ABUNDANCE AND DISTRIBUTION OF ANOPHELES MOSQUITO IN RELATION TO PHYSICOCHEMICAL PROPERTIES IN DELTA STATE, NIGERIA

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ABSTRACT

In this study, the effect of physicochemical parameters as determinants for the abundance and distribution of Anopheles mosquitoes was examined. Physicochemical variables such as pH, temperature, DO, TDS, flow velocity, salinity and electrical conductivity were determined using standard procedures. Three communities in Ukwani LGA, Delta State were mapped out and sampled. Immature stages of Anopheles mosquitoes were collected from potential breeding sites using 350 ml dip ladles and scooping spoon. The physicochemical parameters showed that air, and water temperature, pH, and dissolved oxygen were higher in Umutu compared to the other sampled communities (Obiaruku and Umukwata). Salinity, conductivity, total dissolved solids and flow velocity were higher in Obiaruku and Umukwata compared to Umutu. Various levels of significance (p <0.05) were recorded within sampled months and communities. The density of Anopheles mosquitoes were higher in ponds and puddles (42.1 and 32.6%) in Obiaruku compared to other locations irrespective of the sampled months. Highest density was also recorded in the month of September (42.3%) compared to other sampled months. Temperature, pH, DO, TDS and conductivity were in acceptable limits for mosquito survival. All parameters were positively correlated with the density of Anopheles mosquitoes. Thus, in practical terms for vector control, this study has demonstrated the importance of considering these physicochemical parameters when manipulating mosquito breeding sites for mosquito control programs, discourage their proliferation and decline the malaria burdens.

Keywords: Abundance, Anopheles mosquitoes, Delta State, Distribution, Physicochemical parameters.

INTRODUCTION

Mosquitoes, under favorable environmental conditions of the tropics, are successful and cause several diseases of medical and veterinary concerns such as malaria, lymphatic filariasis, dengue fever, amongst other infections (WHO, 2020). With the continued increase in climate change, case reports of these diseases have skyrocketed especially in Africa where insecticide resistance has become a major challenge to vector control (Muhammad *et al*., 2021). This necessitated the ongoing search to unravel better approaches to tackle the mechanisms involved in insecticide resistance in species, establish efficient larvicides and repellents in plant materials, as well as the scale up of interventions involving treated nets and indoor spraying to reduce the scourge of mosquito-borne infections (WHO, 2016).

The use of insecticides has, therefore been recommended for use by the World Health Organization either in impregnating bed nets or indoor sprays (WHO, 2016). But this intervention alone cannot help reduce the morbidity and mortality caused by the *Anopheles* mosquitoes. Between 2000 and 2020, vector control using insecticide has helped reduce case report from malaria below 45% (WHO, 2020). Even with the decrease in death tolls, Nigeria, amongst other countries in Central and West Africa were marked as major endemic countries with high malaria cases, thus, accounting for 70% of the world's malaria burdens (WHO, 2020). Malaria infection burdens the Nigeria populace where about half of the disease has been ascribed to it from the 50% burdens reported in Africa (WHO, 2020). In Nigeria, the disease reached 60% in patients visiting medical facilities, and mortality reached 30% in infants (WHO, 2017). The

prevalence of malaria could be as a result of the poor environmental hygiene that encourages abundance of potential breeding sites.

The malaria disease caused by *Anopheles* mosquitoes have been reported in most part of the world where over 700 million persons are at risk annually (Adeleke, *et al.*, 2010). *Anopheles* can exploit varieties of breeding habitats containing water either natural or artificial sites near human dwelling (Klinkenberg *et al.,* 2008). According to Aigbodion and Anyiwe, (2005), a number of factors relating to environment and climate directly influence the abundance and distribution of mosquitoes. These factors such as the habitat size, water characteristics, intensity of sunlight, water salinity, turbidity, and presence of emergent or floating vegetation greatly influence the aquatic habitats suitability for the different stages of development of the Anopheline vectors. Human-influenced activities that changes the landscape, including irrigated fields and land settlements, consequently may influence the temporal and spatial distribution of mosquitoes (Zhou *et al.,* 2011). The chemical properties of breeding site equally has a direct impact on habitat selection by gravid female mosquitoes, growth and development of immature stages, and thus mosquito distribution (Noutcha and Anumudu, 2009).

A study by Ciota and Kramer (2013) has shown that human activities such as international trading, climate and urbanization may influence mosquito availability in Afro-endemic areas and environs. With potential breeding sites of mosquitoes thriving everywhere, colonization of newer

geographic areas and the incidence of mosquito-borne diseases of public health concerns would be experienced. According to observation made by Rakotomanana *et al.* (2010), urban expansion have influenced the epidemiology of malaria diseases through the availability of suitable breeding environment for vectors. Most studies have established the susceptibility of mosquitoes to various insecticides (Chukwuekezie *et al.,* 2020; Muhammad *et al.,* 2021; Ojianwuna *et al.,* 2021). However, no information on the exact determination of physicochemical parameters of mosquito breeding site is available as an avenue to estimate the abundance and distribution of mosquitoes in endemic areas. It is, therefore, necessary to determine the physicochemical parameters of *Anopheles* breeding site, and their abundance and distribution in a selected Local Government Area in Delta State.

MATERIALS AND METHOD
Study Area
The research was conducted in Ukwani Local Government Area of Delta State. Ukwani borders Ndokwa West to the East, Ethiope East to the west and Isoko North to the south. Over 110,000 people live in the LGA (Nigerian National Bureau of Statistics, 2006). Ukwani is under Delta North Senatorial District, Delta State (Figure 1). Three communities were mapped out to obtain data on the abundance and distribution of *Anopheles* mosquitoes in Obiaruku (5.836465ºN and 6.159439ºE), Umutu (5.915783ºN and 6.225577ºE) and Umukwata (5.808901ºN and 6.240219ºE).
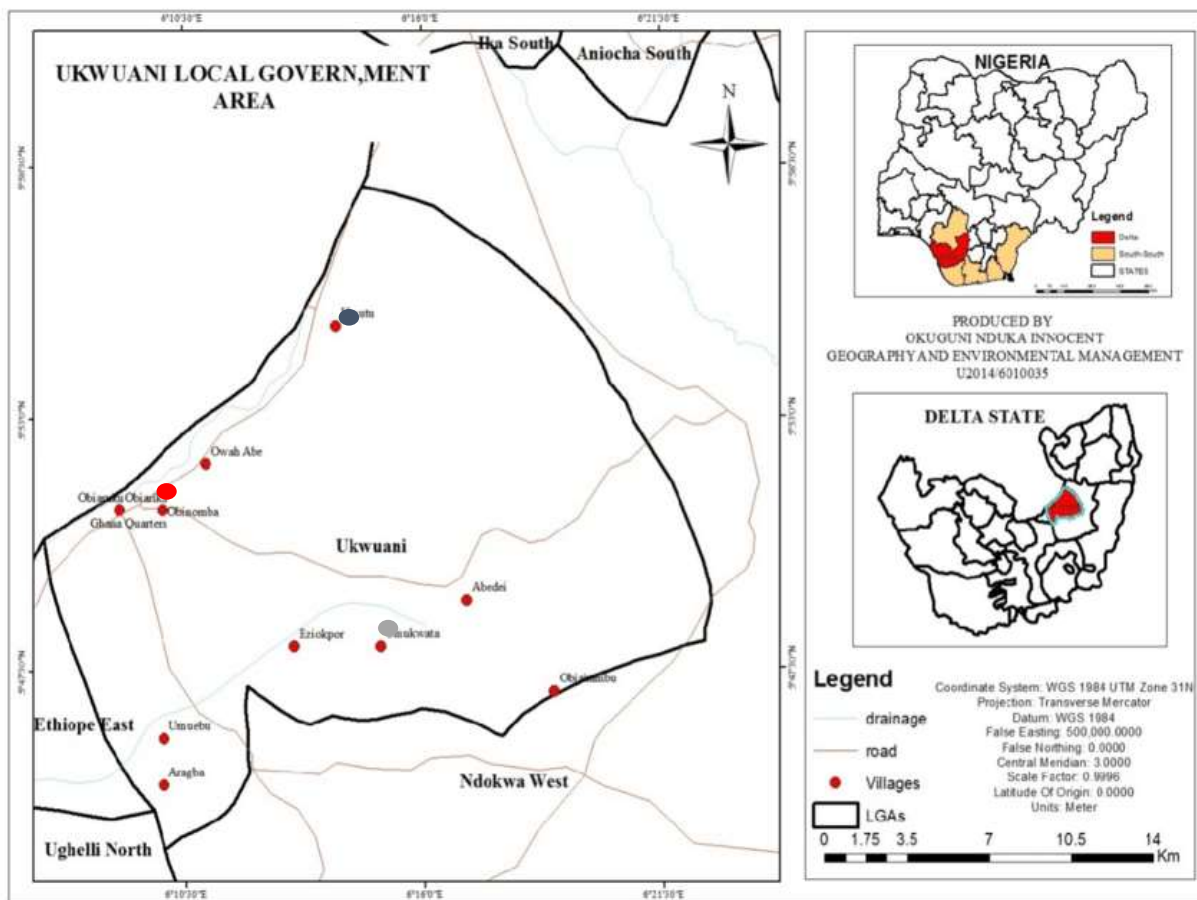

Fig. 1. Map showing study area   Umutu; ● Obiaruku; ● Umukwata ●

MATERIALS
Ladles, transparent buckets, mosquito net caps, collapsible cages, larval trays, scooping spoons, pipette, and thermo-hygrometer and larval recording sheets were the materials used for the collection of mosquitoes in the study.

Sample collection and identification
Larvae and pupae of *Anopheles* mosquito were collected from various communities as well as the physical components of the mosquito breeding habitat. Ladle (350 ml) and scooping spoons were used to collect larva in large water bodies and shallow habitats such as tyre marks and puddles respectively. A total of 35 sites were sampled. Field collections were transported to the Insectary of the Department of Animal and Environmental Biology, Delta State University, Abraka for breeding. Larvae were transferred into trays and kept in insectary with temperature

and relative humidity maintained at 28±3ºC and 78± 3% respectively. Net caps made from mosquito net were used to tightly cover the tray to avoid the escape of emerging adult mosquitoes. Emerging adult mosquitoes were transferred to the adult cages using aspirator and later killed using ethyl acetate in the killing jar before identification using standard key described by Harbach, (2008) and Harbach and Kitching (2016).

Mosquito density
The density of mosquitoes was calculated after 20 dips using ladles in each of the sampled community and the abundance of the larva recorded. Percentage density of *Anopheles* mosquitoes was calculated as:

$$\text{Density of } Anopheles = \frac{\text{Number of } Anopheles \text{ in the ladle}}{20 \text{ dips}} X\ 100$$

Determination of physicochemical parameters

These were carried out in accordance with procedures reported in ASTM, (2012).

pH

The pH is the negative logarithm of hydrogen ion concentration. It was measured electronically using a pH meter, the electrode was washed with de-ionized water and later standardized, then the standardized electrode was introduced into the water sample contained in 100ml Beaker and the reading was taken.

Temperature

Air and water temperature can be measured using a mercury-in-glass thermometer. Water temperature was measured by suspending the thermometer into the water and held for 1-2mins for stability, then the readings were taken. Air temperature was measured using thermohygrometre in the air for few minutes and the reading was taken.

Dissolved oxygen

Water samples were collected with a DO bottle and covered while under the water. The wrinkler solution A & B was added to the sample to trap the oxygen using a syringe. In the laboratory, 100ml of sample was measured using a measuring cylinder and turned into a conical flask. 2ml of H_2SO_4 was added to the sample, this gave it a yellowish colour. Then a few drop of starch indicator was added, and the solution turned black. It was then Titrated using $Na_2S_2O_3$ until solution became colourless.

Do = Titre of value of N x N of $Na_2S_2O_3$ / 100ml

The S.I unit = mg/l

Electrical conductivity

Conductivity (specific conductance) is the numerical expression of the water's ability to conduct an electric current. It is measured in micro Siemens per cm and depends on the total concentration, mobility, valence and the temperature of the solution of ions.

$$G = \frac{1}{R}$$

G – Conductance (mho or Siemens) and R - Resistance

Apparatus required: Conductivity meter

Procedure: The electrode of the conductivity meter was dipped into the sample, and the readings were noted for stable value shown as µS/cm.

Salinity, flow velocity and total dissolved solids (TDS) was determined using pen parameter for water sample determination.

Data analysis

Prior to analysis, data was entered into Excel spreadsheet. Physicochemical parameter data was subjected to two-way analysis of variance (ANOVA) on sample communities and sample months. *P*-values below 0.05 were considered significant. Results were presented in pie charts, bar charts and percentages. Physicochemical parameters were correlated with density of mosquitoes.

RESULTS

Physicochemical parameters

Summary results of some physicochemical parameters of the *Anopheles* breeding sites in Ukwani LGA, Delta State is presented in Table 1. In the three months of intensive sampling (September to November), air and water temperature, hydrogen ion concentration (pH), and dissolved oxygen were higher in Umutu compared to the other communities. The differences were significant (p <0.05) within the sampled months and communities except for pH. Similarly, salinity, conductivity, total dissolved solids and flow velocity were higher in Obiaruku and Umukwata respectively when compared to Umutu. There was also significant differences in most of the physicochemical parameters and the sampled months (p< 0.05) (Table 1).

Table 1. Summary of some physical and chemical parameters of the *Anopheles* breeding sites in Ukwani LGA, Delta State from September to November, 2020.

S/N	Parameter	Obiaruku	Umukwata	Umutu	F-ANOVA		P-value	
					months	Sites	months	Sites
1.	Air temperature (º C)	33.63±0.67 (30.8-35.4)	32.45±0.41 (30.5-34.3)	34.55±0.40 (32.7-36.4)	20.32*	4.32*	0.0041	0.027
2.	Water temperature (º C)	30.00 ± 0.37 (28.3-31.6)	29.91±0.45 (28.5-32.0)	30.95±0.12 (27.3-27.7)	14.3*	2.841	0.0091	0.083
3.	pH	6.12 ± 0.02 (6.06-6.24)	6.09± 0.02 (6.03-6.17)	6.14±0.03 (6.02-6.23)	1.36	1.266	0.263	0.626
4.	Dissolved oxygen (mg/l)	7.8±1.1 (7.1-8.0)	7.4±0.07 (7.0-7.6)	8.1±0.91 (7.3-8.8)	32.33*	7.143*	0.0013	0.0043
5.	Conductivity (µS/cm)	583 ±6.26 (560-603)	424 ±6.52 (405-453)	462 ±12.4 (421-516)	0.1004	87.6*	0.762	<0.0001
6.	TDS	11.25±1.17 (7.0-17.0)	51.30±0.92 (46-55)	51.13±0.65 (48-51)	15.21*	462.2*	0.008	<0.0001
7.	Salinity (ppm)	276.5±4.14 (257-293)	190.3±5.85 (156-210)	149.6±18.7 (74-211)	0.579	5.002*	0.475	0.0167
8.	Flow velocity (mV)	198.0±4.69 (177-215)	287.4±1.68 (281-294)	226.3±3.99 (210-243)	0.204	88.99*	0.668	<0.0001

Physicochemical parameter correlation with Density of Anopheles

The percentage density of *Anopheles* mosquitoes sampled from Ukwani LGA, Delta State is shown in Figure 2. The density of species in Obiaruku was higher (p= 0.0025) compared to other sampled communities while species density was lowest in Umukwata. All physicochemical parameters were positively correlated with density of the mosquitoes and water temperature had the highest correlation (0.485) compared to other parameters (Table 2). Air temperature positively influenced electrical conductivity and total dissolved solids. Water temperature was also influenced

by air temperature which in turn influenced electrical conductivity, total dissolved solids, flow velocity and the density of mosquitoes. Hydrogen ion concentration (pH) and dissolved oxygen affected all other parameters.

More so, electrical conductivity negatively affected water temperature and dissolved oxygen, total dissolved oxygen affected air temperature, pH and electrical conductivity. Flow velocity and salinity also negatively affected air, water temperature, pH, dissolved oxygen and total dissolved solids. Flow velocity and salinity positively correlated with density of mosquitoes (Table 2). The monthly variation in the density of *Anopheles* showed that more species were recorded in

September and in Obiaruku than in other sampled months and communities (Figure 3). Although, the differences was not significant (p >0.05).
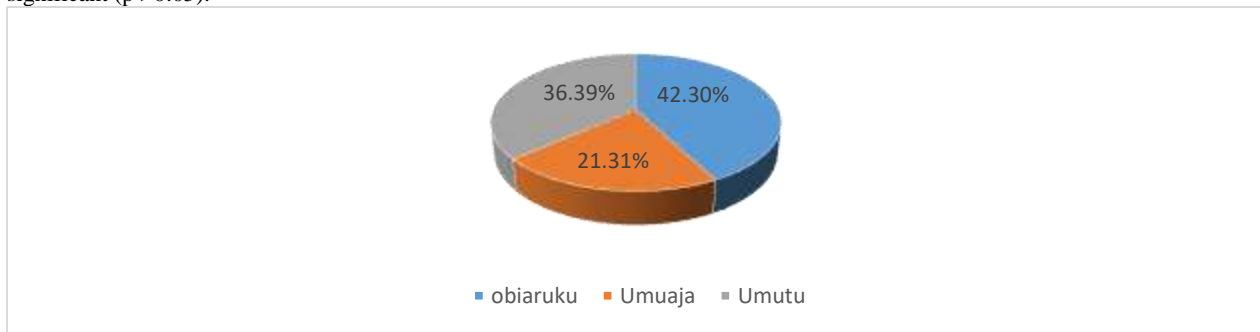

Fig. 2. Showing the percentage density of anopheles mosquitoes sampled from Ukwani LGA, Delta State. (F $_{(density)}$ = 12.59, P= 0.0025)

Table 2: Summary of the physiochemical correlation against the density of anopheles mosquitoes sampled at Ukwani LGA, Delta State.

	AT	WT	pH	DO	EC	TDS	FV	SAL	DEN
AT	1	0.00011	0.007	3.72E-05	0.381	0.629	0.031	0.067	0.012
WT	0.708	1	0.245	0.003	0.615	0.427	0.154	0.095	0.485
pH	0.532	0.247	1	0.006	0.484	0.687	0.015	0.186	0.074
DO	0.739	0.578	0.546	1	0.389	0.163	5.17E-05	0.016	0.149
EC	0.187	-0.108	0.150	-0.184	1	3.36E-10	0.505	0.795	0.001
TDS	-0.104	0.170	-0.088	0.294	-0.916	1	0.151	0.110	0.001
FV	-0.442	-0.300	-0.429	-0.730	0.143	-0.302	1	0.003	0.374
SAL	-0.380	-0.348	-0.279	-0.485	0.056	-0.335	0.573	1	0.358

Note: AT= air temperature, WT= water temperature, pH= hydrogen ion concentration, DO= dissolved oxygen, EC= electrical conductivity, TDS= total dissolved solids, FV= flow velocity, SAL= salinity, DEN= density of mosquitoes .
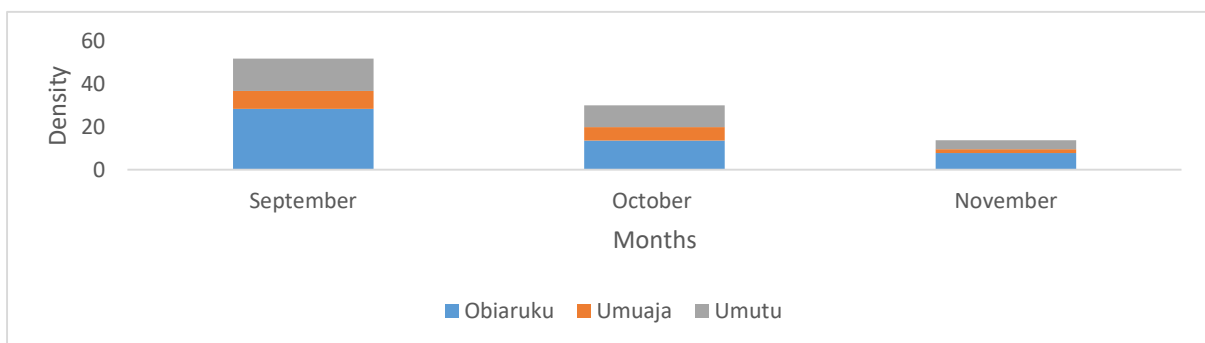

Fig. 3. Monthly variations in the density of anopheles mosquitoes in Ukwani LGA, Delta State. (F $_{(density)}$ = 2.84, P= 0.136)

Abundance and distribution of Anopheles mosquitoes
The abundance and distribution of *Anopheles* mosquitoes sampled from various habitat in Ukwani LGA, Delta State is shown in Table 3. Only *Anopheles gambiae* was encountered in puddles, tyre-marks, ponds, and ditches. Anopheles mosquitoes were preponderant in ponds. Puddles equally had high Anopheles larvae while ditches recorded low species (Table 3).

Table 3. Effect of physiochemical parameters on the abundance and distribution of *Anopheles* mosquitoes sampled from various habitat in Ukwani LGA, Delta State.

Mosquito habitats	Mosquito species collected	No. of mosquito species collected (%)
Puddles	*An. gambiae*	271(32.6)
Tyre-marks	*An. gambiae*	152 (18.3)
Ponds	*An. gambiae*	350 (42.1)
Ditches	*An. gambiae*	59 (7.1)
Total		832 (100.0)

Note: habitats with – signifies absence of mosquito species.

Discussion
In this study, we aimed to determine the abundance and distribution of *Anopheles* mosquitoes in Ukwani L.G.A., Delta State with reference to the physicochemical characteristics of their breeding sites. The appropriate estimation of mosquito species abundance and distribution is

prerequisite to developing an effective control approach in the prevailing malaria and disease in Nigeria. Similar to this study, Kipyab *et al.* (2015) confirmed that the density of mosquito species in breeding sites is a function of some physiochemical parameters. More so, Kweka *et al.* (2012), and Garba and Olayemi (2015) established that there is a link between physicochemical parameters of mosquito breeding sites and mosquito abundance and distribution, as well as the prevalence of the diseases they transmit. Notable studies have implicated *Anopheles* mosquitoes in clean fresh water (Kevin *et al.*, 2014; Manguin, 2013; Kudom, 2015). However, only recently *Anopheles* mosquitoes have been found in polluted waters of their breeding sites (Sattler *et al.,* 2005; Awolola *et al.,* 2007). In some cases *Anopheles* and *Culex* mosquitoes inhabit same habitat even with the disparity in the ecology of habitat, but *Anopheles* species are more likely to be found as noted in studies of (Kweka *et al.,* 2012; Dejenie *et al.,* 2011).

The present study encountered *Anopheles* mosquitoes in clear and turbid water of breeding habitats. Clear waters with associating vegetation were majorly observed in the breeding habitats in this study. Sometimes waters were turbid and perceived to have little organic matter mixed (Kudom, 2015). Physicochemical parameter survey in various breeding sites revealed temperature to be between 29.9 and 34.6°C, pH between 6.09 and 6.14, Dissolved oxygen between 7.4 and 8.1 mg/l, conductivity between 424 and 583 µS/cm, TDS between 11.3 and 51.3, salinity between 149.6 and 276.5 ppm, and flow velocity between 198 to 287.4 mV. Water temperature of the sampled communities were within acceptable limits for larvae survival. Various studies have confirmed that larvae density corresponds to temperature between 28°C and 32°C (Kabula *et al.,* 2011; Kweka *et al.,* 2012; Munga *et al.,* 2013; Imam and Deeni, 2014). Though, air temperature in Umutu was high and probably had influenced the increasing temperature of water in the breeding habitats. It may connote that increased air temperature influenced increased water temperature which thus affects mosquito abundance and distribution in the sampled communities. Air temperature, water temperature, conductivity and total dissolved solids was highest in Umukwata, as pH and DO were highest in Obiaruku and Umutu respectively compared to the other locations. The high conductivity reported in this study must have supported the high density of mosquito larvae in Obiaruku. This observation is in agreement with previous studies of (Kabula *et al.,* 2011; Dejenie *et al.,* 2011) which reported salinity and conductivity supports abundance of *Anopheles* larvae compared to culicine larvae. Higher records of conductivity is linked to run offs contaminated with pesticides, chlorine, phosphoric and nitrous ions other than associating solids in the waters of breeding habitats (Kevin *et al.,* 2014).

Anopheles mosquitoes were highly abundant in September and in ponds than in other sampled months and breeding habitats. The range of water and air temperature reported in this study is in agreement with the study of Mereta *et al.* (2013). Hydrogen ion concentration (pH) of breeding habitats in Obiaruku was neutral and those recorded in the other habitats were slightly acidic. This must have been the reason for high density of *Anopheles* mosquito in Obiaruku compared to the other locations with slightly acidic waters. However, the study of Kwasi *et al.* (2012) noted that hydrogen ion concentration of 10.1 above or 4.4 below would cause larval mortality in breeding sites. The waters of the various breeding habitats in the sampled locations were highly oxygenated following the records presented in this study (Table 1). According to Kengluecha *et al.* (2005), water

temperature, pH, CO_2 and hardness were determining factors of mosquito abundance. However, variation in dissolved oxygen concentration has been reported to be linked to the differences in mosquito larvae density in the various habitat (Lancaster and Downes, 2013). The low pH recorded in Umukwata would be due to the mining activity that could have increased acid deposition via sedimentation. In other locations, increase in pH could be due to fertilizer use which ran off into mosquito breeding sites. Dissolved oxygen was at acceptable limits for mosquito survival and it is in line with other studies of Getachew *et al.* (2020). The record of total dissolved solids reported in this study was remarkable. However, highest concentrations were recorded in Umukwata and were similar to the observations made by the study of Okogun *et al.* (2005). In laboratory culture, Geller *et al.* (2000) noted that *An. gambiae* would thrive well and emerge at stipulated day limits when pH is at tolerable levels and planktons sufficient enough for their consumption. Similar observation was made by Okogun *et al.* (2005) that cool, still and clear water with suitable pH, temperature and nutrient composition would encourage breeding of *Anopheles* species. However, erosion and flooding are enemies of mosquito in their breeding habitats with an observed oxygen depletion and physical harm to the larvae (Mereta *et al.,* 2013).

Considering the density of *Anopheles* mosquito in the different locations, Obiaruku had the highest (42.3%) and Umukwata the lowest density (21.3%). Dissolved oxygen and hydrogen ion concentration (pH) of waters of breeding sites were positively correlated to the density of mosquitoes. Even though other factors including temperature, total dissolved solids and conductivity showed negative correlation, there is likelihood of these parameters impacting on larvae density in the various breeding sites. As evidenced in the study of Noori *et al.* (2015), positive correlation was observed with temperature, pH, nitrate, and *Cx. pipiens*, *Cx. longiareolata*, *Cx. antennatus*, *Cx. caspius*, *Cx. vagans*, *Cx. decens*, *Cx. perexiguus*, *Cx. uniittatus*, *An. multicolor*; turbidity and *An. Arabiensis*; sulphate and *An. sinensis* ; phosphate and *Cx. quinquefasciatus*. In this present study, *Anopheles* mosquitoes were present, abundant and distributed in puddles, tyre marks, ponds and ditches with ponds (42.1%) having the highest number of species collected. Contrary to the findings of this study, Mattah *et al.* (2017) reported that puddles had the highest number of mosquito species. Similarly, the study of Getachew *et al.* (2020) reported higher Anopheles larvae density in rain pools, pools generally and burrow pits compared to other habitats. The differences between those recorded in this present study and previous study may be ascribed to water chemistry, physical and environmental factors. This study has revealed that due to the presence of *Anopheles* mosquito in abundance, sustained malaria infections in the communities investigated is possible. The diversity of breeding habitats of mosquitoes is probably due to the abandonment of developmental projects, lack of sanitary activities, poor environmental maintenance and management practices that prevails in several communities in Nigeria.

CONCLUSION

This study has shown that physicochemical parameters reported favoured mosquito abundance and distribution in all sampled habitats especially Obiaruku. Water temperature, pH, conductivity, dissolved oxygen and TDS being at acceptable limit for mosquito survival. *Anopheles* mosquito density was reportedly high in all locations, positively correlated with all physicochemical parameters and highest

in September. This predicts that habitat of mosquitoes in Obiaruku and Umutu encouraged abundance of mosquito species. Therefore, manipulating the habitat by increasing or decreasing DO and pH would better control species in their local habitat. Mosquito control should be targeted on ponds. This findings could be useful in comprehending the ecology of mosquito larva that may be beneficial in designing and implementing larval control programs.

REFERENCES

Adeleke, M.A., Mafiana, C.F., Idowu, A.B., Adekunle, M.F. & SamWobo, S.O. (2010). Mosquito larval habitats and public health implications in Abeokuta, Ogun State, Nigeria. *Tanzania Journal of Health Research* 10(2): 103-107.

Aigbodion, F. I. & Odiachi, F. C. (2005). Breeding Sites Preferences of Anopheline Mosquitoes in Benin City, Nigeria. *Nigerian Journal of Entomology* 20: 1-7.

ASTM International, ASTM D858-12, Standard Test Methods for water quality, ASTM International, West Conshohocken, Pa, USA, 2012, http://www.astm.org/

Awolola TS, Oduola AO, Obansa JB, Chukwurar NJ, & Unyimadu JP. 2007. *Anopheles gambiae* S.S. Breeding in polluted water bodies in Urban Lagos, southwestern Nigeria. *Journal of Vector Borne Disease*. 44: 241-4.

Chukwuekezie, O., Nwosu, E., Nwangwu, U., Dogunro, F., Onwude, C., Agashi, N., Ezihe, E., Anioke, C., Anokwu, S., Eloy E., Attah, P., Orizu, F., Ewo, S., Okoronkwo A., Joseph, A., Ikeakor I., Haruna, S., and Gnanguenon, V. (2020). Resistance status of *Anopheles gambiae* (s.l) to four commonly used insecticides for malaria vector control in South-East Nigeria. *Parasites and Vectors*.13, 152.

Ciota, A.T. & Kramer, L.D. (2013). Vector-virus interactions and transmission dynamics of West Nile virus. 5: 3021–3047.

Dejenie T, Yohannes M, & Assmelash T. (2011). Characterization of mosquito breeding sites in and in the vicinity of Tigray microdams. *Ethiopian Journal of Health Science*. 21: 57-66.

Garba Y, & Olayemi IK. 2015. Spatial variation in physicochemical characteristics of wetland rice fields mosquito larval habitat in Minna, north central Nigeria. In: International conference on agricultural, ecological and medical sciences, Feb 10th – 11th; p 11-4.

Getachew, D., Balkew, M., and Tekie, H. (2020). Anopheles larval species composition and characterization of breeding habitats in two localities in the Ghibe River Basin, southwestern Ethiopia. *Malaria Journal*, *19*(1): 65.

Harbach, R. (2008). Family Culicidae Meigen, 1818. *Mosquito Taxonomic Inventory*.

Harbach, R.E. and Kitching, I. (2016). The phylogeny of Anophelinae revisited: inferences about the origin and classification of Anopheles (Diptera: Culicidae). *Zoologica Scripta*. **45**: 34–47.

Imam AA, and Deen Y. (2014). Common types of Anopheles gambiae breeding habitats in northwestern Nigeria *Journal of Innovative Research and Engineering Science*. 4:496-504.

Kabula BI, Attah PK, Wilson MD, and Boakye DA. (2011). Characterization of Anopheles gambiae s.l. and insecticide

resistance profile relative to physiochemical properties of breeding habitats within Accra metropolis, Ghana. Tanzan Journal of Health Research 13: 163-87.

Kengluecha A, Singhasivanon P, Tiensuwan M, Jones JW, Sithiprasasna R. (2005). Water quality and breeding habitats of anopheline mosquito in northwestern Thailand. *Southeast Asian Journal of Tropical Medicine and Public Health*. 36(1):46-53.

Kevin R, Daniel K, Christine K, Katie F, and Alex C. (2014). Conductivity, salinity, and total dissolved solids. http://www.fondriest.com/environmental-measurements/parameters/water-quality/conductivity-salinity-tds. Accessed 18th March, 2021.

Kipyab PC, Khaemba BM, Mwangangi JM, and Mbogo CM. 2015. The physicochemical and environmental factor affecting the distribution of *Anopheles merus* along the Kenyan Coast. Parasite Vectors 8:221.

Klinkenberg, E., McCall, P., Wilson, M.D., Amerasinghe, F.P. and Donnelly, M.J. (2008). Impact of urban agriculture on malaria vectors in Accra, Ghana. *Malaria Journal* 7: 151.

Kudom AA. (2015). Larval ecology of Anopheles coluzzi in Cape Coast Ghana: water quality, nature of habitat and implication for larval control. *Malaria Journal* 14: 447.

Kwasi B, Biology A, and Kumasi T. (2012). Physical-chemical assessment of mosquito breeding sites from selected mining communities at the Obuasi municipality in Ghana. *Journal of Environment and Earth Science*. 2:123-30.

Kweka E, Zhou G, Beihe LB, Dixit A, Afrane Y, Lii TMG, *et al*. (2012). Effect of co-habitation between *Anopheles gambia s.s.* and *Culex quinquefasciatus* aquatic stages on life history traits. *Parasites Vectors* 5:33.

Kweka E, Zhou G, Munga S, Lee M, Atieli H, Nyindo M, *et al*. (2012). Anopheline larval habitats seasonality and species distribution: a prerequisite for effective targeted larval habitats control programmes. *PLoS One* 7(12): e52084.

Lancaster J. and Downes BJ. (2013). Aquatic Entomology. Oxford University Press UK pp 41-47.

Mattah PAZ, Futagbi G, Amekudzi LK, Mattah MM, de Souza DK, Kartey-Attipoe WD, Bimi L, Wilson MD. (2017). Diversity in breeding sites and distribution of Anopheles mosquitoes in selected urban areas of southern Ghana. *Parasites and Vectors* 10: 25

Mereta ST, Yewhalaw D, Boets P, Ahmed A, Duchateau L, Speybroeck N, Vanwambeke SO, Legesse W, DeMeester L and Goethals PLM. (2013). Physico-chemical and biological characterization of Anopheline mosquito larval habitats (Diptera: Culicidae): implications for malaria control. *Parasites and Vectors* 6:320.

Mohammed, B. R., Yayo, A. M., Ajanusi, O. J., & Lawal, I. A. (2021). Relative abundance and molecular identification of Culex pipiens complex (Diptera: Culicidae), in Kura Local Government Area, North-western Nigeria. *Parasite epidemiology and control*, *14*, e00213.

Munga S, Vulule J, and Kweka EJ. (2013). Response of Anopheles gambiae s.l (Diptera: Culicidae) to larval habitat age in western Kenya highlands. *Parasite Vectors* 6:13.

Nigerian National Bureau of Statistics (2006). Statistical abstract (NNBS). 2006, Abuja.

Noutcha MAE, and Anumudu CI. 2009. Entomological indices of Anopheles gambiae s.l. at a rural community in Southeast Nigeria, *Journal of Vector Borne Disease* 45: 43-51.

Ojianwuna, C.C, Enwemiwe V.N, and Ossai, P.I. (2021). The use of deltamethrin, permethrin, their combination and synergist on female *Anopheles* mosquito in Isoko South, Delta State. *Nigerian Journal of Science and Environment*. 19(1):39-50.

Okogun GR, Anosike JC, Okere AN, and Nwoke BEB. (2005). Ecology of mosquitoes in Midwestern Nigeria. *Journal of Vector Borne Diseases*. 42(1): 1-8.

Rakotomanana, F., Ratovonjato, J., Randremanana, R.V., Randrianasolo, L., Raherinjafy, R., Rudant, J.P. and Richard, V. (2010). Geographical and environmental approaches to urban malaria in Antananarivo (Madagascar). *BMC Infectious Disease* 10: 173.

Sattler MA, Mtasiwa D, Kiama M, Premji Z, Tanner M, Killeen GF, *et al*. (2005). Habitat characterization and spatial distribution of Anopheles sp. mosquito larvae in Dares Salaam (Tanzania) during an extended dry period. *Malaria Journal* 4:4.

WHO (2014). World Malaria Report 2014. World Health Organization, Geneva Switzerland.

WHO (2016). World malaria report 2015. World Health Organization, Geneva Switzerland.

WHO (2020). World malaria report 2020. World Health Organization, Geneva Switzerland.

WHO. (2017). World Malaria Report 2017. Geneva: World Health Organization.

WHO. (2018). World Malaria Report 2018. Geneva: World Health Organization.

Zhou G, Afrane YA, Vardo-Zalik AM, Atieli H, Zhong D, Wamae P, Himeidan YE, Minakawa N, Githeko AK, Yan G. (2011). Changing patterns of malaria epidemiology between 2002 and 2010 in western Kenya: The fall and rise of malaria. *PLoS One* 6(5):e20318. Doi:10.1371/journal.pone.0020318