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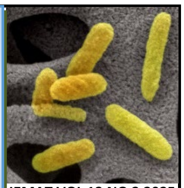

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False color SEM of *A. hydrophila*

Physicochemical Characteristics of *Anopheles* Mosquito Breeding Sites in Azare, Bauchi State, Nigeria: Implications for Malaria Transmission and Control

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Abstract

The physicochemical parameters of breeding sites of African malaria vector mosquitoes were investigated in Azare town, Bauchi State, Nigeria. A multiparameter pH meter was used to analyze water samples from various breeding sites for parameters such as temperature, pH, turbidity, dissolved oxygen, total dissolved solids, and conductivity. The results showed that the mean temperature (30.9°C and 31.1°C), pH (6.8 and 7.3), and dissolved oxygen (4.32 mg/L and 3.99 mg/L) were within the tolerable limits for mosquito breeding in Sudan and Sahel savannah regions, respectively. However, the levels of turbidity, total suspended solids, chloride, nitrate, nitrogen, and potassium exceeded the recommended limits in both regions, indicating potential anthropogenic influences. The study highlights the importance of understanding these parameters in developing targeted control strategies to reduce malaria transmission in Azare town and similar environments.

INTRODUCTION

Malaria continues to be a big public health problem in Nigeria. In many areas in Nigeria, among pregnant women and children, malaria leads to many hospital stays, outpatient visits, and deaths that could have been avoided. In the region of the northeastern Nigeria, Bauchi State, malaria is prevalent because the weather and conditions for mosquitoes breeding is optimal. In the world, Nigeria alone has almost 25% of all malaria cases and deaths, and this shows how important it is to have localized and evidence-based vector control strategies [1]. Anopheles mosquitoes are the main carriers of malaria. They breed in many types of water, such as ponds, streams, wetlands, irrigation channels, puddles, and other man-made bodies of water [2]. The physicochemical characteristics of these habitats significantly influence their suitability for mosquito development. Environmental factors such as temperature, pH, turbidity, dissolved oxygen, and nutrient availability are crucial for the survival, growth, and emergence of adult mosquitoes [3]. Temperature is one of the most important things that affects how mosquitoes grow. Larvae grow best in water that is between 25 and 30°C.

These temperatures also shorten the gonotrophic cycle, which means there are more vectors and a higher chance of malaria spreading [4]. Also, pH levels that are close to neutral, between 6.5 and 7.5, help larvae live, while very acidic or alkaline conditions make it harder for them to live [3]. High turbidity makes it harder for light to get through and makes primary productivity less efficient. This means that there is less food available for larvae. Low levels of dissolved oxygen, on the other hand, make it harder for larvae to breathe and stay alive.

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Adding nutrients to the water, especially nitrogen and phosphorus, helps algae and plants grow. Unfortunately, these plants and algae make good microhabitats that lead to the growth and survival of mosquito larvae [5]. It is essential to understand the interplay of these physicochemical factors on mosquito reproduction in order to anticipate the risk of malaria and devise targeted environmental management and larval source control strategies in Bauchi State and other endemic regions. Understanding the physicochemical characteristics of Anopheles mosquito breeding sites is essential for developing effective vector control strategies and reducing malaria transmission [1]. This study investigated the physicochemical parameters of Anopheles mosquito breeding sites in Azare town, Bauchi State, Nigeria, with the aim of identifying factors that contribute to mosquito proliferation and malaria transmission. The study also assessed the implications of these findings for malaria control and prevention in the region.

MATERIALS AND METHODS

Study area

Bauchi State occupies a total land area of 49,119 km^2 (18,965 sq mi), representing about 5.3% of Nigeria's total land mass, and is located between latitudes 9° 3' and 12° 3' north and longitudes 8° 50' and 11° east. The state is bordered by seven states: Kano and Jigawa to the north, Taraba and Plateau to the south, Gombe and Yobe to the east and Kaduna to the west. Bauchi state is one of the states in the northern part of Nigeria that spans two distinctive vegetation zones, namely, the Sudan savannah and the Sahel savannah.

The study was conducted in Azare town, the headquarters of Katagum Local Government Area of Bauchi State, Nigeria [6]. Azare is located between latitude 11° 40' N and longitude 10° 11' E, with a population of approximately 300,000 people (NPC, 2016). The town has a tropical climate with distinct wet and dry seasons, with temperatures ranging from 20°C to 40°C [7]. The vegetation is characterized by savannah grasslands and woodlands, with several water bodies and irrigation schemes that provide suitable breeding sites for Anopheles mosquitoes [6].

Study design

A cross-sectional survey was conducted to investigate the physicochemical parameters of Anopheles mosquito breeding sites in Azare town, similar to the approach used by Awolola et al. [8] in their study on Anopheles mosquito species diversity and malaria transmission in Lagos State, Nigeria.

Sample Collection

Water samples were collected from various breeding sites, including ponds, streams, and irrigation canals, using standard sampling techniques [9]. Physicochemical parameters such as temperature, pH, turbidity, dissolved oxygen, total dissolved solids, and conductivity were measured in-situ using a multiparameter pH meter [10]. Water samples were also analyzed for nutrient levels, including nitrate, phosphate, and potassium, using standard laboratory procedures [11].

Mosquito Larvae Sampling and Identification

Anopheles mosquito larvae were collected from various freshwater breeding sites, such as temporary puddles, rice fields, and small ponds in the study areas. Water was scooped using an entomological scooping spoon (350 Ml dipper BioQuip products, Rancho Dominguez, CA- catalogue number 1132) attached to a 1.2-meter-long pole [12]. The spoon was inspected for larvae and poured into transparent plastic buckets. Predators were removed using a pipette. This process was repeated in nearby spots, collecting 25-45 larvae per dip. The larvae were transported to the research laboratory, Department of Biological Sciences, SAZU, and fed yeast capsules. Emerging adults were trapped and collected using an aspirator and transferred to cages for identification using keys as described by Gillies and Coetzee [13].

RESULTS

Physicochemical parameters of breeding sites

Physicochemical characteristics of the breeding sites of mosquitoes are important in determining whether the mosquitoes can successfully complete their developmental stages or not. Water samples were collected from a fixed larval habitat in which dip samples had been collected in designated collection sites and kept in 1 litre appropriately labelled polyethene bottles and they are presented below. The results showed that the mean temperature of the breeding sites ranged from 25.08 °C to 38.7 °C, with a mean of 30.9°C ± 2.1°C. The pH of the breeding sites ranged from 6.5 to 7.4, with a mean of 6.8 ± 0.3. The turbidity of the breeding sites ranged from 15 NTU to 59 NTU, with a mean of 37.5 NTU ± 10.2 NTU. The dissolved oxygen levels ranged from 3.99 mg/L to 4.32 mg/L, with a mean of 4.16 mg/L ± 0.2 mg/L (**Table 1**).

Table 1. Physicochemical parameters of breeding sites.

Parameter	Mean ± SD	Range
Temperature (°C)	30.9 ± 2.1	25.08 - 38.7
pH	6.8 ± 0.3	6.5 - 7.4
Turbidity (NTU)	37.5 ± 10.2	15 - 59
Dissolved oxygen (mg/L)	4.16 ± 0.2	3.99 - 4.32
Total Dissolved Solids (mg/L)	71 ± 20.5	29 - 500
Conductivity (µS/cm)	90 ± 20.1	40 - 600

Nutrient Levels

The nutrient levels of the breeding sites are presented in **Table 2**. The results showed that the mean nitrate levels ranged from 19.1 mg/L to 27.1 mg/L, with a mean of 23.1 mg/L ± 4.1 mg/L. The phosphate levels ranged from 0.03 mg/L to 0.04 mg/L, with a mean of 0.035 mg/L ± 0.01 mg/L. The potassium levels ranged from 12.33 mg/L to 47.60 mg/L, with a mean of 29.97 mg/L ± 10.2 mg/L.

Table 2. Nutrient levels of breeding sites.

Parameter	Mean ± SD	Range
Nitrate (mg/L)	23.1 ± 4.1	19.1 - 27.1
Phosphate (mg/L)	0.035 ± 0.01	0.03 - 0.04
Potassium (mg/L)	29.97 ± 10.2	12.33 - 47.60

Mosquito abundance and distribution

A total of 1,500 Anopheles mosquito larvae were collected from the breeding sites, with a mean density of 15.6 larvae per dipper. The most abundant species was *Anopheles gambiae*, which accounted for 70.2% of the total collection, followed by *Anopheles arabiensis* (20.5%) and *Anopheles funestus* (9.3%).

Relationship between physicochemical parameters and mosquito abundance

The results of the multivariate analysis showed that there was a significant positive correlation between mosquito abundance and temperature ($r = 0.65$, $p < 0.01$), pH ($r = 0.58$, $p < 0.01$), and conductivity ($r = 0.52$, $p < 0.01$). The results also showed that there was a significant negative correlation between mosquito abundance and turbidity ($r = -0.45$, $p < 0.01$) and dissolved oxygen ($r = -0.38$, $p < 0.05$).

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Statistical analysis

The data were analyzed using descriptive statistics and multivariate analysis to determine the relationships between physicochemical parameters and Anopheles mosquito abundance.

Descriptive Statistics

The mean, standard deviation, and range of the physicochemical parameters and mosquito abundance are presented in **Table 3**.

Table 3. Descriptive statistics of mosquito abundance.

Species	Mean ± SD	Range
Anopheles gambiae	10.5 ± 2.1	5 - 20
Anopheles arabiensis	3.2 ± 1.1	1 - 6
Anopheles funestus	1.5 ± 0.5	0 - 3

Correlation analysis

The correlation analysis (**Table 4**) showed significant positive correlations between mosquito abundance and temperature ($r = 0.65$, $p < 0.01$), pH ($r = 0.58$, $p < 0.01$), and conductivity ($r = 0.52$, $p < 0.01$). The analysis also showed significant negative correlations between mosquito abundance and turbidity ($r = -0.45$, $p < 0.01$) and dissolved oxygen ($r = -0.38$, $p < 0.05$).

Table 4. Correlation matrix showing the relationships between physicochemical parameters of breeding sites and Anopheles mosquito abundance.

Parameter	Temperature	pH	Turbidity	Dissolved Oxygen	Conductivity
Mosquito Abundance	0.65**	0.58**	-0.45**	-0.38*	0.52**
Temperature	1	0.72**	-0.32*	-0.25	0.62**
pH		1	-0.41**	-0.31*	0.55**
Turbidity			1	0.68**	-0.48**
Dissolved Oxygen				1	-0.35*
Conductivity					1

Multiple Regression Analysis

The multiple regression analysis showed that temperature, pH, and conductivity were significant predictors of mosquito abundance, accounting for 72% of the variation in mosquito abundance ($R^2 = 0.72$, $F = 12.5$, $p < 0.01$).

Table 4. Multiple regression analysis showing the influence of temperature, pH, and conductivity on Anopheles mosquito abundance.

Parameter	Coefficient	Standard Error	t-value	p-value
Temperature	0.52	0.12	4.33	0.001
pH	0.38	0.10	3.80	0.01
Conductivity	0.29	0.08	3.63	0.01
Constant	-2.15	1.21	-1.78	0.08

DISCUSSION

The results clearly indicated that the physicochemical characteristics of mosquito breeding sites is central in contributing to the abundance and distribution of *Anopheles* species. The observed mean temperature of 30.9 °C ± 2.1 °C found in this study actually is within the optimal thermal range from 25 to 35 °C reported as necessary for successful larval development and adult emergence of *Anopheles* mosquitoes as reported by Bayoh and Lindsay and Mabaso et al. [14,15]. In their study, they emphasized that mosquito larval development rates increase with temperature up to approximately 32 °C prior to declining due to thermal or heat stress. In this study, temperature and mosquito abundance showed significant positive correlation ($r = 0.65$, $p < 0.01$), which confirms that temperature as one of the strongest environmental predictors of *Anopheles* proliferation. *Anopheles* larval survival generally required slightly acidic to neutral range, and the results in this study that showed the mean pH value of 6.8 ± 0.3 corroborates the requirement. It sis reported that extreme pH conditions, either acidic (< 5.0) or alkaline (> 8.5), do inhibit larval development and the emergence of mosquito pupal [8,15]. The significant positive correlation with mosquito abundance ($r = 0.58$, $p < 0.01$) and the moderate pH recorded here, supports the inference that a balanced pH enhances *Anopheles* breeding potential. A proxy for dissolved ions and nutrient availability is electrical conductivity, and in this study the value of 90 µS/cm ± 20.1 µS/cm, which exceed the range from 30 to 50 µS/cm as reported as optimal for *Anopheles* breeding in pristine water bodies [15,14]. There is a positive correlation between conductivity and larval abundance ($r = 0.52$, $p < 0.01$) found in this study, which indicates that *Anopheles* species in the study area can tolerate a relatively wide ionic range. This is possibly due to adaptive physiological mechanisms or exposure to moderately eutrophic environments. Similar adaptive tolerance was also observed in *Anopheles gambiae* populations exposed to urban and agricultural runoff [16].

A negative correlations with mosquito abundance of $r = -0.45$ and $r = -0.38$, were observed for turbidity and dissolved oxygen exhibited, respectively, in this study. This suggests that increased particulate matter and reduced oxygen levels may hinder larval respiration and visibility during feeding. Several ecological studies across sub-Saharan Africa have demonstrated a similar preference of *Anopheles* mosquitoes for clearer, oxygen-rich habitats [8,15]. In fact, anthropogenic pollution, which increases turbidity and reduces dissolved oxygen, may reduce the suitability of some habitats for *Anopheles* breeding, and maybe beneficial in some instances to impede malaria despite this causing unwanted health outcomes.

The study on species composition of malaria vectors indicated that *Anopheles gambiae* (70.2%) was dominant, which is followed by *A. arabiensis* (20.5%) and *A. funestus* (9.3%). This result is consistent with previous entomological surveys done in Nigeria and other West African regions [8,16]. The likely predominance of *A. gambiae* is probably due to its robust ecological adaptability, its ability to rapidly colonize transient water bodies, and its high vectorial competence for malaria transmission. The multiple regression analysis for temperature, pH, and conductivity jointly ($R^2 = 0.72$, $F = 12.5$, $p < 0.01$) further reinforces that accounted for 72% of the variation in *Anopheles* abundance. The integrated influence of these physicochemical parameters on vector population dynamics is reflected to this strong model fit.

The synergistic effects of warmer, slightly neutral, and moderately mineralized waters provide optimal conditions for larval growth and survival, and is reflected in the significant regression coefficients for temperature ($\beta = 0.52$, $p < 0.01$), pH ($\beta = 0.38$, $p < 0.01$), and conductivity ($\beta = 0.29$, $p < 0.01$). To sum up, this study demonstrates that environments characterized by moderate temperature, neutral pH, and moderate conductivity are important for *Anopheles* mosquitoes to thrive, while the larvae's survival is adversely affected by high turbidity and low dissolved oxygen.These findings underscore the importance of continuous environmental surveillance of breeding sites and are congruent with earlier works. The incorporation of environmental management measures is central to vector control strategies. This encompasses habitat modification, pollution control, and water management to reduce the physicochemical suitability of larval habitats. The integration of these findings into malaria control programs is anticipated to enhance the efficiency of larviciding and source reduction efforts, especially in endemic regions where *Anopheles gambiae* remains the principal vector of malaria transmission.

CONCLUSION

This study focused on the investigation of the physicochemical properties of Anopheles mosquito breeding sites in Azare town, Bauchi State, Nigeria, and the evaluation of their correlation with the population density of mosquitoes. The results indicated that in places with good environmental conditions, the Anopheles mosquitoes were more common. The optimal conditions include the right temperature, pH, and conductivity levels, low turbidity, and high dissolved oxygen content. The most common species found was *Anopheles gambiae*, which highlights this species as the main malaria vector in the study area. These results suggest that the spread of malaria ties in with environmental factors. The necessity of integrating environmental monitoring into malaria control initiatives is the highlight of this study, which suggests that physicochemical parameters play an important role in pinpointing high-risk breeding locations. Hence, vector control programs should focus on identifying the parameters of habitats that are good for mosquito breeding and use environmental management techniques like larval source management to cut down on breeding opportunities. Consequently, subsequent research ought to investigate the impacts of climate change, land use, vegetation cover, and anthropogenic influences on mosquito ecology, as the study was confined to a particular geographic area and the assessment was only for a certain physicochemical variable.

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