Rapid Assessment of Mosquito Larvae Distribution in Three Micro Habitats in Port Harcourt Metropolis Using Geospatial Methods

Nwabuoku Omoye[1], Onwuteaka John[1*], Ebere Nwabueze[1] and Okeke Nnaemeka[1]

[1]*Department of Applied and Environmental Biology, Rivers State University, Port Harcourt, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Author EN designed the study, Authors OJ and ON performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript and managed the analyses of the study. Author NO managed the literature searches. Both authors read and approved the final manuscript.

Article Information

Original Research Article

ABSTRACT

The technique of Geographic Information System (GIS) was used in the rapid assessment of the abundance and distribution of mosquito larvae in three micro habitats (stagnant drainage, transient puddles and transient water in tyre) in Port-Harcourt metropolis in 2018. Mosquito larvae were collected over a period of four months in 7 zones (21 stations), reared to adult stage; identified up to species level and their abundance recorded. A total of 830 mosquito larvae were caught, belonging to three genera and five species. A GIS mapping showed a spatial variation in the abundance of the five species of mosquito which varied significantly, *Culex quinquefasciatus* had the highest mean abundance (15.5), followed by *Anopheles gambiae* (10.3), *Aedes aegypti* (7.5), *Aedes albopictus* (4.42) and *Culex tigripes* (2.41). Mosquito larvae species abundance was highest in stagnant drainage (51%), followed by transient puddles (30%) and then transient water in tyre (19%). All the mosquito genera have the capacity to occur as the only species within the microhabitats chosen for this study even as the microhabitats are in different landuse classes. Culex and the Anopheles

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*Corresponding author: E-mail: onwuteaka.john@ust.edu.ng;

genera occurred together in combinations as dominants and co-dominants within two (stagnant drainage and transient puddles) out of the three microhabitats. Aedes genus occurred insignificantly in combination with Anopheles only in the water-in-tyre microhabitat and with Culex and Anopheles in transient puddle microhabitat.

A GIS modeling based on maximum Anopheles mosquito flight distance (9km) was used to develop a surface hazard model of mosquito infestation. Spatial results produced individual hazard assessments from different cardinal points. Combined results of the individual hazard assessments confirmed a composite multi-hazard risk assessment where the distribution of risk was not based on the environmental attributes of the land use class. Provided the potential capacity to predict the health vulnerability of the population within each composite hazard class. This study offer insight on the promising nature of GIS-based models in a data scarce environment to help in a meaningful way extrapolate evidence-based mitigation planning and resource allocation in mosquito control programmes.

1. INTRODUCTION

Vector-borne diseases such as those transmitted by mosquitoes, contribute significantly to the total disease burden in developing countries. Mosquitoes, belong to the Culicidae family in the order Diptera, and comprise of about 3,500 species dispersed all over the world [1]. Nonetheless only a limited number of species within the *Anopheles*, *Aedes*, and *Culex* genera have been well documented due to their importance in medical system [2]. The report of World Health Organization [3], shows that over a half of the world's population is at a constant risk of mosquito transmitted pathogens [4].Several studies on larval distribution and abundance [5,6,7] have shown how mosquito is dispersed and the conventional methods employed in these studies include local participatory surveillance, selected ecological indices, and empirical knowledge-based method [5,6,7]. Geographic Information System (GIS) has been used to study the spatial spread of mosquito and its associated diseases adequately by several researchers [6,8,9,10]. With the aid of the GIS in these studies, vector presence, diseases transmission, spatial patterns and distribution, risk and response have been improved better than the old or conventional system.

Port Harcourt city in Rivers State had the highest prevalence of malaria in Rivers State. The epidemics of mosquito borne disease and subsequent mosquito nuisance remain a major challenging problem in the state and has become a severe threat to the public health [11]. Nevertheless, it is apparent that as habitats change because of dynamic economic activities added to new patterns of consumption, new and potential favourable microhabitats emanates and thus supports mosquito breeding and subsequent enhancement in its disease transmission efficiency. Tracking these breeding sites requires an easier and smoother approach which GIS provides. GIS are extremely valuable tools for evaluating the epidemiology of vector-borne diseases in space and analyzing the associated infection risk [12]. Thus in the present study conducted in 2018, GIS was used to map and model the distribution of larvae in different breeding habitats in order to show spatial patterns of likely malaria transmission in relation to vector abundance.

2. STUDY AREA

The study area is located within Port Harcourt City as shown in Fig. 1. Port Harcourt City lie between latitude 4°43'E – 4°50' E and longitude 6°57'N – 7°05'N. Port Harcourt is a compactly populated city with intensive activities of humans in different sectors ranging from food vendors, restaurants, open street and stall markets, transportation, industrial activities, rental apartments with very poor sanitation and waste management infrastructures, sub-standard indigenous residential homes popularly called "batcha", auto-workshops waste dump sites scattered at various locations within the city and poor stagnant drainage network that crisscrosses the entire city [13].

A total of 7 zones, 21 stations and 3 microhabitats (stagnant drainage, transient puddles and transient water in tyre as shown in Plate 1) were sampled viz: Rainbow, GRA, NPA, Diobu, Trans-Amadi, Marine base and Eagle Island. Rainbow and Marine base are a mixed

use development area comprising of industries and residential areas with a moderate population; Trans-Amadi on the other hand is the industrial and commercial core of Port Harcourt metropolis with high density; Diobu is a densely populated area of Port Harcourt, comprising low income houses, stalls, and it accommodates the State's University; NPA is an industrial/commercial area with low density, popularly known for shipping and marine associated businesses; while GRA and Eagle Island district are organized, low density residential areas.
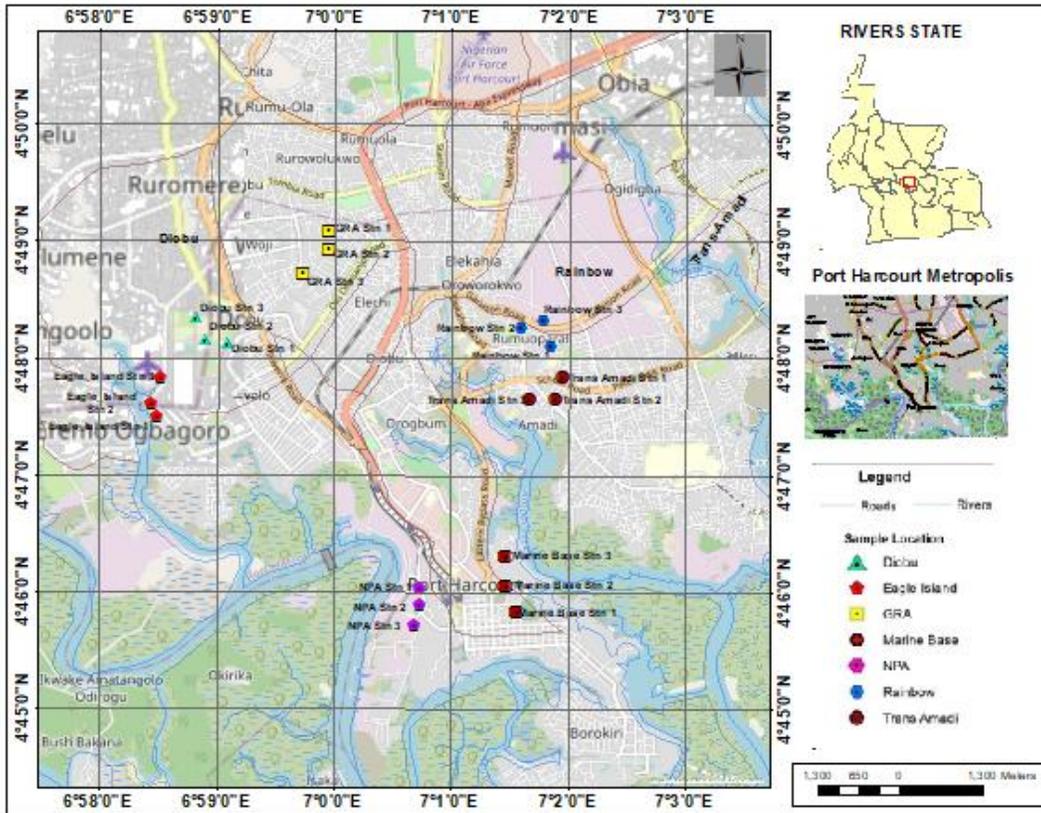
Fig. 1. Study area and stations of the survey

Plate 1a. Stagnant drainage microhabitat

Plate 1b. Tyre microhabitat with pools of water

Plate 1c. Transient puddles of water

3. MATERIALS AND METHODS

3.1 Larva Collection

A three hundred and fifty milliliters (350ml) dipper (BioQuip) was used to collect mosquito larvae from three microhabitat sites (stagnant drainage, transient puddles and transient water in tyre) [14]. The 1st, 2nd and 3rd instar larvae were usually collected between 7am and 9am during the sampling periods. The dipper was used at an angle of 45^0 in mosquito breeding habitats. Proper care was taken while filling the dipper so that the larvae may not be washed out. The dipper was immerged slowly; the larvae were disturbed and moved to the bottom with the result that they may escapes in the collection. The shadow of the hand of the collector approaching the site disturbed the larvae; therefore, the site was approached carefully. Between each dip an interval of 2-3 minutes was given so that the 3rd and 4th instar larvae and pupae may return to the surface, for those places where the water surface was covered with dense floating vegetation or organic debris, it was first of all cleared and then watched for 3-5 minutes so that the larvae may come to the surface.

3.2 Larva Rearing and Identification

The water containing the larva from various stations were puddled together and transferred into 5-Litre plastic containers for each station and labeled according to the stations. The larvae were reared by placing them in bowls covered with net and fed with wheat powder every two days until adult mosquitoes emerged as described by Ebere [15].The emerged adults were introduced into paper cups, properly labeled and covered with net using an aspirator. After 2 days, the adult mosquitoes were aspirated out of paper cups for morphological identification [16]. Dead mosquito samples were placed in Eppendorf tubes and sent to the Arbovirus Institute Enugu for further identification.

3.3 GIS Method

ESRI's Arc GIS 10.4.1 for desktop was the major software used for all the analysis done in this study. Modeling was implemented through the optimal utilization of different tools and modules of Spatial Analyst Extension in the Arc GIS 10.4.1 environment for cartography, and modeling. The spatial distribution of the sample stations was modeled within the environment for visualization while the backend database was populated with the species abundance values for each micro habitat in the months under investigation. Pie chart was used to illustrate the proportion of the abundance of each species in a micro habitat in each sampled month. Euclidean distance tool which develops a straight-line

distance from each input feature cell was used to model the travel distance of mosquito larvae species from each sample location. The raster surfaces generated for each mosquito species using the Euclidean distance model were iterated in a composite overlay process. The result of the iteration of the overlay processes using the Map algebra tool in ArcGIS provided visual measurements of the Composite Malaria Hazard model which shows the hotspot zones of potential malaria infestation from mosquitoes.

4. RESULTS

4.1 Spatial and Temporal Abundance and Distribution

The spatial distribution of larval mosquito species in the three (3) micro-habitats in the month of April (2018) is shown in Fig. 2a to Fig. 2c. Fig. 2a shows that only Culex species (100%) occurred in five stations namely Marine Base, NPA, Trans-

Amadi, Rainbow and GRA. The remaining two stations recorded the presence of Aedes (12%). and Anopheles (19%) in Diobu station and Anopheles (5%) in Eagle Island station in addition to Culex species.

In Fig. 2b. the pattern of occurrence in transient pool microhabitat shows the higher occurrence of Culex over Anopheles and Aedes in only four stations namely GRA (100%), Trans-Amadi (73%), NPA (88%), and Eagle Island (68%). The percentage dominance of Anopheles was observed in three stations namely Marine base (71%), Rainbow (71%), and Diobu (75%).

In Fig. 2c. the occurrence of mosquito larvae was recorded in only three water-microhabitats of transient tyre namely Rainbow (100%), Marine Base (100%) and NPA (100%) of only Aedes species. No larval mosquitoes were observed in GRA, Diobu, and Eagle Island stations.
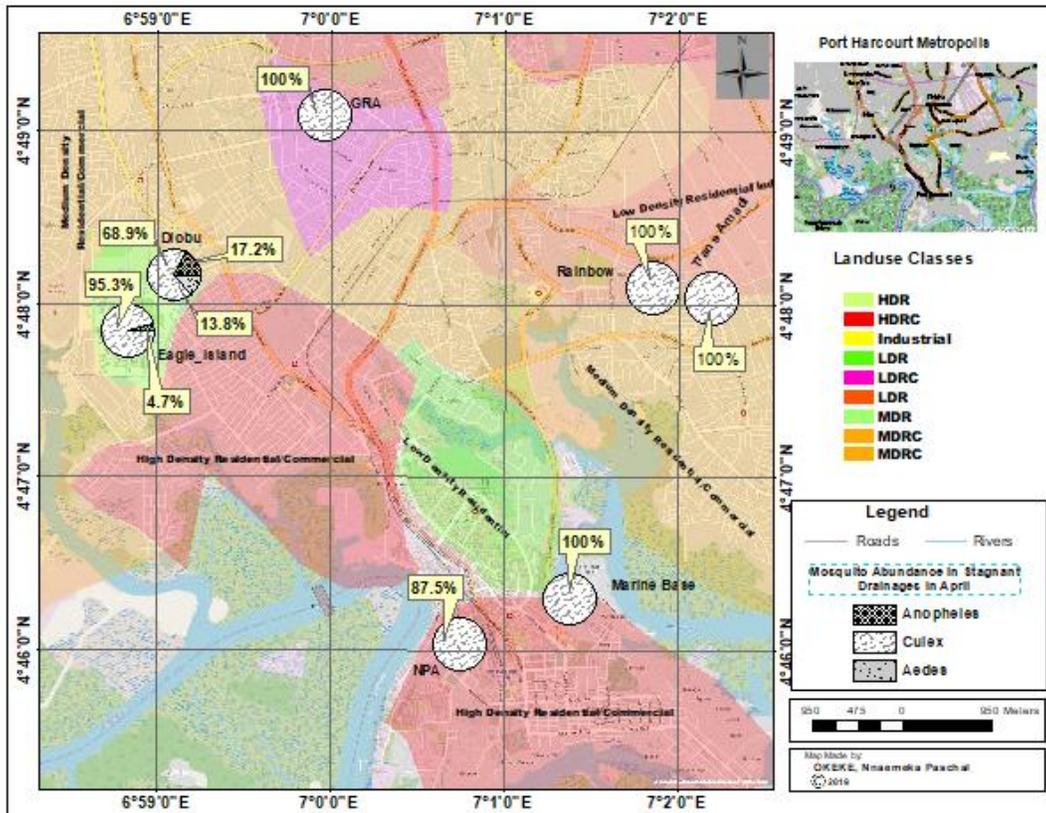
Fig. 2a. Spatial abundance of mosquito larva from stagnant drainage in April 2018
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)
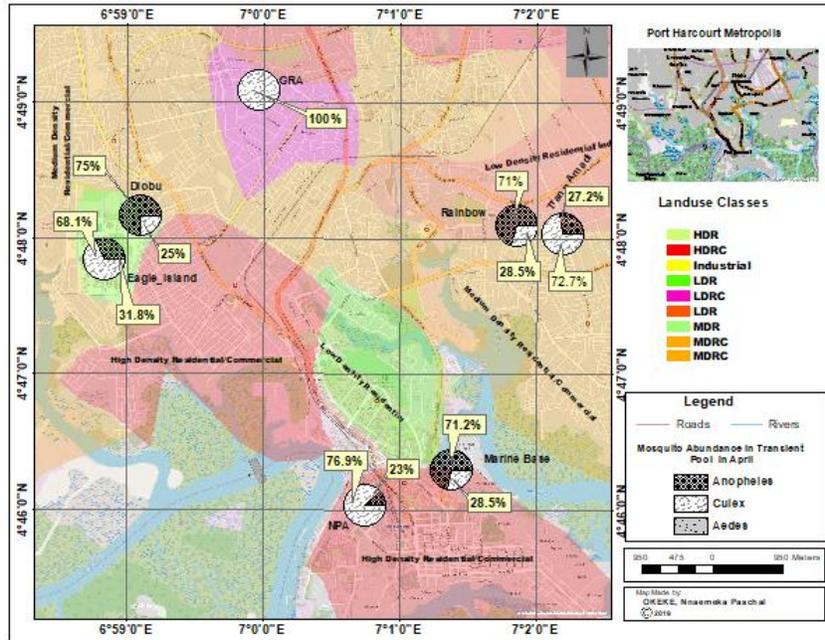
Fig. 2b. Spatial abundance of mosquito larva from transient puddles in the month of April (2018)
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)
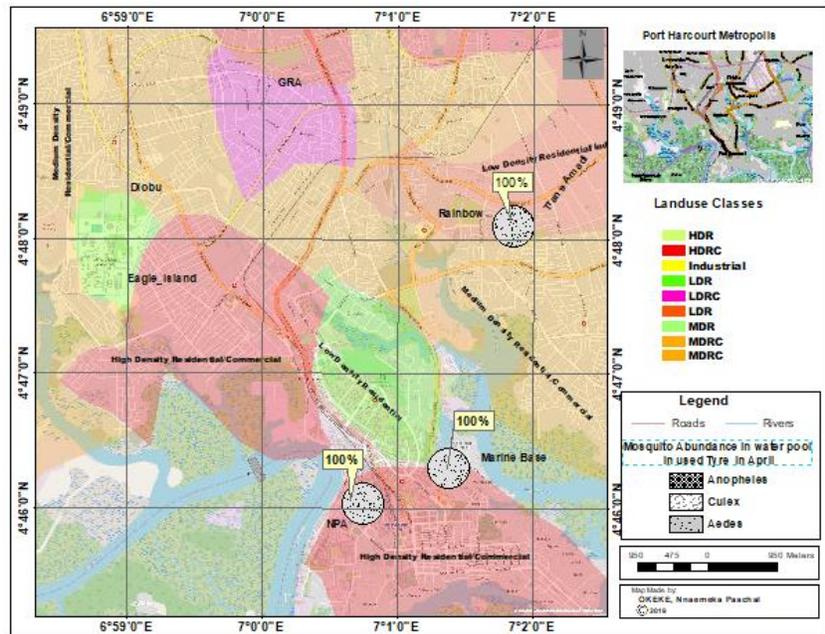
Fig. 2c. Spatial abundance of mosquito larva from pools in used tyre in the month of April (2018)
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

The spatial distribution of larval mosquito species for the three (3) micro-habitats for the month of May (2018) throughout the sample locations is shown in Fig. 3a to Fig. 3c.

Fig. 3a shows that only Culex species (100%) occurred in stations GRA, Eagle Island, Rainbow, Trans-Amadi and Marine base. The remaining two stations recorded three species with Culex as the most abundant (47%), followed by Aedes (37%) and Anopheles (16%) as the least abundant at Diobu station; and recorded two larval mosquito species with Culex as the most abundant (87%) and Anopheles as the least abundant (13%) at the NPA station.

In Fig. 3b, the pattern of occurrence in transient pool microhabitat shows the abundant

occurrence of Culex in NPA (77%), Marine Base (53%) and Diobu (50%) stations. The Anopheles larvae were also abundant in Trans-Amadi (75%) Eagle Island (57%) and Diobu (50%) stations. The occurrence of Anopheles (45%) and Culex (40%) at the Rainbow station included Aedes species at a low percentage (5%). No larval mosquitoes were observed at the GRA station in the month of May 2018.

In Fig. 3c, only Aedes species (100%) were recorded in pools of water in tyre microhabitat stations such as GRA, Eagle Island, NPA, Marine Base and Rainbow. The Anopheles species was recorded in 100% occurrence in Diobu station while two species namely Aedes (87%) and Anopheles (13%) were observed at the Trans-Amadi station
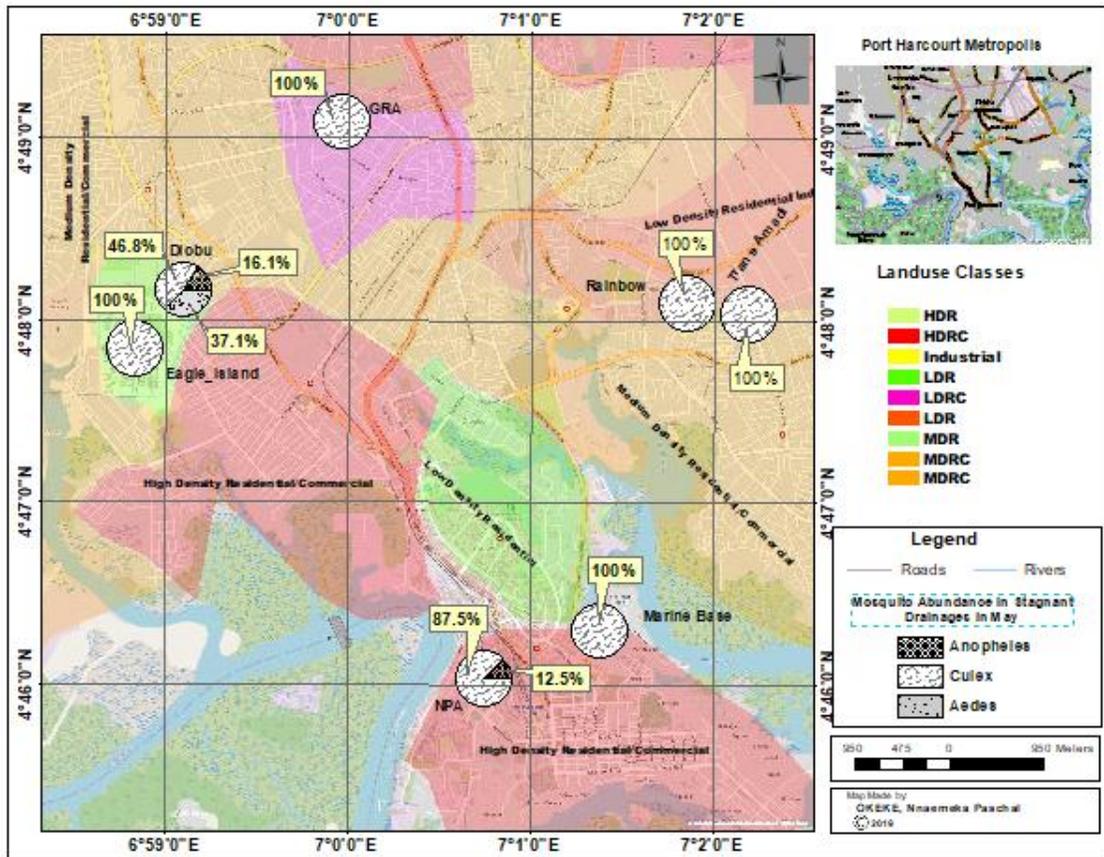
Fig. 3a. Spatial abundance of mosquito larva from stagnant drainage in the month of May (2018)
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

The spatial distribution of larval mosquito species for the three (3) micro-habitats for the month of June/July (2018) throughout the sample locations is shown in Fig. 4a to Fig. 4c. The map in Fig. 4a shows that Culex species was the only larval mosquito species (100%) observed in stations GRA, Eagle Island, Diobu and NPA. The occurrence of Culex and Anopheles were recorded in Trans-Amadi (92%; 8%), Rainbow (97%; 3%) and Marine Base 90%; 10%) stations with Culex species clearly more abundant. In Fig. 4b, the stations in transient puddles microhabitat recorded only Anopheles species and Culex species in various proportions. In GRA station, Culex species was the most abundant (64%) and Anopheles species was the least abundant (36%). Similarly, in Diobu and Marine Base stations, Culex species was the most abundant

(57% and 66% respectively), and Anopheles species the least abundant (43% and 34% respectively). In contrast, the Anopheles species was the most abundant in Rainbow, Trans-Amadi and Eagle Island stations (59%, 62%, and 77% respectively), while Culex was the least abundant species (41%, 38% and 23% respectively). At the NPA station the larval mosquito species abundance were in equal proportion (50% Culex species and 50% Anopheles species).

In Fig. 4c, only Aedes species were observed to have occurred in pools of water in tyre microhabitats. The recorded observations were in only three stations namely Eagle Island, Rainbow and NPA. No mosquito larvae were recorded at Marine base, Diobu, GRA and Trans-Amadi stations.
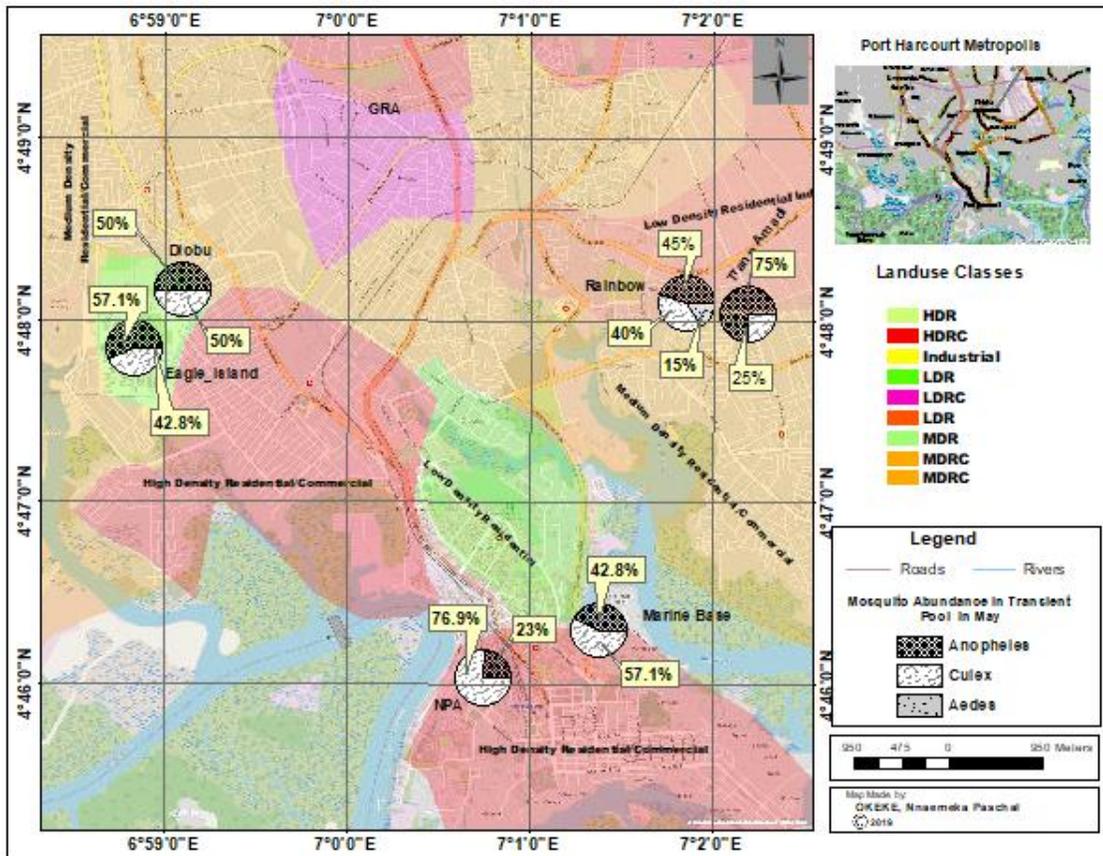
Fig. 3b. Spatial abundance of mosquito larva from transient pool in the month of May (2018)
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)
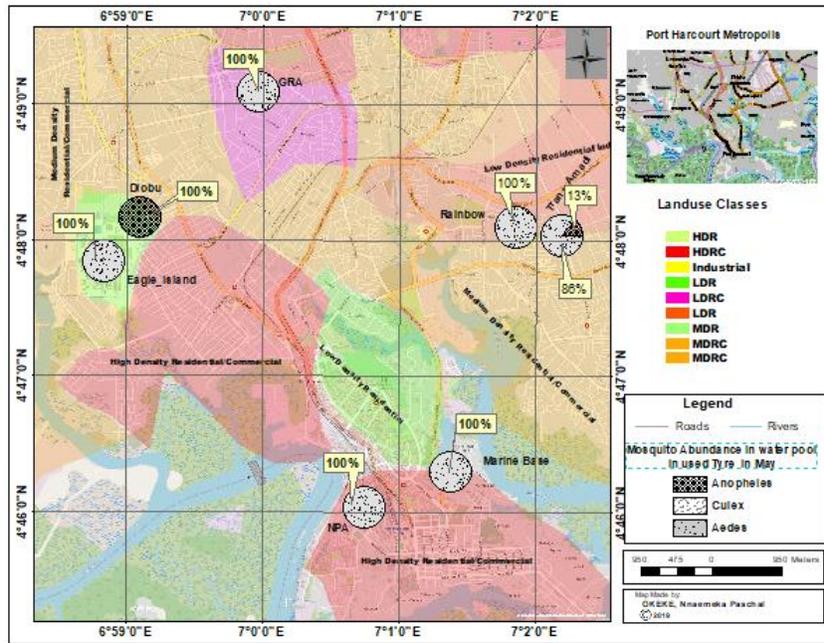
Fig. 3c. Spatial abundance of mosquito larva from water in used tyre micro-habitat in the month of May (2018)

(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)
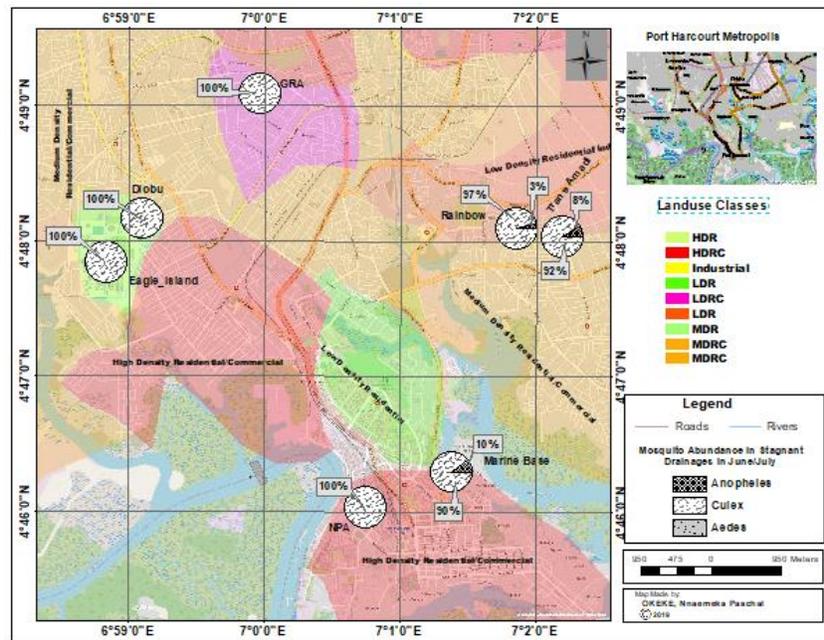
Fig. 4a. Spatial abundance of mosquito larva from stagnant drainage in the month of June/July (2018)

(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)
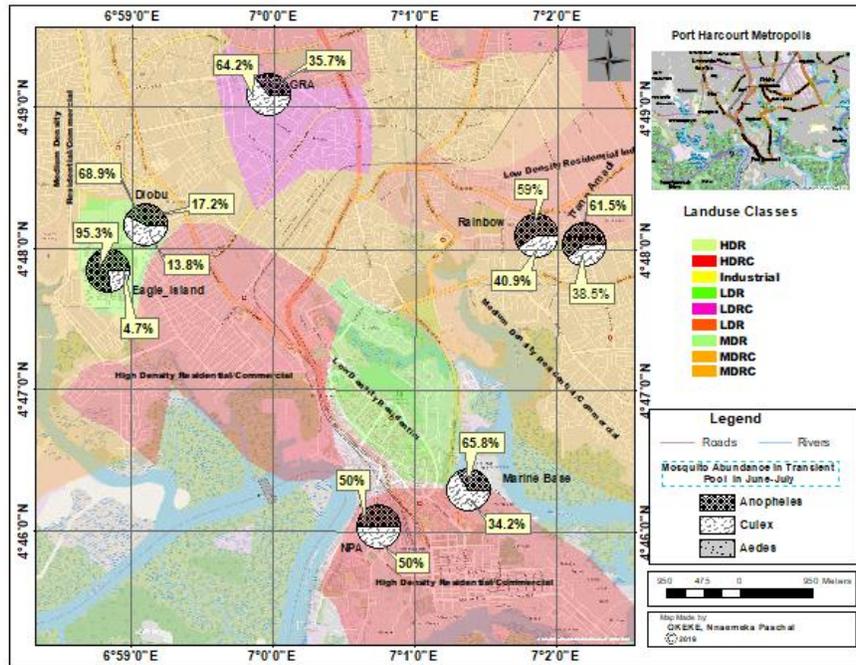
Fig. 4b. Spatial abundance of mosquito larva from the transient puddle for June/July (2018)
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)
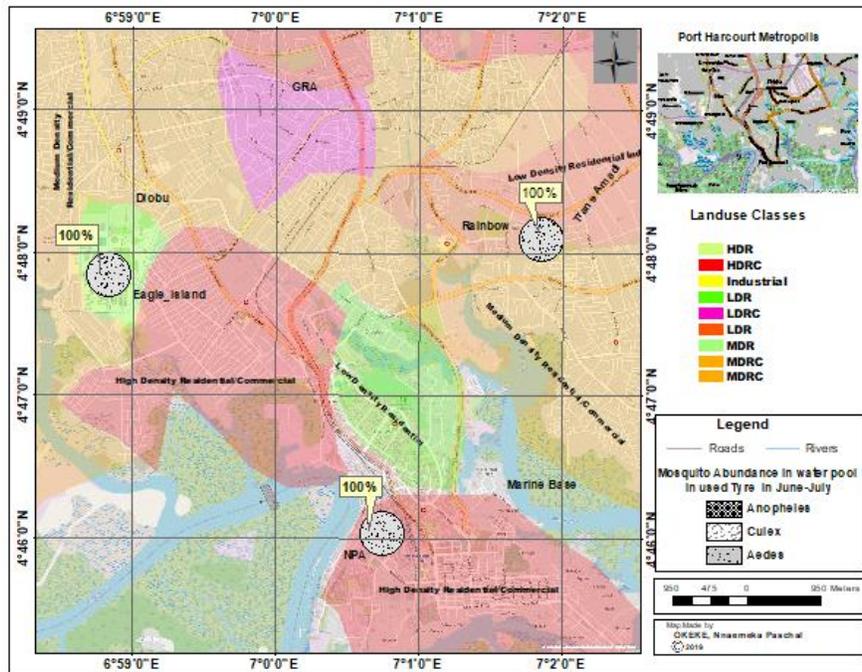
Fig. 4c. Spatial abundance of mosquito larva from water in used tyre for June/July (2018)
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

4.2 Malaria Hotspot Modeling

Figs. 5 to 11 shows the malaria hazard surface model based on maximum Euclidean travel distance of 9-10 km by Anopheles species. Figs. 5 to 11 show the malaria hazard surface model based on individual Euclidean distances from sampling sites. Each individual hazard surface model assumes a dependency based on the flight distance being on a straight path without the cost of any impedance. In other words, the assigned distance of 9000 meters (maximum travel distance of an anopheles) assumes that that this relation remains same across space without any other urban variables along the path or direction of flight. However, for each set of locations, the model assumes equal distance of reduced flight performance dependent on many aggregate physiological and morphological factors [17,18]. In Figs. 5 to 9 the hazard surface models show individual paths through different land use with human habitation.

In Fig. 5, the hazard surface originating from Diobu station shows an epicenter that is intersecting three land use types namely: High density residential/commercial; low density residential; and medium density residential/commercial.In Fig. 6, the hazard surface originating from Trans-Amadi station shows an epicenter that is intersecting two land use types namely: low density residential/industrial; and medium density residential/commercial.In Fig. 7, the hazard surface originating from Eagle Island station shows an epicenter that is intersecting three land use types fully and partially. Full intersection is evident for the low density residential while partial intersection is evident for medium density residential/commercial and high density residential/commercial.

In Fig. 8, the hazard surface originating from Rainbow station shows an epicenter that is intersecting two land use types fully and partially.
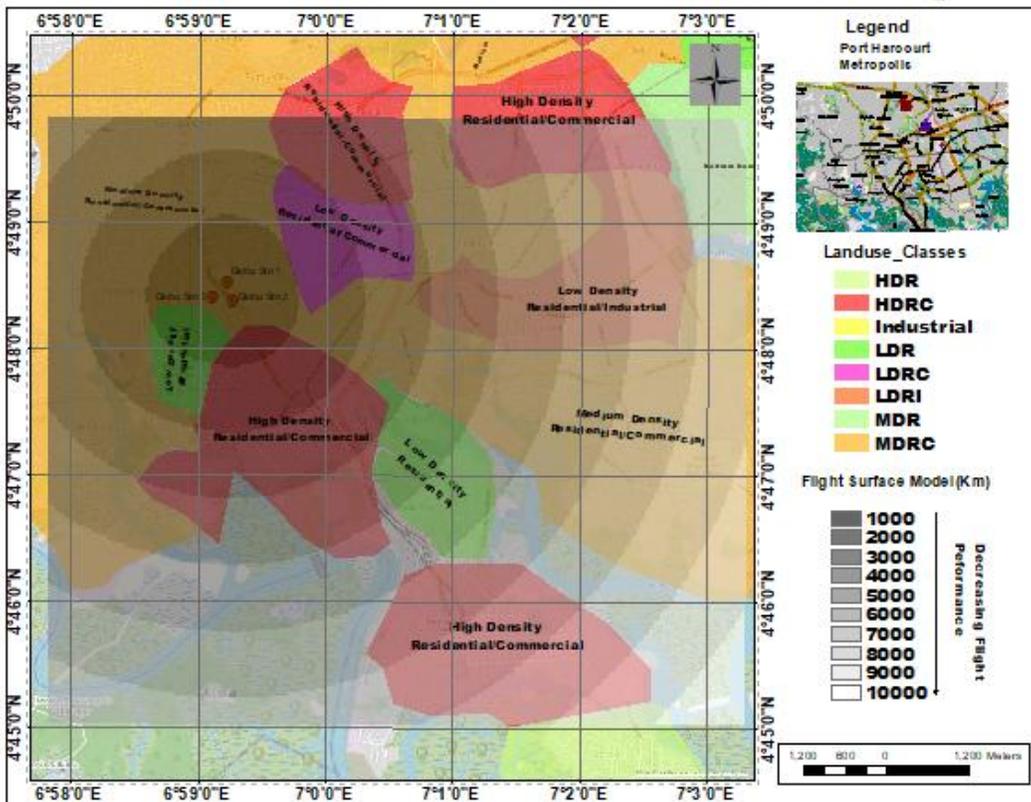
Fig. 5. Malaria hazard surface model from maximum flight distance of Anopheles mosquito from Diobu stations
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

Full intersection is evident for the low density residential/industrial while partial intersection is evident for medium density residential/ commercial. In Fig. 9, the hazard surface originating from GRA stations shows an epicenter that is intersecting two land use types fully and partially. Full intersection is evident for the low density residential/commercial while partial intersection is evident for medium density residential/commercial.In Fig. 10, the hazard surface originating from Marine Base station shows an epicenter that is intersecting three land use types partially namely low density residential; medium density residential/commercial and high density residential/commercial.In Fig. 11, the hazard surface originating from NPA stations shows an epicenter that is intersecting three land use types partially namely low density residential; medium density residential/commercial and high density residential/commercial.

5. DISCUSSION

The study of the abundance of mosquito larvae species from April to July 2018 in seven zones of Port Harcourt Metropolis showed the presence of

five (5) species from available identification. These were *Ae. aegypti*, *Ae.albopictus, Cx. quinquefasciatus*, *Cx. tigripes,* and *An. gambiae*. The overall abundance of the mosquito larvae species across the seven zones sampled in Port Harcourt metropolis was dominated by *Culex genera* followed by *Aedes* and the least was *Anopheles*; which agreed with Aigbodion and Uyi [19] who stated that *Culex spp*. and *Aedes* had high abundance than *Anopheles* in the distribution and habitat diversification of mosquito species in Benin City, Nigeria. In the study *Culex* was more consistent across the four sampling months which also collaborates with the details in Aigbodion and Uyi [19]. In all the stations the general trend showed that mosquito populations were highest in June/July rising from the month of April. The likely explanation is the abundance of more water habitats as more rains creates ideal breeding conditions for mosquitoes [20,21,22].

A spatial analysis of the distribution in occurrence of the three genera of mosquitoes across the seven land use zones provided some significant differences. The Culex genera
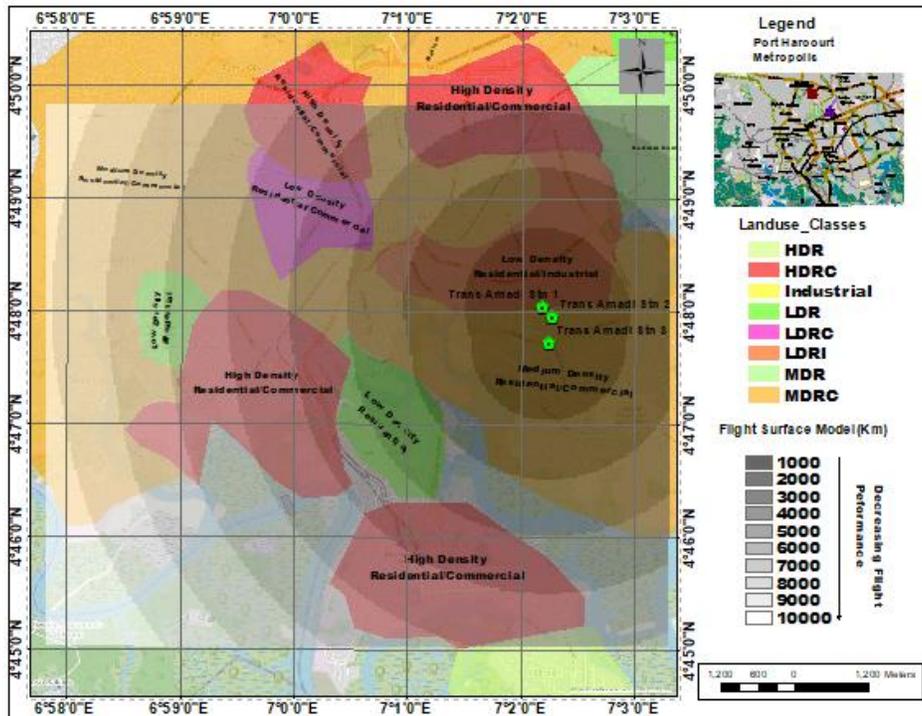
Fig. 6. Malaria hazard surface model from maximum flight distance of Anopheles mosquito from Trans-Amadi stations
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

occurred in two water microhabitats of stagnant drainage and transient puddles in all the land use zones with divergent population density. This contrasts with other studies showing that Culex are found in tyres [23,24,25] in combination with Aedes. Despite this contrast, the evidence shows that irrespective of the population density of a built environment, perennial stagnant drainages and transient pools of water serve the Culex genera very well for breeding. In contrast to the Culex, the Anopheles genus occurred in stagnant drainages that were in only land use types which have residential and commercial uses. Spatially they occurred in transient puddles in all land use types irrespective of population density. This also contrasts with documented studies which indicate that Anopheles breeds more successfully in permanent habitats than temporal ones [26-29]. Despite the disparity, the study shows that Anopheles can be successful in all land use types within the built environment with a

mix of temporary pools of water and permanent drainages with perennial water.

The Aedes genus in contrast to the Culex and Anopheles genera has shown a distinct distribution mostly in pools of water in used tyres within all the land use classes in the study. This preference for used tyres by Aedes is supported by many studies [30-36]. In general, the study documented three classes of information from the geospatial analysis. Firstly, all the genera have the capacity to occur as the only species within the microhabitats chosen for this study even as the microhabitats are in different land use classes. Secondly the Culex and the Anopheles genera occurred together in combinations as dominants and co-dominants within two (stagnant drainage and transient puddles) out of the three microhabitats chosen for the study. Thirdly the Aedes genus occurred insignificantly in combination with Anopheles only
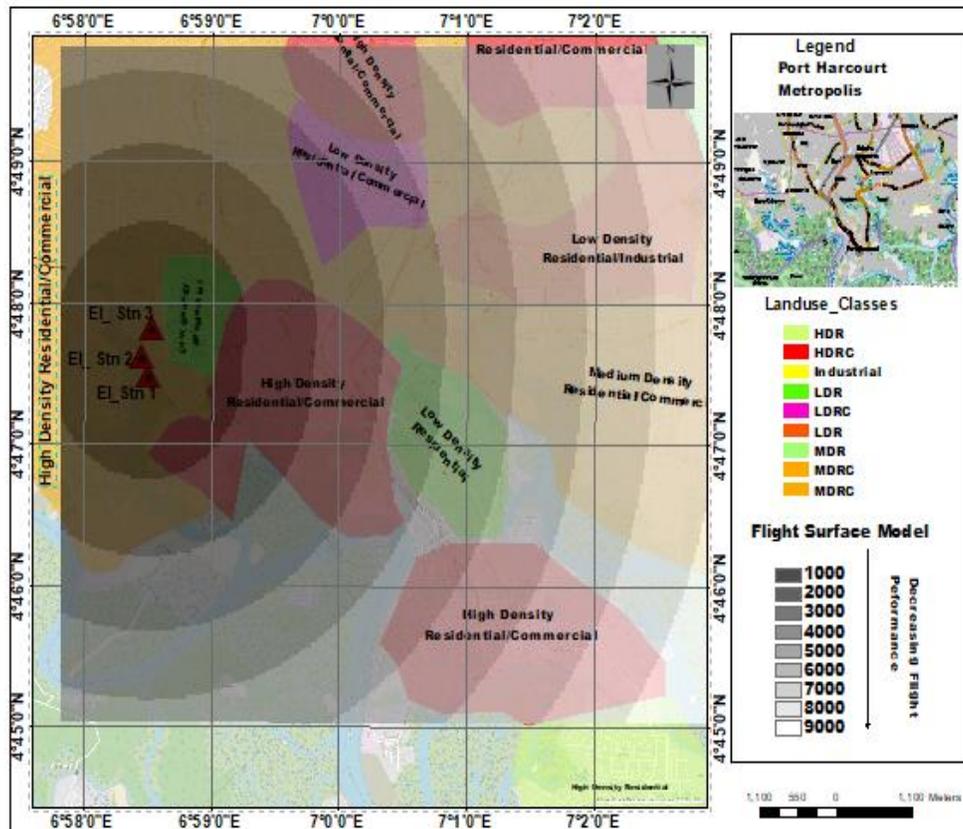
Fig. 7. Malaria hazard surface model from maximum flight distance of Anopheles mosquito from Eagle Island (EI) stations
(Landuse classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

in the water-in-tyre microhabitat and with Culex and Anopheles in transient puddle microhabitat. These distinct differences between occurrence and abundance within microhabitats in the mosquito genera suggests that further research on larval ecology must be a prerequisite for any mosquito control programme.

The malaria hazard surface model generated from individual stations showed a geospatial distribution that assumed a smooth decay function [37]. The surface hazard models show that the spatial features of interest intersecting with the epicenter of the hazard source which is the Anopheles mosquito differ in number and type of land use. A site-site analysis shows a likelihood that the maximum hazard impact from individual Anopheles infestation epicenter was highest for Diobu and NPA stations. This was followed in decreasing impact value by Marine Base, Eagle Island, Trans-Amadi, Rainbow and GRA. By normalizing the aggregated individual Anopheles infestation hazard model, a hotspot

epicenter is identified which provides spatial clusters that can be classified as medium, medium to high, or high hazard risk zones. This is likely due to the compound nature of hazard risk in the study area because most landuse areas are susceptible to multiple hazards from individual epicenters. This is because while any given station may show low risk within the surface hazard model it may simultaneously be susceptible to neighborhood hazards in proximity.

The composite hazard model revealed a hotspot zone that has maximum value of high hazard risk for the low density residential land use class. Interestingly this area has better access to piped water, sewerage infrastructure, and electricity. This part of the metropolis has a more regulated environment with good roads, greater access to critical resources and other services provided by government white collar private firms. Beyond the epicenter, identification of possible land use neighbors, and the geographic distribution of
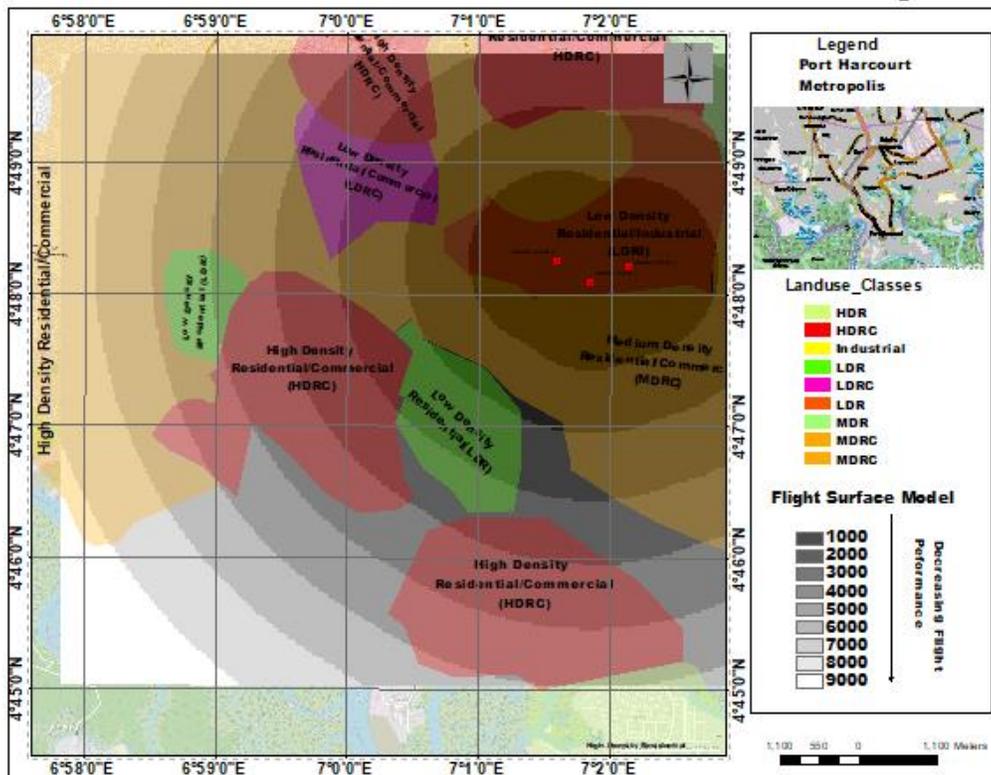
Fig. 8. Malaria hazard surface model from maximum flight distance of Anopheles mosquito from Rainbow stations
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

vulnerable populations to Anopheles infestation located in different land use classes is made possible.

In general, the study has been used to achieve three objectives. Firstly, the spatial results have produced individual hazard assessments from different cardinal points in a rapidly growing city like Port Harcourt. Secondly it has combined results of the individual hazard assessments to confirm a composite multi-hazard risk assessment where the distribution of risk is not based on the environmental attributes of the land use class. Thirdly it provides the capacity to predict the health vulnerability of the population within each composite hazard class.

This study has presented the methods and techniques to assess and map the vulnerable areas of the mosquito infestation hazard. Although our model was able to identify risky areas in the study area, it demonstrated many challenges one of which is the lack of comprehensive multi-dimensional data. A few studies have utilized multiple risk factor variables in geospatial modeling of malaria hazard mapping [38,39,40] unlike in this study where only a risk factor (mosquito abundance) was used to model the malaria hazard in 2D space. The study however offer insight on how GIS-based models are promising in data scarce environment to help extrapolate in a meaningful way evidence-based mitigation planning and resource allocation.
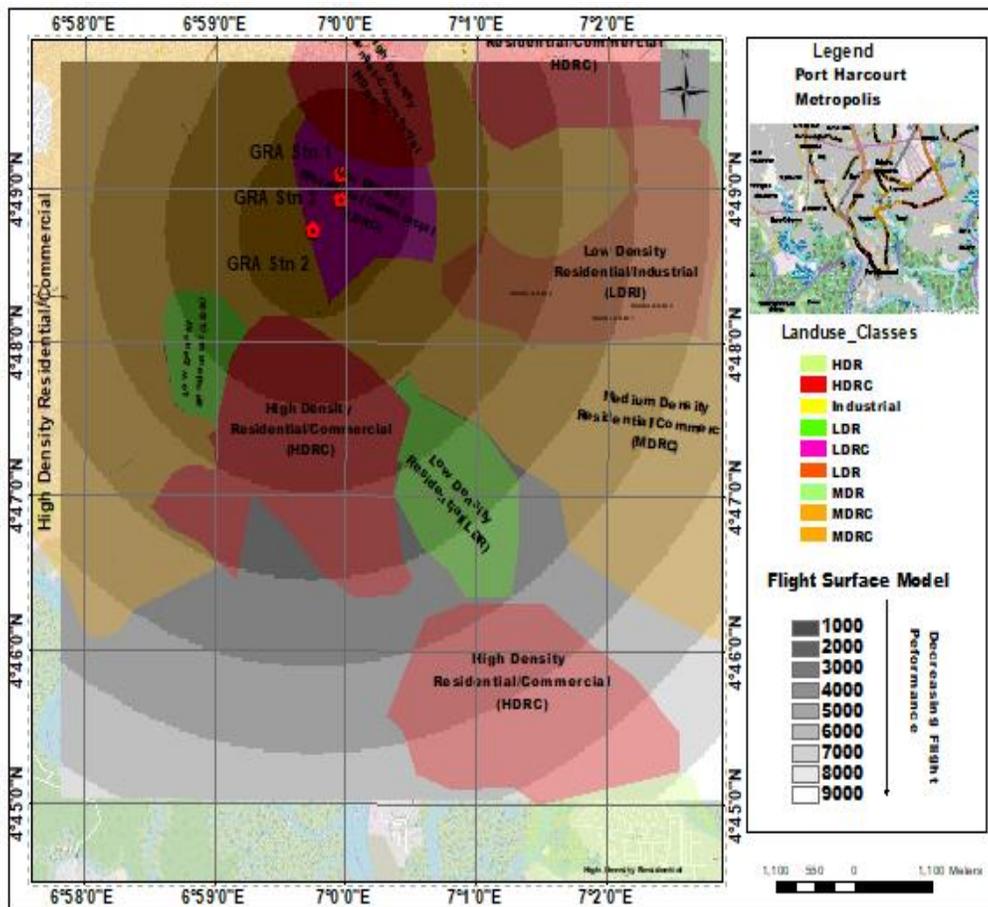
Fig. 9. Malaria hazard surface model from maximum flight distance of Anopheles mosquito from GRA stations
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)
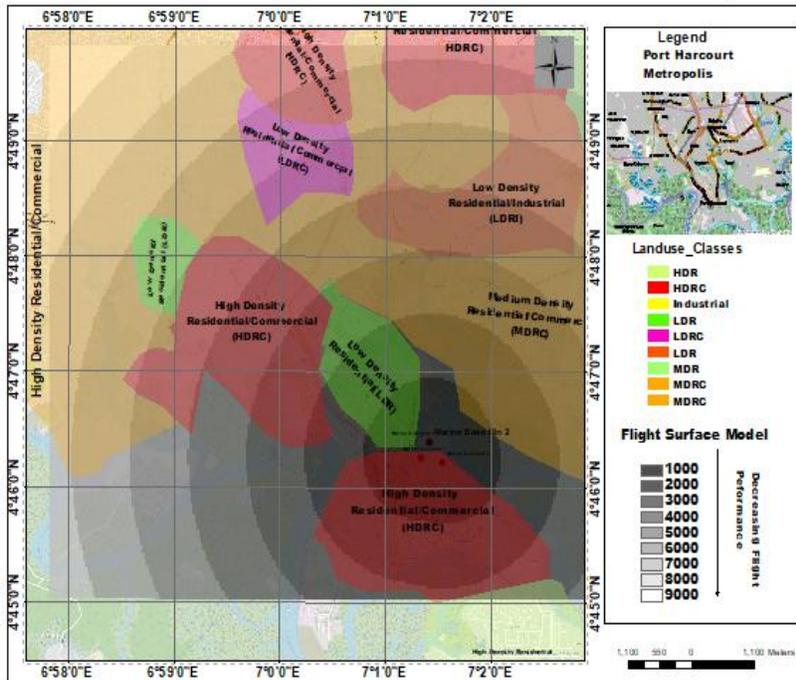
Fig. 10. Malaria hazard surface model from maximum flight distance of Anopheles mosquito from Marine base stations
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)
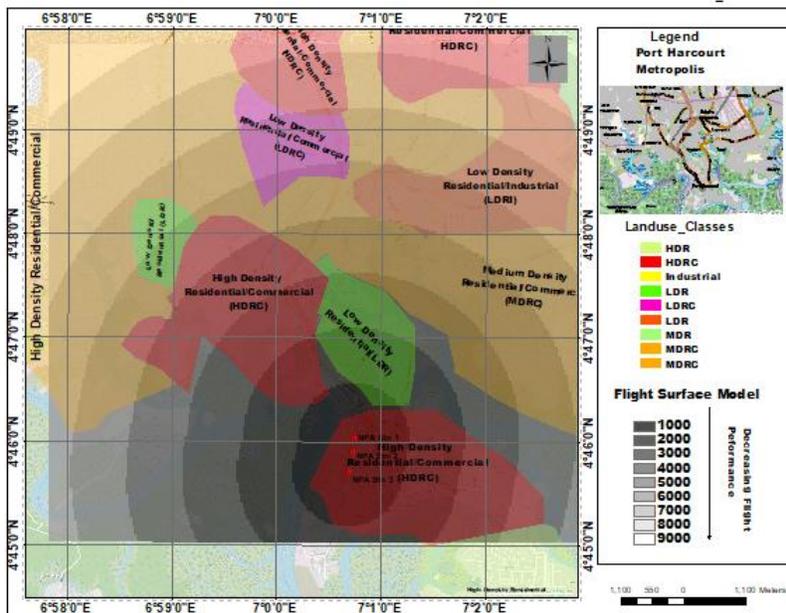
Fig. 11. Malaria hazard surface model from maximum flight distance of Anopheles mosquito from NPA stations
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

Stations
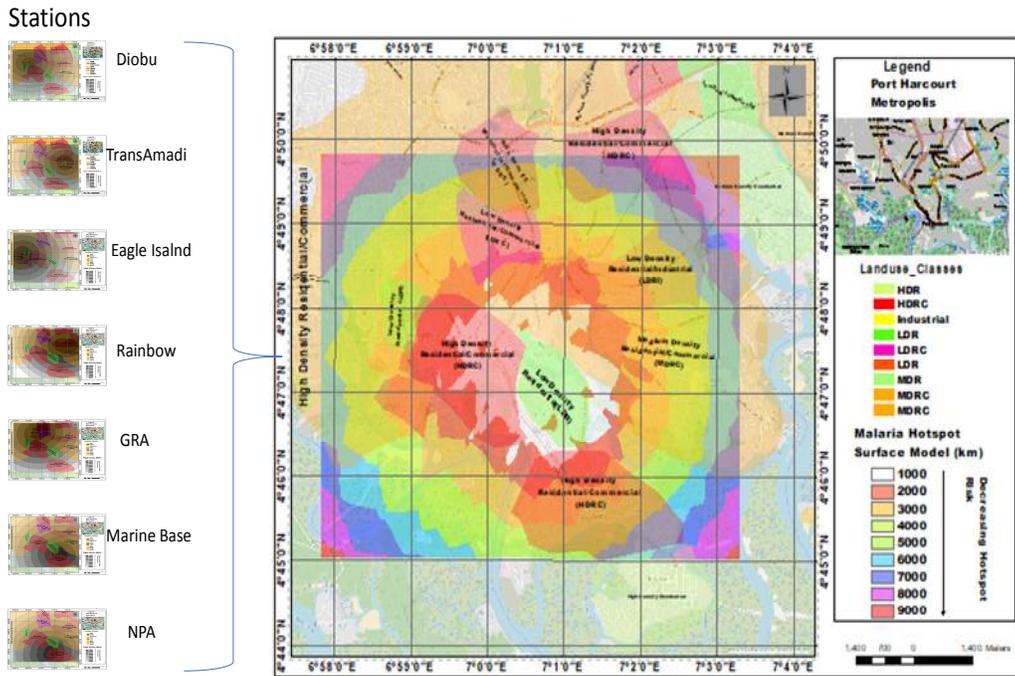
Fig. 12. Composite Malaria hazard surface model map
(Land use classes: HDR=high density residential; HDRC=high density residential/ commercial; LDR= low density residential; LDRC = low density residential/commercial; MDR= medium density residential; MDRC= medium density residential/commercial)

6. CONCLUSION

GIS was used in the rapid assessment of the abundance and distribution of mosquito larvae in three micro habitats in Port-Harcourt metropolis namely stagnant drainage, transient puddles and discarded tyres. Five mosquito larvae species namely *Cx. quinquefasciatus, Cx. tigripes. Ae. aegypti, Ae. albopictus,* and *An. gambiae* and were identified in the seven stations in Port Harcourt Metropolis. A geospatial analysis showed that the Culex genera was the most abundant and present in two out of the three microhabitats. The most restricted genus was Aedes which was observed to have a strict preference for the discarded tyre microhabitat. An individual and composite Anopheles hazard model was developed based on the maximum flight distance of Anopheles mosquito. The composite hazard model was completed by assessing and combining the Anopheles infestation risk from the individual station surface hazard models which was subsequently developed into a multi-hazard risk model. Three objectives were achieved. Firstly, the spatial results produced individual hazard assessments from different cardinal points in a rapidly growing city like Port Harcourt. Secondly, it combined results of the individual hazard assessments to confirm a composite multi-hazard risk assessment where the distribution of risk was not based on the environmental attributes of the land use class. Thirdly it provided the capacity to predict the health vulnerability of the population within each composite hazard class. The study shows that with geospatial techniques, an assessment of mosquito-malaria hazards can be conducted and employed to inform mitigation-based decision making.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Jacob BG, Griffith DA, Novak RJ. Decomposing malaria mosquito aquatic habitat data into spatial autocorrelation eigenvectors in a SAS/GIS® module. Transactions in GIS. 2008;12(3):341-64.
2. Huang YM. A pictorial key for the identification of the subfamilies of

Culicidae, genera of Culicinae, and subgenera of Aedes mosquitoes of the Afrotropical Region (Diptera: Culicidae). Proceedings-Entomological Society of Washington. 2001;103(1):1-88.

3. World Health Organization. Global technical strategy for malaria 2016-2030. World Health Organization; 2015.

4. Bradley P, Kutz FW. Proceedings of the workshop on stormwater management and mosquito control. US Environmental Protection Agency, Office of Research and Development. EPA/903/R-06/004; 2016.

5. Focks DA, Brenner RJ, Chadee DD, Trosper JH. The use of spatial analysis in the control and risk assessment of vector-borne diseases. American entomologist. 1999;45(3):173-83.

6. Palaniyandi M. Web mapping GIS: GPS under the GIS umbrella for Aedes species dengue and chikungunya vector mosquito surveillance and control. International Journal of Mosquito Research. 2014;1(3): 18-25.

7. Thompson PN, Etter EM. Epidemiological surveillance methods for vector-borne diseases. Revue Scientifique et Technique-Office International des Epizooties. 2015;34(1):235-247.

8. Eisen L, Eisen RJ. Using geographic information systems and decision support systems for the prediction, prevention, and control of vector-borne diseases. Annual review of entomology. 2011;56:41-61.

9. Palaniyandi M. The role of remote sensing and GIS for spatial prediction of vector-borne diseases transmission: A systematic review. Journal of vector borne diseases. 2012;49(4):197.

10. Dom NC, Ahmad AH, Latif ZA, Ismail R. Integration of GIS-based model with epidemiological data as a tool for Dengue surveillance. Environment Asia. 2017; 10(2).

11. Abah AE, Awi-Waadu GD, Nduka FO, Richard A. Malaria infection and socioeconomic status of some residents of Port Harcourt metropolis, Rivers State, Nigeria. Journal of Applied Sciences and Environmental Management. 2017;21(2): 299-304.

12. Kolivras KN. Mosquito habitat and dengue risk potential in Hawaii: A conceptual framework and GIS application. The Professional Geographer. 2006;58(2):139-54.

13. Ogbalu OK, Onwuteaka JN. Microhabitat ecology of mosquitoes in Port Harcourt Metropolis and Environs. Annual Research & Review in Biology. 2016;1-3.

14. World Health Organisation. Larval source management: A supplementary measure for malaria vector control. An Operational Manual. 2013;116.

15. Ebere N. Report on baseline studies of malaria vectors in Ikwerre, Etche and Emohua Local Government Areas of Rivers State. 2013;125.

16. Gillett JD. Common African mosquitos and their medical importance. London, UK, William Heinemann; 1972.

17. Suarez RK. Energy metabolism during insect flight: Biochemical design and physiological performance. Physiological and Biochemical Zoology. 2000;73(6):765-71.

18. Kaufmann C, Briegel H. Flight performance of the malaria vectors *Anopheles gambiae* and *Anopheles atroparvus*. Journal of Vector Ecology. 2004;29:140–153.

19. Aigbodion FI, Uyi OO. Temporal distribution of and habitat diversification by some mosquitoes (Diptera: Culicidae) species in Benin City, Nigeria. Journal of Entomology. 2013;10(1):13-23.

20. Adeleke MA, Mafiana CF, Idowu AB, Adekunle MF, Sam-Wabo SO. Mosquito larval habitats and public health implications in Abeokuta, Ogun State, Nigeria. Tanzania Journal of Health Research. 2008;10(2):103-7.

21. Anosike JC, Nwoke BE, Okere AN, Oku EE, Asor JE, Emmy-Egbe IO, Adimike DA. Epidemiology of tree-hole breeding mosquitoes in the tropical rainforest of Imo State, south-east Nigeria. Annals of Agricultural and Environmental Medicine. 2007;14(1).

22. Okogun GR, Anosike JC, Okere AN, Nwoke BE. Ecology of mosquitoes of Midwestern Nigeria. Journal of vector borne diseases. 2005;42(1):1.

23. Kling LJ, Juliano SA, Yee DA. Larval mosquito communities in discarded vehicle tires in a forested and unforested site: Detritus type, amount, and water nutrient differences. Journal of Vector Ecology: Journal of the Society for Vector Ecology. 2007;32(2):207.

24. Yee DA, Kneitel JM, Juliano SA. Environmental correlates of abundances of mosquito species and stages in discarded

vehicle tires. Journal of Medical Entomology. 2010;47(1):53-62.

25. Rubio A, Cardo MV, Vezzani D. Tire-breeding mosquitoes of public health importance along an urbanisation gradient in Buenos Aires, Argentina. Memórias do Instituto Oswaldo Cruz. 2011;106(6):678-84.

26. Gimning JE, Ombok M, Otieno S, Kaufman MG, Vulule JM, Walker ED. Density-dependent development of *Anopheles gambiae* (Diptera: Culicidae) larvae in artificial habitats. J Med Ent. 2002;29:162–72.

27. Ndenga BA, Simbauni JA, Mbugi JP, Githeko AK, Fillinger U. Productivity of malaria vectors from different habitat types in the western Kenya highlands. PLoS One. 2011;6(4):e19473.

28. Kudom AA, Mensah BA, Agyemang TK. Characterization of mosquito larval habitats and assessment of insecticide-resistance status of *Anopheles gambiae* senso lato in urban areas in southwestern Ghana. Journal of Vector Ecology. 2012;37(1):77-82.

29. Mattah PA, Futagbi G, Amekudzi LK, Mattah MM, de Souza DK, Kartey-Attipoe WD, Bimi L, Wilson MD. Diversity in breeding sites and distribution of Anopheles mosquitoes in selected urban areas of southern Ghana. Parasites & Vectors. 2017;10(1):1-5.

30. Berry WJ, Craig JrGB. Bionomics of *Aedes atropalpus* breeding in scrap tires in northern Indiana. Mosquito News. 1984; 44(4):476-84.

31. Sprenger PR. The used tire trade: A mechanism for the worldwide dispersal of container breeding mosquitoes. J Am Mosq Control Assoc. 1987;3:494.

32. Andreadis TG. A survey of mosquitoes breeding in used tire stockpiles in Connecticut. Journal of the American Mosquito Control Association. 1988;4(3): 256-60.

33. Baumgartner DL. Suburban accumulations of discarded tires in northeastern Illinois and their associated mosquitoes. Journal of the American Mosquito Control Association. 1988;4(4):500-8.

34. Dieng H, Saifur RG, Ahmad AH, Salmah MC, Satho T, Miake F, Jaal Z, Abubakar S, Morales RE. Unusual developing sites of dengue vectors and potential epidemiological implications. Asian Pacific Journal of Tropical Biomedicine. 2012; 2(3):228-32.

35. Vijayakumar K, Kumar TS, Nujum ZT, Umarul F, Kuriakose A. A study on container breeding mosquitoes with special reference to *Aedes (Stegomyia) aegypti* and *Aedes albopictus* in Thiruvananthapuram district, India. Journal of Vector Borne Diseases. 2014;51(1):27.

36. Ferede G, Tiruneh M, Abate E, Kassa WJ, Wondimeneh Y, Damtie D, Tessema B. Distribution and larval breeding habitats of Aedes mosquito species in residential areas of northwest Ethiopia. Epidemiology and Health. 2018;40.

37. Anselin L. GIS research infrastructure for spatial analysis of real estate markets. Journal of Housing Research. 1998;9(1): 113-33.

38. Adebote AD, Oniye JS, Ndams SI, Nache KM. The breeding of mosquitoes (Diptera: Culicidae) in peridomestic containers and implication in yellow fever transmission in villages around Zaria, Northern Nigeria. J Entomol. 2006;3(2):180-8.

39. Afolabi OJ, Ndams IS, Mbah CE, Kogi E. The effects of alteration of pH on the breeding characteristics of mosquitoes in phytotelmata in Ahmadu Bello University Zaria, Nigeria. International Journal of Bioscience. 2010;5(1):32-6.

40. Clements AN. The biology of mosquitoes. Volume 1: Development, nutrition and reproduction: AN Clements. London: Chapman & Hall. 1992;xxii+ 509. Price£ 50. ISBN 0-412-40180-0.