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Research Article

Assessing the Risk of Exposure to Vectors of Malaria using Entomological Inoculation Rate among Houses at Auyo Irrigation Rice Farming Community in Jigawa State

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ABSTRACT

A longitudinal entomological survey of malaria vectors was carried out aiming to assess the transmission risk factors with regard to housing types at the rice irrigation community of Auyo LGA. The study was carried out in 32 households from March 2017 to February 2018. Adult mosquitoes were collected from the selected residential houses using the Pyrethrum spray collection method. The Human biting rate, sporozoite and entomological inoculation rates (EIR) were calculated based on common housing type and three seasons of the collection period. A total of 3,998 female Anopheline mosquitoes were collected. The most abundant species was *Anopheles gambiae sl,* (94.5%) followed by *An. Funestus* (4.5%) and other minor spp (1%) including *An*. *pharoensis* and *An. coustani*. Members of *An. gambaie* complex was analysed by PCR and *An. coluzzi* accounts for about 92.3%, *An. gambiae ss* 3.9% and *An. arabiensis* 3.7%. The human biting rate was highest in the thatch houses (22.64), compared to Mud and concrete houses with 10.6 and 2.4 respectively. Enzyme-linked immunosorbent Assay (ELISA) yielded 64 positive results which account for a sporozoite rate of 0.11(11%). The rates of infection by *Plasmodium species* in mosquitoes and Entomological Inoculation Rate (EIR) were higher in thatch and mud houses compared to concrete houses. The estimated cumulative infective bites per person per year was (138) in thatch, (74) in mud and (0) in concrete house (p- 0.001). Based on these findings, it is recommended that malaria control may be achieved by introducing mosquito-proofed housing and good environmental management.

Keywords: Entomological inoculation rate; Malaria risks; Housing types; Irrigation; Rice

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INTRODUCTION

Six countries in sub-Saharan Africa accounted for 55% of the 241 global malaria cases out of which 27% of the cases were recorded in Nigeria (WHO, 2021). Currently, the highest prevalence of malaria in Nigeria has been recorded in the four states of the Northwest geo-political zone including Kebbi (49%), Zamfara (36.6%), Kano (25.5%) and Jigawa (25.4%.) (NMEP, 2021). Several studies have documented heterogeneity in malaria transmission patterns and significant differences in density of local populations of the malaria vector species between urban and rural areas elsewhere and in Nigeria (Belisse *et al*., 2021; NMEP, 2021; Adeogun *et al.,* 2023). The major malaria vector species in Nigeria, *An*. *gambiae* sl and *An. funestus* are known to feed and rest indoors and as such their biting rates have been inferred to be affected by housing design and structure (Atieli *et al.,* 2009). Houses with closed eaves and installed ceilings have been associated with less Anopheline density and lower transmission rates than those with opened eaves (Jatta *et al.,* 2018; Abongo *et al*., 2023). The entomological inoculation rate(EIR) defined as the number of infective mosquito bites received per person in a period of time has been used as an important index for measuring the intensity of malaria transmission and it gives an estimate of the risk of contracting malaria in a particular place (Abrahma *et al.*, 2017; Yamba *et al*., 2020). A meticulous extensive review of studies on measurements of annual EIR conducted from 1980 onwards in sixteen countries across Africa, reported a mean EIR value of 121 infected bites per annum (Hay *et al.,* 2002). These studies partially demonstrated substantial variability in risk of exposure to malaria within countries, ranging from (0 – 884) depending on land – use and whether the ecotype is rural, urban or irrigated rice (Hay *et al.,* 2002). Historic data from a comprehensive study on malaria epidemiology carried out between 1971-1975 at Garki an LGA adjacent to Auyo documented a maximum EIR value of 145 sporozoite-positive bites per year. Considerable variations in the EIR values ranging from (8 – 145) between the villages have been demonstrated but the local intra-village malaria risk factors have not been investigated (Mollineaux and Grammicia, 1980). The Garki project data was generated before the introduction of large irrigation schemes in the area and the urbanization due to the creation of Jigawa State, however, this data was collected over 40 years and therefore would not be representative of the conditions today. The construction of large irrigation project in late 1970 has transformed Auyo into irrigated rice farming community and provides a favorable ecology for supporting huge populations of malaria vectors but the concomitant malaria risk is poorly understood. In this study, we assessed the risk of exposure to malaria which individuals dwelling in concrete, mud and thatch houses are exposed to by measuring and comparing the EIR values in the housing types. The rationale was to provide evidence for decision making on housing policy that would enhance community participation in sustainable locality specific malaria control measures to reduce malaria in high burden areas.

MATERIALS AND METHODS

Study Area

Auyo LGA is located at Sahel vegetation belt lying at 12° 21′ 36′′N and 9°59′8′′E. It is a low land area drained by Hadeja-Jamaare – Kano – Komadugu river systems which eventually drained into the Lake Chad basin. The population is mainly rural comprising farming communities living in villages of varying sizes. Dwellings may be grouped as temporary, semi-permanent or permanent. The buildings are made from local materials comprising of mud, cement, wood, or cornstalk and the rooms are circular or rectangular. During the cold and rainy seasons, people tend to remain indoors while in the hot and peak of dry season, the people stay outside for longer periods. Agriculture is dominated by both rain-fed and irrigation farming and in addition animal husbandry in the form of rearing cattle, sheep, goats and poultry is practiced. (Abdu *et al.*, 2015)

Study Design

The study was designed as a longitudinal survey of Anopheline malaria vector species from sentinel houses selected in the LGA. The houses were selected to represent the rural - urban characteristics, ecological diversity and housing types. A total of 32 houses were randomly selected across the cardinal directions of the study area i.e N, S, E and W. The houses were enumerated and assigned code containing the location, cardinal direction and serial number eg (AN01: A= Auyo, N= north 01 serial number).

Questionnaire/Interview

The heads of each of the participating (Selected) households were interviewed on: population of the household, number of rooms, occupation, types of interventions used, knowledge on mosquito and malaria, and domestic animal kept. Also the distance of each of the house from mosquito breeding sites as well as type of dwelling were measured. All the question and answers session were in Hausa and later translated into English.

Mosquito Collection

Adult mosquito populations in the area were surveyed using the conventional entomological collection technique, the Pyrethrum Spray Collection (PSC) adopting the established protocol (WHO, 2003).

Pyrethrum Spray Collection

A total of thirty-two (32) households were selected randomly across the study area. The houses for PSC were selected based on the expected cooperation of the occupants. Adult mosquitoes were collected monthly between March 2017 and February 2018. The mosquitoes were collected from the rooms in which people slept the previous night. The PSC was carried out once and between 4.30am – 6.30am on the day of the collection. Food, cooking utensils, animal pets were removed from the room before spraying. A white sheet of cloth about 2x4m was used to cover the entire surface of the floor. Doors and windows were closed and the room was sprayed with aerosol containing pyrethrum insecticide (Mortein) for 2 minutes. After 10 minutes, knocked-down mosquitoes were picked carefully with entomological forceps. Mosquitoes were transferred to petri-dish, labeled and transported to the laboratory at Aminu Kano Teaching Hospital (AKTH).

Morphological Identification

Mosquitoes were counted and sorted into genera Culex and Anopheles based on taxonomic characters (Service, 1980).. The genus *Anopheles* was further identified into *An. gambiae s.l, An. funestus* group and other minor species. Morphological characteristics including the number and patterns of bands on wings, palps and legs were used to separate the species. The females were classified based on the physiological status as: Blood fed (BF), unfed (UF) or Gravid (GV). The members of the *Anopheles gambiae* complex were identified further by PCR.

Molecular Species identification

Polymerase chain reaction (PCR) was used to identify members of sibling species of the *An. gambiae* complex. Genomic DNA was extracted from individual mosquito specimen using the LIVAK extraction method. PCR reaction was done according to protocol of Scott *et al*. (1993). A quantity of one micro litre of the genomic DNA was used in a PCR reaction containing 25ul of the reagents. Cocktail of universal and specie specific primers were used in the PCR reaction. Universal primer UN (GTC TGC CCC TTC CTC GAT GT), *An arbiensis* specicific primer AR (AAT TGT CCT TCT CCA TCC TA) and *An gambiae* specific primer GA (CTC GTT TGG TCG GCA CGT TT) were used to amplify specie specific genes. GA and AR amplified products diagnostic for *An. gambiae* (390 bp) and *An. arabiensis* (315 bp). The DNA fragments were visualized under ultra violet (UV) light and the size of the products was confirmed using the molecular ladder. Molecular forms of the *An. gambiae* were identified further by PCR – restricted length polymorphism (PCR-RFLP) as described by (Fanello *et al.,* 2002) using primers specific for *An. Coluzzii* (formerly *An. gambiae* Mopti or „M" form) and *An. gambiae* s.s. Giles (formerly *An. gambiae* Savannah or „S" form) to distinguish between molecular M and S forms.

Sporozoite and Entomological Rate Determination

Malaria infection in mosquitoes was assessed by testing for the presence of *Plasmodium falciparum* circumsporozoite protein (CSP) in their head and thoraxes using a monoclonal sandwich Enzyme Linked Immuno-Sorbent Assay (ELISA) developed by Burkot *et al*. (1987). In the sporozoite ELISA tests, two technical replicates of each sample were run in two different microplates at the same time and retested in cases where the first result was ambiguous. The absorbance of the solutions/reactions at the end of each ELISA was measured using microplate reader (ELX808; BIO-TEK) at 450nm. To avoid any false positives (due to background noise), a sample was considered positive for an assay when its optical density (OD) was twofold higher than the average of the OD of both negative and positive controls. The CSP rate and the 95% CI were calculated. The entomological inoculation rate (EIR) was thereafter determined by multiplying the annual human biting rate (HBR) by the mean CSP rate for each species at the different housing types and seasons (Kilama *et al.,* 2014).

RESULTS

Housing types and distance to breeding sites

Thirty two houses participated in the period of study out of which about 62.5% were made up of mud, 25.0% cement, and 12.5% thatch. The categories of thatch houses are nearest to the breeding sites (1.07m – 14.23m), compared to (2.3m – 75.9m) mud and (4.9m – 62.5m) concrete. On the average, there are about 5 – 7 persons per house in each category, with the mud housing tending to have more and the concrete least number of occupants. The housing types, number of occupants and distance of houses to breeding sites is shown (Table 1).

Abundance and distribution of Anopheline species

A total of 3,998 Anopheline species were collected during the period, out of which about 94% were *An. gambiae* sl, 4.5% *An. funestus* and 1% *An. pharoensis* and others unidentified. Seven hundred and eighty five (19.7%) of Anophline species were collected from thatch, three thousand and seventeen (76.3%) from mud and one hundred and fifty (0.04) from concrete housing types. About 54% were collected in the period

July – October (rainy season). The abundance and distribution of the Anopheline mosquito species were found to be significantly associated with season and housing types (p-value – 0.03) Table 2.

Abundance and composition of *Anopheles gambiae* complex sibling species

The PCR result of about 15% of the specimen of *An. gambiae* complex analyzed are presented in Table 3. The result revealed that 92.3% were *An. colluzzi*, 4% *An. gambiae* ss and 3.7% *An. arabiensis*. The members of *An. arabiensis* were found only in thatch houses.

Estimated Human biting, sporozoite and Entomological Inoculation Rates in relation to house types

The estimated Human biting, sporozoite and Entomological Inoculation Rates with respect to house types is shown in Table 4. The highest and lowest human biting rates 13.08 and 1.1 respectively were recorded in thatch and concrete house types between July and October. With respect to sporozoites rate, the highest value of 0.15 was observed in the mud house type in the period between March and June. No sporozoite infected mosquitoes were observed in concrete house type throughout the study period. The highest EIR (1.7) was obtained in thatch house type between July and October.

Table 1. Housing types, number of occupants and distance to breeding sites

House Type	No. of Houses (%)	Population	Distance to Breeding Sites		
			Rice Field (m)	Ponds (m)	Rivers (m)
Thatch	04 (12.5)	25	1.1-10	1.5-8.3	0.61-24.4
Mud	20 (62.5)	140	1.6-50	1.5-63.7	3.8-11.4
Concrete	08 (25.0)	38	1.4-50	2.1-89.4	11.2-48

Table 2. Seasonal abundance and distribution of Anopheline species by housing type

Seasons	House Type									Total
	Thatch			Mud			Concrete			
	An. gambiae (%)	*An. funestus* (%)	Others (%)	*An. gambiae* (%)	*An. funestus* (%)	Others (%)	*An. gambiae* (%)	*An. funestus* (%)	Others (%)	
Mar–Jun	23.5	1.4	0.3	68.8	4.3	0.9	2.6	0.8	0.0	**1264**
Jul – Oct	19.3	0.9	0.3	73.1	2.3	0.2	3.6	0.2	0.0	**2176**
Nov–Feb	4.8	1.6	0.5	85.1	1.9	1.3	3.4	1.3	0.0	**558**
Total	**727**	**45**	**13**	**2880**	**113**	**24**	**128**	**22**	**0**	

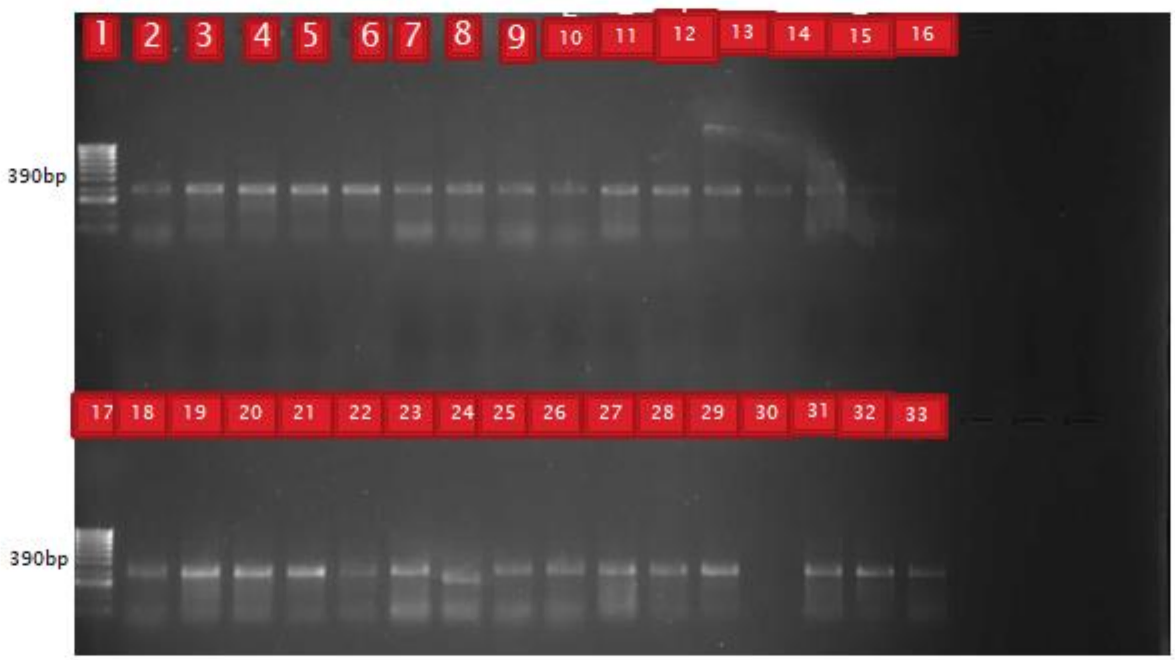

Figure 1: Gel chromatograph showing molecular specie identification of Anophelines gambiae complex. lane 1 and 17 represent DNA ladders of 1000bp each, Lane 1-15, 18-29 and 31-33 show amplification at 390bp indicating *An colluzzii* while lane 16 and 30 show no amplification

Table 3 Seasonal variation in composition of sibling species of *An. gambaie* complex

Season	House Type											
	Thatch				Mud				Concrete			
	AG	AC	AA	Total Analysed	AG	AC	AA	Total Analysed	AG	AC	AA	Total Analysed
Mar - Jun	5	30	8	43	4	123	0	127	0	5	0	5
Jul – Oct	3	45	13	61	7	226	0	233	1	11	0	12
Nov – Feb	0	4	0	4	2	68	0	70	0	3	0	3
Total	**8**	**79**	**21**	**108**	**13**	**417**	**0**	**430**	**1**	**19**	**0**	**20**

AG – *An. gambiae* ss, AC – *An. colluzzi*, AA – *An. arabiensis*

Table 4. Human biting, sporozoite and Entomological Inoculation Rates in relation to house type

Seasons	Thatch			Mud			Concrete		
	HBR	SR	EIR	HBR	SR	EIR	HBR	SR	EIR
Mar – Jun	8.6	0.07	0.602	3.5	0.15	0.525	0.87	0.0	0.0
Jul – Oct	13.08	0.13	1.7	5.1	0.14	0.714	1.1	0.0	0.0
Nov – Feb	0.96	0.0	0.0	2	0.07	0.14	0.44	0.0	0.0

HBR: Human biting rate SR: Sporozoites rate EIR: Entomological Inoculation Rate

DISCUSSION

Malaria transmission in Nigeria remains intense especially at high burden areas such as communities living in rice irrigation ecosystems. Understanding the local determinants for the heterogeneity of malaria transmission including the variations in malaria risk of people dwelling in different types of houses is critical to developing effective locality specific alternative vector control measures to reduce malaria to pre-elimination level. This research has generated evidence that may guide formulation of malaria free housing policy in the area. The result revealed that significant numbers of the houses in the study area were made from mud and cement compared to those made from corn stalk, and grass (thatch category). This is evidence that there is remarkable improvement in structure of the housing compared to the situation reported in late 1970s (Molineaux and Grammiccia, 1980). Study have shown that urbanization has been observed to have offer reduced parasitological, behavioral and entomological effects on malaria risks (Hay *et al.,* 2005). Endophilic mosquitoes gain entrance readily in houses made of thatch which offer less protection compared to those made of mud and cement (Abongo *et al.,* 2022).The Specie identification has shown that *An. gambiae sl* accounts for 94% of the mosquito population followed by *An. funestus* and the minor species throughout the study period. This is in contrast to Garki project which showed dominance of *An. funestus* over *An. gambiae* in the dry season (Molineaux and Grammiccia, 1980). The members of A*n. gambiae*, *An. funestus*, and minor other species notably *An. pharoensis* have recently reported to exist in sympatry in the area (Adegun *et al*., 2023). This suggests probably the greater adaptive response of populations of *An. gambiae* to the long term climatic and local human induced ecological changes in the area. The distribution of *An. gambaie sl* reported in this study corroborate modeled predicted distribution of the species in Nigeria (Adegun *et al.,* 2023). The relatively high Anopheline mosquito found in thatch houses (196 per structure) compared to mud (150 per structure) and concrete (19 per structure) may be due to the nearness of the thatch houses to breeding sites and the porosity of the thatch house to mosquitoes. The housing structure may largely contribute to high number of mosquitoes collected because factors such as number of people in each house type which influence mosquito entry are similar. Molecular analysis of *An. gambiae* complex revealed high prevalence of *An. colluzzi* 92.3% over *An. gambaie ss* and *An. Arabiensis*. This is similar to the proportions in composition of these sibling reported recently across Nigeria (Adegun *et al.,* 2023). The *An. arabiensis* identified were from the specimen collected exclusively from thatch houses where more animals are kept suggesting the zoophagic feeding preference of this malaria vector [(Eshetu *et al*., 2023; Asale *et al.,* 2017). The poor construction and dilapidated condition of the categories of thatch and mud houses may partly explain the high human biting and sporozoite rates observed in these structures compared to concrete. The cumulative entomological inoculation rate or annual entomological inoculation AEIR value 138 infective bites per person per year recorded in thatch was higher than the African mean EIR value of 121 (Hay *et al.,* 2000). The EIR values recorded for the mud and concrete houses are significantly less than the African value and this demonstrates the heterogeneity of malaria risks to which people living in these categories of houses are exposed. These results are similar to findings of Belisse *et al.,* (2021) who reported average EIR of 145 in rural areas, Kilama *et al.* (2014) of EIR 125 in rice-growing area, and Epopa *et al.* (2019). It is worth noting that the high EIR currently recorded in thatch houses at Auyo despite the rice irrigation farming is lower than that documented at Garki 50 years ago (Molineaux and Grammiccia, 1980). This probably may be attributed to the protection derived from the use of LLINS, IRS, coils and other personal protection measures. In addition to housing structure, efficiency of the local vector species, availability of breeding habitats, topography, land use and environmental conditions may be contributing actively to high entomological indices of malaria transmission at Auyo. It has been postulated that malaria elimination may be achieved in high-burden areas by introducing mosquito-proofed housing and environmental management (Lindsay *et al.,* 2002; WHO, 2019). The principle of "building the vector out" is at the core of all housing interventions. The entry of disease-transmitting vectors into human habitations is prevented by screening windows, doors and eaves of houses (Kilama *et al.,* 2014; WHO, 2017).

CONCLUSION

Malaria control can be achieved by the improvement of house construction especially in communities living near irrigation due to heterogeneity in entomological inoculation rate and sporozoite rate observed in mud and thatch housetype compared to brick housetype. *An gambiae sl* was the major malaria vector species observed in the study and therefore served as the potential target of a malaria control program in the area. This data provides preliminary evidence to inform policy decisions on the incorporation of improvement of housing as a component of a strategy to control malaria vectors at high burdened areas of Nigeria.

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Author contribution

Yayo Abdulsalami Manu and Ado AbdulJalal and Asmau Hamza Abubakar : Carried out Conceptualization, Methodology and Supervision.

Yayo Abdulsalami Manu and Asmau Hamza Abubakar: Carried out Laboratory investigation and draft the original article.

Habibu Usman, Almukhtar Adamu, Alhassan Abdullahi, A. Aliyu and A. Yusuf: Review and Edit the manuscript

Fatima Idris Sambo and Mahmud Safiyanu: Carried out Result analysis.

REFERENCES

Abdu, Z., Abba, A., Chigozie, A.S. and Mohammad, A.B. (2015). Resource Use Efficiency in Onion Production among Participating and non-Participating Farmers in Hadejia Valley Irrigation Project, Jigawa State, Nigeria. *IOSR*.8(**8)**:69-73.

Abongo, B., Gimnig J.E., Omoke D., Ochomo, E. and Walker, E. D.(2022). Screening Eaves of Houses Reduces Indoor Mosquito Resting Density in Rural, Western Kenya.*Malaria Journal*. **21**:377.

Abrahama, M., Masseboa, F., Lindtjørnb, B.(2017). High Entomological Inoculation Rate of Malaria Vectors in Area of High Coverage Of Interventions in Southwest Ethiopia: Implication for Residual Malaria Transmission. *Parasite Epidemiology and Control.* **2:**61–69

Adeogun, A., Babalola, A.S. and Okoko, O.O (2023). Spatial distribution and ecological niche modeling of geographical spread of Anopheles gambiae complex in Nigeria using real-time data. *Sci Rep* 13, 13679.

Asale, A.,Duchateau L., Devleesschauwer, B.,Huisman, G. and Yewhalaw, D. (2017). Zooprophylaxis as a Control Strategy for Malaria caused by the Vector Anopheles arabiensis(Diptera: Culicidae): A Systematic Review. *Infect Dis Poverty*.**6**:160

Atieli, H., Menya, D., Githeko, A. and Scott, T. (2009). House Design modification reduces Indoor Resting Malaria Vector Density in Rice Irrigation Scheme Areas in the western. Kenya. *Malaria Journal,* **8**:108.

Belisse, P.D., Kopya, E., Ngadjeu, C. S., Sonhafouo, C., Talipouo, A., Djamouko D.L., Awono-Ambene, H. P. and Wondji, S. (2021). Urban Malaria in Sub-Saharan Africa: Dynamic of the Vectorial System and the Entomological Inoculation Rate. *Malaria Journal*, **20**:364.

Burkot, T. R., Graves, P. M., Cattan, J. A., Wirtz, R. A., and Gibson, F. D. (1987). The Efficiency of Sporozoite Transmission in the Human Malarias, *Plasmodium falciparum* and P. vivax. *Bulletin of the World Health Organization*, *65*(3): 375.

Collins, F. H., Mendez, M. A., Rasmussen, M. O., Mehaffey, P. C., Besansky, N. J., and Finnerty, V. (1987). A Ribosomal RNA gene Probe Differentiates Member species of the Anopheles gambiae complex. *The American journal of tropical medicine and hygiene*, *37*(1): 37–41. https://doi.org/10.4269/ajtmh.1987.37.37

Epopa, P.S., Collins, C.M., North, A., Millogo, A., Benedict, M.Q., Tripet, F. and Diabate, A. (2019). Seasonal Malaria Vector and Transmission Dynamics in Western Burkina Faso. *Malaria Journal* **18**:113 https://doi.org/10.1186/s12936-019-2747-5.

Eshetu, T., Eligo, N. A. and Massebo, F. (2023). Cattle Feeding Tendency of Anopheles Mosquitoes and their Infection Rates in Aradum Village, North Wollo, Ethopia: An Implication for Animal based Malaria Control Strategies. *Malaria Journal,* **22**:81.

Fanello, C., Santolamazza, F. and Della, A. (2002): Simultaneous Identification of species and Molecular forms of the Anopheles gambiae complex by PCR-RFLP. *Med Vet Entomol.*, **16**:461-464.

Gillies, M. and Coetzee, M. A Supplement to the Anophelinae of Africa south of the Sahara (Afrotropical region).vol 55 (1987). *South African Institute for Medical Research, Johannesburg.*

Hay, S.I., Cox, J., Rogers, D.J., Randolph, S.E., Stern, D.I., Myers, M.F. and Snow, R.W. (2002). Climate Change and the Resurgence of Malaria in the East African Highlands. *Nature.* 415:905–909. [PubMed: 11859368]

Hay, S.I., Guerra, C.A, Tatem, A.J., Noor, A.M. and Snow, R.W. (2004).The Global Distribution and Population at Risk of Malaria: Past, Present and Future. *Lancet Infect. Dis*.; **4:**327–336. [PubMed: 15172341]

Hay, S. I, Rogers, D. J., Randolph, S. E. and Snow, R. W. (2005).Urbanization, Malaria Transmission and Disease Burden in Africa. *Nat Rev Microbiol*. 3(**1**): 81–90. doi:10.1038/nrmicro1069.

Jatta, E., Jawara, M., Bradley,J., Jefferies,D., Balla, Kande, B., Knudsen, J.B., Wilson,A.L., Pinder, M., D'Alesandro,U. Lindsay, S.W.(2018). How House Design Affects Malaria Mosquito Density, Temperature, and Relative Humidity: An Experimental Study in Rural Gambia.*Planetary Health*.2.

Kilama, M., Smith, D.L., Hutchinson, R., Kigozi, R., Yeka, A., Lavoy, G., Kamya, M.R. and Sarah, G. (2014). Estimating the Annual Entomological Inoculation Rate for Plasmodium falciparum Transmitted by Anopheles gambiae s.l. using three sampling methods in three sites in Uganda. *Malaria Journal 2014*, **13**:111.

Lindsay, S.W. and Emerson, P.M. (2002).Reducing Malaria by Mosquito Proofing Houses. *Trends in parasitology*.18(**11**):510-514.

National Malaria Elimination Programme (NMEP) [Nigeria], National Population Commission (NPC) [Nigeria] and ICF.2003. 2021 Nigeria Malaria Indicator Survey: Atlas of key indicators. Rockville Maryland, USA: NMEP, NPC and ICF.

Molineaux, L. and Grammicia, C. (1980): The Garki Project: Research on Epidemiology and Contro of Malaria in the Sudan Savannah of West Africa. *WHO, Geneva*, Pp 311

Scott, T. W., Clark, G. G., Lorenz, L. H., Amerasinghe, P. H., Reiter, P. and Edman, J. D. (1993). Detection of Multiple Blood Feeding in Aedes aegypti (Diptera: Culicidae) During a Single Gonotrophic Cycle using a Histologic Technique. *Journal of Medical Entomology*, *30*(**1**), 94-99.

Service, M.W. (1980): A Guide to Medical Entomology, Macmillan International College Edition. Oxford Press Ltd., Pp 23 – 45

World Malaria Report (2017). Geneva: World Health Organization; 2021. License: CC BY-NC-SA 3.0 IGO.

World Malaria Report 2019. Geneva: World Health Organization; 2021. License: CC BY-NC-SA 3.0 IGO.

World Malaria Report 2021. Geneva: World Health Organization; 2021. Licence: CC BY-NC-SA 3.0 IGO.

Yamba, E. I., Tompkins, A. M., Fink, A. H., Ermert, V., Amelie, M.E., Amekudzi, L.K. and Briet O. J. T. (2020). Monthly Entomological Inoculation Rate Data for Studying Malaria Transmission in Africa. *Dataset* 5(**2**): 31.