a strong negative association between nitrate

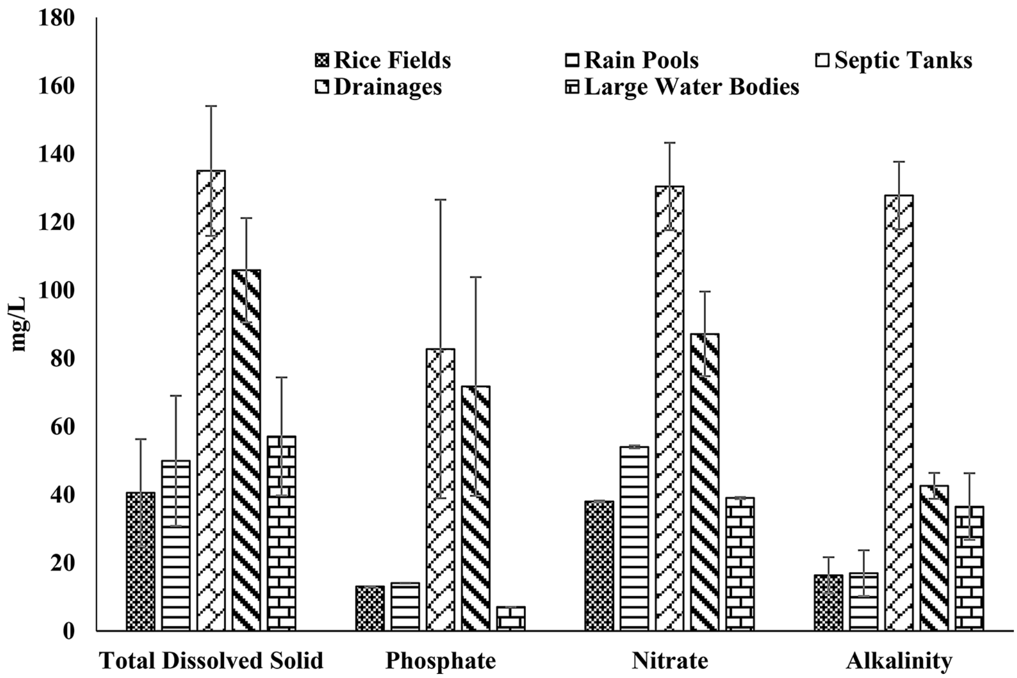


Fig. 9 Habitat-wise variation in total dissolved solids, phosphate, nitrate and alkalinity of *Culex* mosquito larval breeding habitats in Minna during the study period

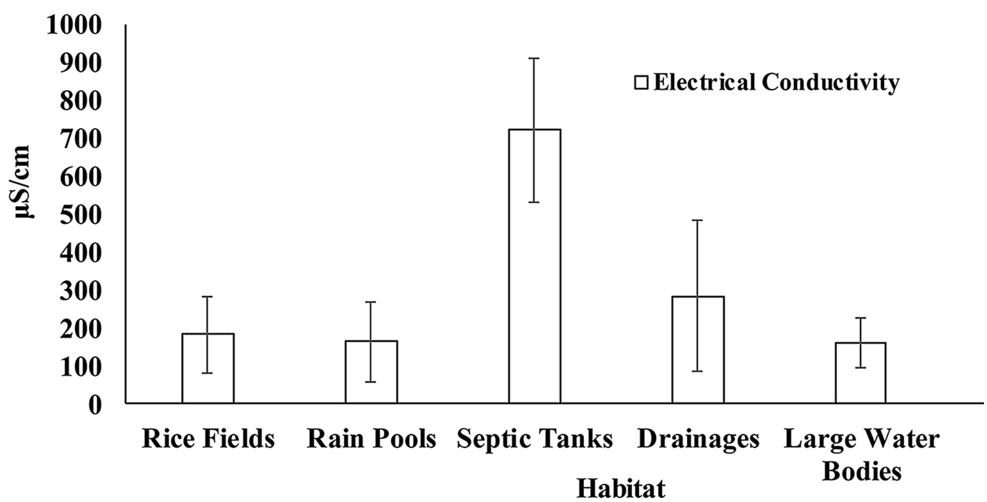


Fig. 10 Habitat-wise variation in electrical conductivity of *Culex* mosquito larval breeding habitats in Minna during the study period

and temperature, as well as nitrate and DO. The relationship between COD and temperature was weakly negative (Fig. 12).

Focused principal component analysis (FPCA) of the relationships between *Culex* mosquito species and physico-chemical variables

The correlations of *Cx. salinarius* with physicochemical variables were largely negative (inverse) (yellow dots) rather than positive (direct) (green dots) (Fig. 13A). Most of the relationships between species and factors were modest. The abundance of *Cx. salinarius* was significantly ($p<0.05$) associated ($r=0.06$) with COD and phosphate levels. The species' abundance is associated highly with nitrate, EC, and alkalinity levels ($r>0.4$). Its abundance was unaffected by the BOD level (Fig. 13A).

For *Cx. nigripalpus*, the relationships with physicochemical factors were mostly positive (green dots) (Fig. 13B). Most correlations were weak ($r<0.4$), and factors were not significantly ($p>0.05$) related to species abundance. Temperature and DO were strongly associated, as were TDS, phosphate, EC, and alkalinity. However, the former group of characteristics (temperature and DO) had a weak correlation with the latter group (TDS, phosphate, EC, and alkalinity) (Fig. 13B).

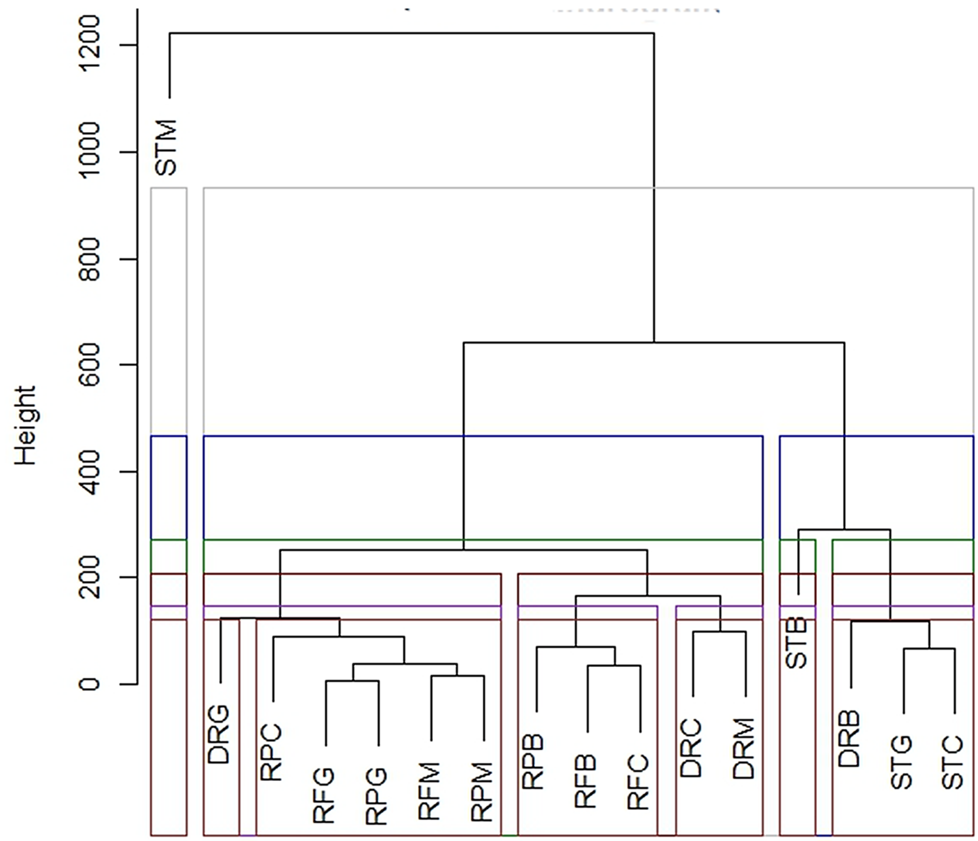


Fig. 11 Cluster of Chemical features of *Culex* mosquitoes Breeding Habitats in Minna. STM–Septic Tanks in Maikunkele, RFM–Rice Fields in Maikunkele, RPM-Rain Pools in Maikunkele, DRM–Drainages in Maikunkele, STC–Septic Tanks in Chanchaga, RFC–Rice Fields in Chanchaga, RPC-Rain Pools in Chanchaga, DRC–Drainages in Chanchaga, STB–Septic Tanks in Bosso, RFB–Rice Fields in Bosso, RPB-Rain Pools in Bosso, DRB–Drainages in Bosso, STG–Septic Tanks in Gidan Kwano, RFG–Rice Fields in Gidan Kwano, RPG-Rain Pools in Gidan Kwano, DRG–Drainages in Gidan Kwano

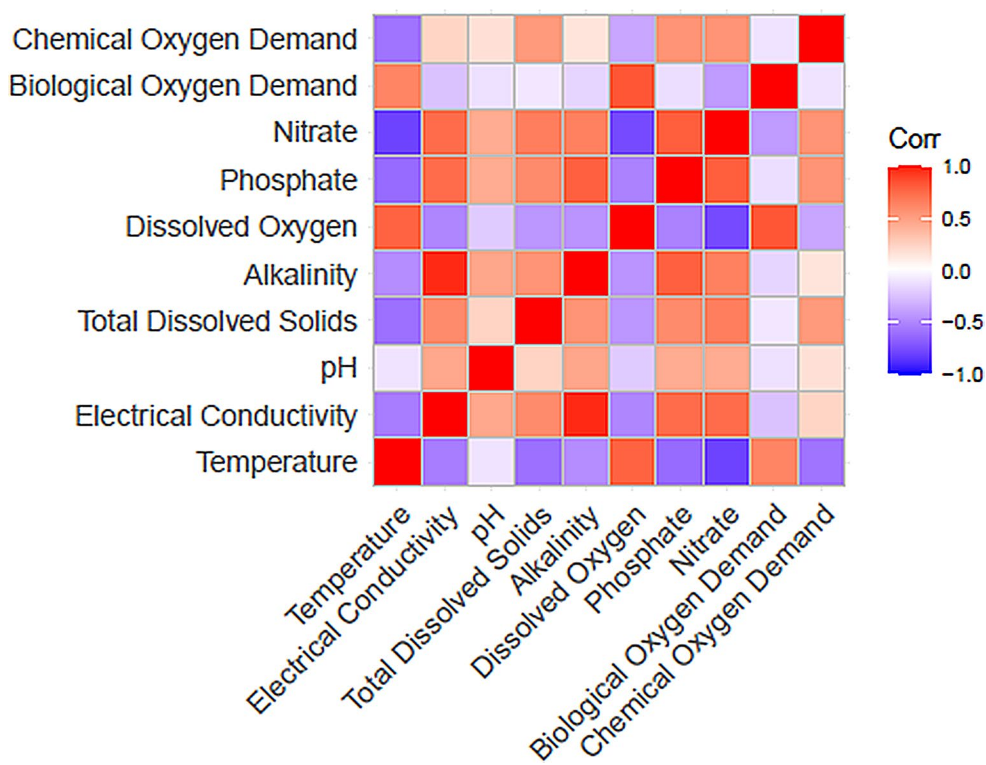


Fig. 12 Correlation Matrix of Physico-Chemical Variables in *Culex* mosquito breeding habitats in Minna during the study period

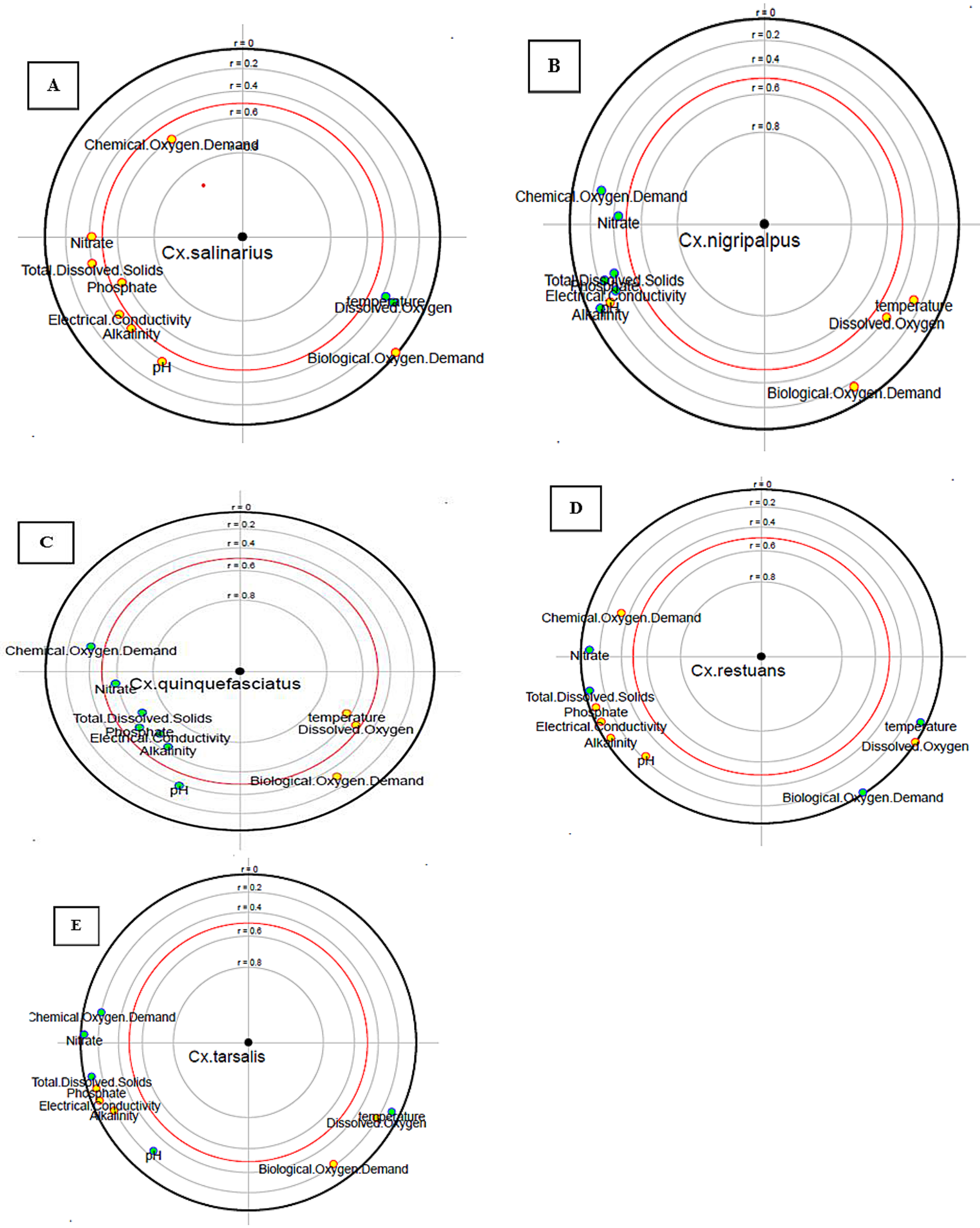


Fig. 13 Focused Principal Component Analyses (FPCA) diagram showing the correlation between the *Culex* mosquito species encountered in Minna with physico-chemical parameters of mosquito habitats **(A)** *Cx. salinarius* **(B)** *Cx. nigripalpus* **(C)** *Cx. quinquefasciatus* **(D)** *Cx. restuans* **(E)** *Cx. tarsalis*

The abundance of *Cx. quinquefasciatus* in the study area was positively associated with the physical and chemical variables (Fig. 13C). The species' abundance was strongly associated ($p < 0.05$) with nitrate, TDS, phosphate, EC, alkalinity, temperature, and DO levels. Apart from the association of the species with COD, pH, and BOD, most of the associations were strong. The TDS level, phosphate, EC, and alkalinity were all strongly associated, as were temperature and DO. These two groups of variables, however, had a weak correlation (Fig. 13C).

The associations of *Cx. restuans* and physicochemical variables were mostly inverse (Fig. 13D). Just like for *Cx. nigripalpus*, these variables were not significantly ($p > 0.05$) correlated with the abundance of the species. The variables were either very weakly or weakly correlated with the abundance of the species (Fig. 13D).

Similarly, for *Cx. tarsalis*, the physico-chemical variables did not significantly ($p > 0.05$) correlate with the abundance of the species (Fig. 13E). Most of the variables were also either very weakly or weakly correlated with the abundance of the species (Fig. 13E).

Discussion

The current study identified five *Culex* mosquito species. Previously, Olayemi et al. (2014d) identified four species in the same study area: *Cx. p. pipiens*, *Cx. restuans*, *Cx. tarsalis*, *and Cx. quinquefasciatus*. Olayemi and Ande (2008) encountered three *Culex* species (*Cx. quinquefasciatus*, *Cx. pipiens*, and *Cx. decens*) in Ilorin, North-Central Nigeria. The abundance of *Culex quinquefasciatus* in the study area may be due in part to its catholic behaviour, better adaptation, and plasticity (Ukubuiwe et al. 2016). The abundance of *Cx. quinquefasciatus* presents an epidemiological risk in the event of a disease outbreak in the study region, as the species is responsible for urban transmission of filarial worms.

Amao et al. (2018) found a similar dominance status for *Cx. quinquefasciatus* in Lagos, southwestern Nigeria, but with a different dominance structure that included one eudominant, two dominant, two subdominant, and one rare species. In Bannu, Pakistan, the dominance of *Cx. quinquefasciatus* have also been reported (Khan 2022). Similarly, in Hawaii, New Zealand and the Galápagos islands, Harvey-Samuel et al. (2021) reported the dominance of this species of mosquitoes and their implication for the spread of the avian virus. This geographical variance in mosquito dominant status could be explained by the diversity of vector ecology, breeding site characteristics, study area coverage, anthropogenic variables, and habitats sampled. These factors interact in various ways to determine mosquito species composition and abundance in larval breeding habitats.

Rice fields, rain pools, septic tanks, and drainages were highly productive for mosquitoes due to their physical, biological, and chemical properties, as well as their high nutrient (organic and inorganic) loads. According to Olayemi et al. (2014b), high nutritional loads are necessary for mosquito proliferation. Egg-laden female mosquitoes also prefer these nutrient-laden habitats for egg-laying because they ensure an appropriate supply of nutrients for their embryonic growth (Olayemi et al. 2014).

In this study, *Culex* mosquito species showed preferences for specific habitats. For example, *Cx. quinquefasciatus* preferred drainage, whereas *Cx. salinarius* preferred rice fields. Earlier research has found comparable habitat selection in this mosquito genera (Slaff 1990), notably in locations with abundant emergent and decaying vegetation.

Culex mosquitoes did not breed in large water bodies at any of the sampling locations. The availability of predators and resting sites, as well as their relative size, depth, clarity, and rapid flow rate of these large bodies of water, may have contributed to the absence of mosquitoes. Other activities seen at these habitat types included washing kitchen utensils, and motorbikes, and clothing by the residents. These activities introduce substances that may deter oviposition (Adefemi and Awokunmi 2010) or be larvicidal in nature (Schwab et al. 2019).

Allospecific and conspecific mosquito species (Anopheline and Culicine larvae and pupae) were found in most of the sites sampled for this study. This indicates that gravid female mosquitoes find the habitats that were studied to be highly appealing. Additionally, the existence of aquatic life stages of these mosquitoes (larval and pupal) indicates that these habitats supported the development of these mosquito genera – with the attendant increased chances and frequency of human-vector-pathogen contact. Conspecifics in mosquito habitats change the surface tension for oviposition and act as an attractant for gravid females during oviposition (Schwab et al. 2019). Although, according to Dambach (2020), it encourages the invasion of aquatic predators of mosquitoes.

Given that *Anopheles* mosquitoes typically breed in shallow, sun-lit pools of water (Lawal et al. 2022), it was unexpected to find that there were reasonable densities of these mosquitoes in sewage tanks in Minna. Although, Olayemi et al. (2010) had earlier reported the absence of *Anopheles* larvae in similar contaminated habitats in the study area. *Anopheles* mosquitoes' capacity to reproduce in such unusual settings as septic tanks may suggest that the species is adaptable in its choice of habitats.

Anopheline mosquitoes were abundant in rice fields and rain pools, and Culicine mosquitoes were encountered in all productive habitats. This is epidemiologically important as farming is the main occupation of the residents of the study area. Further, longer months of rainfall create rain pools and other mosquito breeding grounds. This information is crucial for the effective implementation of LSM programs there.

The comparatively high pupal productivity of the rice fields, rain pools, and septic tank habitats during this study period was more concerning. According to Yee et al. (2010), this is a measure of larval abundance, which suggests a high rate of immature survivorship and, thus, a high likelihood of an adult population explosion (Ukubuiwe et al. 2016). Therefore, any LSM intervention must give top emphasis to these habitat types.

In mosquito habitats, aquatic vegetation enhances the quality of the water (Gardner et al. 2013). Additionally, these provide perches for aerial mosquito larval and adult predators as well as resting places for recently emerging adults (Couret et al. 2020). Given its function in oviposition and as a resting place, the aquatic vegetation seen in the rice field studied may have created an environment conducive to mosquito growth (Braks et al. 2007).

The prevalence of mosquito larvae in rice fields, despite the presence of predators, is understandable because these mosquitoes are *R*-strategists, producing as many progenies as possible to ensure survival (Gillott 2005). All the large water bodies sampled in this study had predators, which may have contributed to the lack of mosquitoes.

When taken as a whole, these findings clearly show that the mosquito habitats sampled in Minna during the present study are attractive to gravid female mosquitoes and support immature survivorship, favouring the proliferation of *Culex* mosquitoes. This necessitates the implementation of an integrated and comprehensive larval control program to prevent disease outbreaks.

The physical (close to human homes - which guarantees the availability of blood meals) and chemical (high nitrate content) characteristics of all the drainages sampled in this study made them productive for mosquitoes. Therefore, this habitat type should also be given priority in larval source management programs in the study area since it poses a serious hazard to public health.

The habitats that were closest to human habitations were septic tanks and drainage systems, which were also highly productive for mosquitoes. These systems are close to residential areas because they are essential parts of the study area's sewage and liquid waste disposal systems. These sites' proximity to human habitation is significant from an epidemiological and entomological standpoint due to the availability of oviposition sites (Chaves et al. 2009) and the increased likelihood of human-vector contact (for the acquisition of blood meals and the transmission of parasites) (Torres-Estrada et al. 2004).

Most of the habitats (septic tanks, rain pools, and drainages) sampled in this study were situated less than 10 m from residential buildings. This circumstance puts mosquitoes closer to a source of blood meals, which raises the likelihood of disease pathogen transmission. A significant percentage of all the habitats that were sampled were situated between 0 and 100 m away from an occupied house or dwelling. Greenberg et al. (2012) state that most vector mosquito species can fly within this range (0 to 100 m). With the present habitat conditions in Minna, blood meal sources, resting, oviposition, and breeding sites are all assured for both strong and weak fliers (Verdonschot and Besse-Lototskaya 2014).

In addition, a larger percentage of the habitats that were studied were situated between 0 and 100 m from adult resting places, which is a crucial entomological characteristic for adult female mosquitoes' digesting of blood meals. Nonetheless, mosquitoes have a variety of preferences for biting and resting behaviours, including varied combinations of endophagy (inside feeding), endophily (indoor rest), exophagy (outside feeding), and exophily (outdoor rest).

All the large bodies of water under study were deeper than one metre. Paaijmans et al. (2008) and Buxton et al. (2020) reported that because of the lower temperatures, mosquitoes cannot develop in water deeper than five metres. These depths promote predator colonisation and development (Vinogradov et al. 2022), a situation that deters or discourages oviposition in Mosquitoes. Large bodies of water in the study area might not have been productive for mosquitoes because of these conditions.

Rain pools and drainages in the sampling stations were primarily shallow, with rice fields often less than 0.5 m deep. According to Olayemi et al. (2014c); Couret et al. (2014), these depths allow sunlight to reach the substratum, warming the habitats generally and accelerating development concurrently. Such shallow habitats should be accorded priority in mosquito larval control programme(s) in these areas.

Almost all the habitats that were sampled were wider than 10 m. The only habitats that were smaller than 10 m wide were the rain pools, and no predators were seen. It could be because this habitat is ephemeral. Minakawa et al. (2005) state that species occurrence and the extent of competition and predator colonisation are determined by the size of a mosquito's habitat.

A significant amount of the habitats that were sampled were turbid. Most large bodies of water were clear, but none of the septic tanks were. The former's clarity might indicate that organic food ingredients are lacking, which would explain some of its lack of productivity.

The amount of sunlight that reaches a habitat and phytoplankton productivity (main mosquito larval food source) are both influenced by the degree of turbidity of the habitat (Paaijmans et al. 2008). Among the habitat types sampled, rain pools were the warmest and septic tanks the coolest. Despite this variation in water temperature, mosquitoes were very productive in both habitats.

The temperature range of 25 to 28 °C was found in a significant percentage of the habitats sampled in this study. Because they were shallow and allowed the sun's heat to fully penetrate, only the rain pools had temperatures between 31 and 32 and 33 and 34 °C. This wide range of temperatures did not exclude the presence of *Culex* species. According to laboratory studies, *Culex* mosquitoes species may flourish in water that is between 28 and 34 °C (Dodson et al. 2012; Olayemi et al. 2016).

The vast majority (> 75%) of the habitats sampled in this study had open surfaces with 0–25% shadow cover. However, unlike *Anopheles* species, *Culex* mosquitoes can reproduce in cooler water bodies (Mahe et al. 2021). According to Getachew et al. (2020), shade covers, which are produced by overhanging tree branches or artificial structures, limit sunlight penetration and control oviposition dynamics and immature success.

Most habitats (> 65%) had pH values in the range of 6 to 7, which is probably the ideal range for mosquito development and survival (Afolabi et al. 2010; Ukubuiwe et al. 2020). The concentration of hydrogen ions in mosquito habitats affects the availability of nutrients and their appeal to gravid female mosquitoes (Olayemi et al. 2010; Varun et al. 2013; Nambunga et al. 2020).

Although they were mosquito-free, large bodies of water had the highest DO content. This may indicate that DO is not the primary factor affecting the occurrence of mosquitoes in this habitat. Similar negative relationships between DO concentration and mosquito species occurrence have been documented in previous studies (Alkhayat et al. 2020; Yamada et al. 2020; Akeju et al. 2022). Positive connections, however, have been documented in a few investigations (Kenawy et al. 2013; Bashar et al. 2016). Mosquitoes rely more on oxygen from the atmosphere than DO, of course, but the DO concentrations measured in the habitats investigated during the study period were higher than the minimal (3 mg/L) recommended threshold for aquatic life's sustenance (WHO 2022).

The abundance of *Cx. salinarius* was positively influenced by COD and phosphate levels but adversely impacted by nitrate content, EC, and alkalinity. The abundance of *Cx. salinarius* was unaffected by BOD. It's interesting to note the abundance of *Cx. nigripalpus*, *Cx. restuans*, and *Cx. tarsalis* was not primarily determined by physico-chemical factors in the habitats tested. Although the cause of this remained unclear, we believed that it was possible that the mosquitoes' preferred habitats might not have been sampled.

The main factors influencing the abundance of *Cx. quinquefasciatus* were temperature, DO concentration, alkalinity, EC, phosphate content, TDS, and nitrate content. Similar findings were previously reported by Lawal et al. (2022) in Katsina, Northwest Nigeria. The study also showed that even while septic tanks and drainage systems had far lower DO, *Cx. quinquefasciatus* could still thrive there. As previously noted by Akeju et al. (2022), this suggests that DO was not a major predictor of mosquito abundance in these habitat types.

Even though the selected mosquito breeding habitats in Minna during the study period were widely situated and separated, they showed varied degrees of biological, physical, and chemical similarities and differences. Despite their remote locations, the Gidan Kwano and Maikunkele sample stations, for instance, had rice fields, rain pools, and septic tanks with comparable biological characteristics, and they were all productive for Anopheline and Culicine larvae and pupae. Therefore, these habitat types should be given priority during LSM programs.

The peri-urban setting and substrate types of Maikunkele may be the reason for the significant chemical differences between sewage tanks there and septic tanks and other habitat types in the other test stations (Olayemi et al. 2014c). The chemical similarities between the rain pools and rice fields in Maikunkele and Gidan Kwano may have resulted from runoff from pesticide inputs.

Conclusion

During the investigation, five species of *Culex* were found in the areas that were sampled. The predominant *Culex* species in the communities was *Cx. quinquefasciatus*, the primary vector of lymphatic filariasis. The biological, chemical, and physical characteristics of the selected conventional mosquito breeding habitats of *Culex* mosquitoes in the study area varied significantly. Large bodies of water were not productive for mosquitoes. The study also demonstrated the habitat types shared similar characteristics and epidemiological significance. The data produced is crucial for the successful implementation of LSM protocols in the research region.

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Declarations

Conflict of interest The authors have no financial or non-financial interest to disclose. The authors also have no competing interests to declare that are relevant to the contents of this article. All Authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. All authors have no financial or proprietary interests in any material discussed in this article.

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