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Modeling a covered drainage system for the reduction of malaria prevalence

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A B S T R A C T

A community based, cross-sectional study design was adopted using 501 consented children under the age of 14 years from 200 households. Mathematical model for determining the relationship between malaria prevalence (MP) and features of the household surroundings was designed using multiple regression models. Children age was 75.0 ± 45.5 months (range = 3–168 months). MP was 29.9/100, Most of the houses 99.0% had open drainage immediately around their surrounding, 7.1% of the drainages were flowing while 91.9% were stagnant. Solid Wastes in Drains (SWD), Stagnation of Wastewater in Drains (STWD), Presence of Open Drains (POD), and Presence of Weeds (POW) significantly predicted MP while reduction in MP after a 12-months intervention was 14.4%. Features of the household surroundings contributed more to MP and covered drainage system could reduce the burden of malaria through free flow of waste water. This engineering solution could be encouraged in communities with high MP.

1. Background

Malaria is known to have been present since the existence of man. It was linked with poisonous vapours of swamps or stagnant water on the ground since time immemorial. The term *malaria* (from the Italian *mala* "bad" and *aria* "air") was used by the Italians to describe the cause of intermittent fevers associated with exposure to marsh air or miasma [1]. Malaria is a serious public health challenge in Africa where one in every five childhood deaths is due to the effects of the disease; every 30 s, a child dies from malaria [2]. One third (3.3 billion people) of the world population in 97 countries and territories are at risk of malaria while 1.2 billion are at high risk (>1 in 1000 chance of getting malaria in a year). According to the latest estimates, 198 million cases of malaria occurred globally in 2013 and the disease led to 584,000 deaths. The burden is heaviest in the World Health Organization (WHO) African Region, where an estimated 90% of all malaria deaths occur, and in children aged less than 5 years, accounting for 78% of all deaths [3].

Malaria in pregnancy carries a high mortality for the fetus or unborn child and for the mother in low communal immunity. Pregnant women and their unborn children are also particularly vulnerable to malaria, which is a major cause of perinatal mortality, low birth weight, and maternal anemia [4]. Outside Africa, approximately two thirds of the remaining cases occur in three countries: Brazil, India, and Sri Lanka. However, malaria is still endemic in more than 100 countries [5]. South Africa has a relatively low prevalence of malaria particularly in the period 2000–2002 with economic cost during this period ranging between US$15million and US$41million, excluding estimates of the human suffering and lost investment [6]. International funding for malaria control has continued to rise to a peak of US$ 2 billion in 2011. The amounts committed to malaria, while substantial, still fall short of the resources required to reach malaria control targets, estimated at more than US$ 5 billion per year for the years 2010–2015 [7]. The cost of malaria treatment and prevention in Nigeria has been estimated to be over $1 billion per annum [8].

Mathematical models have the ability to address several multiplicative, feedback and nonlinear effects that enhance or suppress the effects of factors such as, exposure, immunity, spatiotemporal heterogeneities, control measures and environment, in order to capture key linkages to the complex transmission dynamics. They can also include stochasticity in different variables and parameters to simulate realistic scenario. These comparative analyses of differ-

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ent mathematical models of malaria would contribute to consolidate understanding about the evolution of these models, and may also help in developing new models by incorporating features discussed above to improve predictions and deciding realistic control measures [9,10]. This study applied a model to reduce malaria burden with the application of covered drainage system.

2. Materials and methods

2.1. Study area and study location

This study was carried out in Okelele community of Ilorin East Local Government of Kwara state. Kwara State with its capital in Ilorin has 16 local Government areas, located within Longitudes 4°30′ and 4°45′E and Latitudes 8°25′ and 8°40′N. It covered a land area of about 75 km^2 and an estimated population of 1.4 million people. The climate is tropical with mean annual temperature, relative humidity and rainfall of 27 °C, 76% and 1800 mm respectively. The climate presents two distinct seasons: a rainy season between April and October, with high rainfall during the months of June and August, and a dry season (November – March) completely devoid of rain. The vegetation in Ilorin reflects that of the Guinea savanna zone, characterized by a predominance of tall grass, which are frequently removed by violent bush burning activities in the dry season [8].

Okelele community, with a population of 36,191 (National Population Commission) lies between longitude 04°32′ and latitude 08°26′ and covered an estimated land area of 1.5 km^2. The relief flanking the flood plains around Okelele is between 290 m and 305 m above the sea level (Personal communication through the office of surveyor general, Kwara State government and confirmed through GIS). Okelele, was chosen following a review of the records of admissions at the Emergency Paediatric Unit (EPU) of the University of Ilorin Teaching Hospital, the largest and most patronized Hospital in the State, which revealed that majority of the patients admitted into the Unit for severe malaria were from Okelele area of the town. Of a total of 226 with severe malaria in a one year period, 121 (53.6%) of the subjects were from Okelele area. Subjects from this area also accounted for 44% of the malaria related mortality [11]. The obvious geographical pattern in the distribution of severe malaria patients seen in this facility raised the consideration of a probable environmental determinant for high burden of malaria in the area.

2.2. Ethical considerations

This study was approved by the University of Ilorin Teaching Hospital, Ilorin, Kwara state Ethical Review Committee before the commencement of the field work. Also, permission was obtained from the district authorities and community leaders. Individual interviews and tests for baseline data were only started after the purpose of the study had been clearly explained to the participants (parents of children/guardians) and informed consent obtained. Participation was made voluntary and no form of coercion was adopted. There was no undue influence on the participants. Participants were ensured of confidentiality of all information obtained from them and respondents' names were not written on the questionnaire in order to ensure anonymity.

2.3. Study design

This study was community-based and cross-sectional in design. Two children aged less than 14 years old were randomly selected from each household and their consents and that of their respective mothers or guidance were sought before the commencement of the survey. A 3-stage random sampling techniques was used to select Zones, Households and 501 children aged less than 14 years to participate in the study. A pro-rata form was developed to collect information such as the characteristics of the children and household surroundings from their parents/guidance.

2.4. Study population and sampling techniques

This study was carried out among children aged less than 14 years old; representing the most susceptible age group to the disease [4,12,13]. Okelele Community was purposively selected and divided into five zones; Lowin, Amuyankan, Omoboriowo, Jagun, Babaladifa. Forty (40) households, each from the 5 zones, were randomly selected by balloting. From each of the selected household, two or three children aged less than 14 years old were randomly selected through balloting per household.

2.5. Laboratory analysis

Malaria prevalence was determined using the malaria Rapid Diagnostic Test (RDT) kit, Paracheck. This test kit is based on the identification of parasite's *Histidine* rich protein II (HRP-2) that is present on the parasite cell wall. Malaria parasite prevalence was calculated as the proportion of children less than 14 years with positive slide results per total number of children screened.

2.6. Modeling engineering solution for malaria burden reduction

The engineering solution was validated by modeling. A number of the variables generated were fed into the development of the mathematical model for determining the relationship between malaria prevalence (RDT) and environmental factors. Using Stepwise multiple regression models, the designed covered reinforced concrete drainage is expected to nullify Presence of Open Drains (POD), Stagnation of Wastewater in Drains (STWD), and Solid Waste in Drains (SWD).

2.7. Data analysis

Data generated from the field were edited daily. Then they were coded and entered into the computer for analyses using Statistical Package for Social Science 20.0 version. Data were presented as mean standard deviation for continuous variables and percentages for categorical variable. Chi-square statistic was used to determine the associations between characteristics of the children and the malaria prevalence. Also multiple regression models were used and statistical significance was defined at $p < 0.05$.

3. Results

3.1. Characteristics of children

Table 1 shows the characteristics of children that participated in this study. The mean age of the children was 75.0 ± 45.5 months (range = 3–168 months) and 51.9% were male. Mean weight of the children was 19.1 ± 8.8 kg (Range = 2–53 kg) while 45.3% and 1.8% fell within the weight category of greater than 10–20 kg and greater than 40 kg respectively. Mean body temperature was 36.5 ± 0.7 °C (Range = 34.5–40.0 °C) while only 11.2% used mosquito net.

3.2. Malaria prevalence before the engineering intervention

The RDT positivity ratio was found to be 29.9% (29.9/100) and comparing with children's sex, age category and use of mosquito

Table 1
Characteristics of Children (N = 501).

Children data	Number	%
Age (in months)		
⩽12	35	7.0
12–59	165	32.9
60–118	182	36.3
119–168	119	23.8
Mean ± SD = 75.0 ± 45.5 months, Range = 3–168 months		
Sex		
Male	260	51.9
Female	241	48.1
Weight (in kg)		
⩽10	94	18.8
10–20	227	45.3
21–30	133	26.5
31–40	38	7.6
>40	9	1.8
Mean ± SD = 19.1 ± 8.8 kg, Range = 2–53 kg		
Temperature (°C)		
Mean ± SD = 36.5 ± 0.7 °C, Range = 34.5–40.0 °C		
Used mosquito net		
Yes	56	11.2
No	445	88.8

net, It was revealed that several (45.5%) of male children were RDT positive compared to 54.4% of their female counterparts. The association between Malaria prevalence (RDT positivity) and children's sex was statistically not significant at $p = 0.05$. Likewise, Malaria prevalence was compared with the children's age category using cross tabulation and the association was not significant. Furthermore, Malaria prevalence was compared with the use of mosquito's net. A non-significant association existed between Malaria prevalence and the use of mosquito net.

3.3. Features of household surroundings

Most, 93.0% of the households had no weeds immediately around their surroundings, 7.0% had weeds, whereas only 1.5% stated that they cut the weeds immediately around their houses once in a month. Most of the houses 99.0% had open drainage immediately around their surrounding, 91.9% of the drainage were stagnant while 7.1.0% of the drainages were flowing.

Correlation of household surroundings features included availability of drains (AVD), number of drains (NUMD), Solid Wastes in Drains (SWD), Stagnation of Wastewater in Drains (STWD), Presence of Open Drains (POD) and Presence of Weeds (POW). Correlation between household surroundings features and malaria prevalence (RDT positivity) was determined as seen in Table 2. No significant correlation was found between AVD and NUMD with malaria prevalence (RDT positivity). In contrast, a significantly positive correlation was observed between POD (r = 0.667, p < 0.01), SWD (r = 0.513, p < 0.05), STWD (r = 0.596, p < 0.01), POW (r = 0.748, p < 0.01) and malaria prevalence.

Modelling of household surroundings features and malaria prevalence were carried out using multiple regression analysis (Table 3). This was done to find out the predictors of malaria prevalence in the study area. The predictors: availability of drains (AVD); Presence of Open Drains (POD); Solid Wastes in Drains (SWD); Presence of Weeds (POW) around the house has a negative regression coefficient (α-value), which shows a negative regression relation with (RDT). Stagnation of Wastewater in Drains (STWD) has the highest β-value (0.4292). The following predictors: Solid Wastes in Drains (SWD), Stagnation of Wastewater in Drains (STWD), Presence of Open Drains (POD), and Presence of Weeds (POW) having p-value < 0.05 level of significance contributes significantly as independent variables in explaining the dependent variable, malaria prevalence.

3.4. Validation of designed drainage system for malaria control after the engineering intervention

Step-wise multiple regression analysis was used and the final model is given as follows:

Malaria prevalence (RDT)% = 89.42 + 30.87STWD − 28.73POW − 21.28SWD − 16.72POD.

Forecasting/interpolation were used to obtain the likely estimate of RDT% after the intervention. The intervention is assumed to change each level of the significant variable from level 1 to 2 or vice versa as the case may be.

From the model we now have:

(RDT)% after intervention = 89.42 + 30.87(1) − 28.73(1) − 21.28(2) − 16.72(2) = 89.42 + 30.87 − 28.73 − 42.56 − 33.44 = 15.56%

Therefore the intervention has reduced the prevalence of malaria from 29.9% (before the intervention) to 15.56% after the intervention. Thus, the study found a reduction in malaria prevalence after intervention by 14.34%.

4. Discussion

The study found that more than half of the children (study population) were male. This shows that more male children participated in the study than the female or it may be a cultural barrier for a female child is always behind the scene. Less proportion of the children used mosquito net. This study revealed that sleeping under mosquito net especially among children less than 14 years old was not common in the study area. Although it was a monitoring and evaluation system for implementing routine larviciding of malaria vectors in African cities [14], showed considerable potential for sustained, rapid responsive, data-driven and affordable application in the use of Insecticide Treated Net (ITN). In another

Table 2
Correlation matrix of household surroundings features as predictors of malaria prevalence (RDT positivity).

Variables	AVD	NUMD	POD	SWD	STWD	POW	RDT positivity
AVD	1						
NUMD	0.319	1					
POD	0.221	0.174	1				
SWD	0.151	0.096	0.287	1			
STWD	0.146	0.091	0.111	0.157	1		
POW	0.149	0.041	0.248	0.171	0.034	1	
RDT positivity	0.114	0.083	0.667**	0.513*	0.596**	0.748**	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 3
Modeling household surroundings features as predictors of malaria prevalence (RDT positivity).

Variables	R square	α (coefficient)	B	F/t (p Value)
Malaria prevalence (RDT positivity) (Non adjusted)				
Model	0.5478			25.245 (0.000)
POD		−19.7046	−0.2569	4.67 (0.000)
SWD		−14.5096	−0.1302	2.54 (0.012)
STWD		31.5975	0.4292	7.85 (0.000)
POW		−27.6002	−0.3423	6.35 (0.000)
Constant		86.9497		

similar study, a cost analysis for malaria control involving Larval Source Management (LSM), Long Lasting Insecticidal Nets (LLINs), and Indoor Residual Spraying (IRS), shows that LSM intervention compares favourably with cost for IRS and LLINs [15]. Data from this study revealed RDT positivity ratio of 29.9% (29.9/100). Although not statistically significant, this study revealed that several (45.5%) of male children were RDT positive compared to 54.4% of their female counterparts. This is an indication that sex of the children had no influence on RDT positivity. Likewise, children's age category, and the use of mosquito's net did not show any significant association with RDT positivity.

It was found that large percentage of the households had no weeds immediately around their surroundings whereas most of the houses had open drainage immediately around their surroundings. The open drainage could be a conducive environment for mosquito breeding hence lead to increase in the malaria burden especially among study children. This is in accord with the findings of [16], in their study conducted at Solomon Islands who reported that the presence and abundance of mosquito larvae are influenced by environmental factors. 99% had open drainages around their houses, emphasizing a habitable environment for mosquito larvae. This study documents that presence of open drains within the surroundings related positively with malaria prevalence RDT. This is similar to the work reported by [17] which showed that uncontrolled disposal of wastes clogs the drainage system and creating numerous health problems including mosquito breeding.

As a result of lack of waste collection systems in the study site, residents found it most convenient to dump their waste in drainages and open dumps around their homes. This study found that solid waste in drains was positively related to the malaria prevalence. These findings suggested that surroundings with solid waste in drains had contributed to malaria prevalence among children less than or equal to 14 years old in the study community [18]. In a similar study by [12] it was documented that proximity of municipal waste dumpsites to residential neighborhoods and rate of hospitalization for malaria, revealed a significant increase in the incidence of malaria and rate of hospitalization among the children observed. Similarly, a strong relationship between distance from the waste dumpsite and malaria disease in the overall sample was recorded. It was reported that certain construction activities such as water resources development, road construction have resulted in vector borne infections like malaria [19]. It is in accordance with these findings that mismanagement of waste including health care waste increases the vector borne infection like malaria and other health risks associated with these poor waste management practices [20,21]. Further, stagnation of wastewater in drains positively correlated with the malaria prevalence. This shows that stagnation of wastewater in drains increased mosquito breeding and hence malaria prevalence among the study participants.

This study found that solid wastes in drains, stagnation of wastewater in drains, presence of open drains, and presence of weeds predicted malaria prevalence among the study participants. Bush clearing was reported to be an ineffective method of malaria prevention but part of an intervention to reduce adult mosquitoes [22]. The findings revealed that each of the above stated variables contributes significantly as independent variables in explaining malaria prevalence. Without doubt, proper surface and subsurface drainage to remove excess water in a safe and timely manner plays an important role in controlling malaria. Mosquito larvae breeds in fresh water and fresh water-filled depressions either natural or man-made such as drains, vehicle tracks, foot prints, pig wallows and borrow pits [16]. In the study conducted at Solomon Islands, they concluded that the presence and abundance mosquito larvae are influenced by environmental factors within the large streams. Descriptive information on households also gave 99% as having open drainages around the house; majority (69.0%) of households examined has at least one open drain around the house while 16.5% has up to two. This means that proper surface and subsurface drainage to remove excess water in a safe and timely manner plays an important role in controlling water-related diseases including malaria. Misuse and lack of maintenance are the two main reasons why drainage structures are often associated with environmental health problems. The drainages found at the study area are not covered, unkept and no form of maintenance is deployed.

5. Conclusion

It was found that most of the houses had open drainage immediately around their surrounding and RDT positivity ratio was 29.9% (29.9/100). Solid Wastes in Drains (SWD), Stagnation of Wastewater in Drains (STWD), Presence of Open Drains (POD), and Presence of Weeds (POW) significantly predicted malaria prevalence (RDT-positivity). A 14.4% reduction in malaria prevalence was observed after the intervention (from 29.9% to 15.6%). These features of the household surroundings contributed more to malaria prevalence and covered drainage system could reduce the burden of malaria through free flow of waste water. This engineering solution could be encouraged in communities with high prevalence of malaria.

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