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Emerging Computational Strategy for Eradication of Malaria

[1]Monday Eze, [2]Jane Labadin and [3]Terrin Lim
Faculty of Computer Science and Information Technology,
Universiti Malaysia Sarawak, 94300 Kota Samarahan, Malaysia
[1]eze_monday@yahoo.com, [2]ljane@fit.unimas.my and [3]terrin@fit.unimas.my

Abstract: **Even with a lot of efforts by researchers, malaria eradication is yet to become a reality. The link between malaria infected and non-infected human beings, which led to transmission of the disease, is bridged by infected malaria vectors, through blood sucking bites. Such bites take place either in residential homes or public places. Suppose the residential homes are placed under reliable vector control, malaria transmission will still persist unless the public places are taken into consideration. The emerging computational strategy is about leveraging on the interactions between human beings and mosquitoes in public places to build realistic network models with the ultimate aim of applying relevant search techniques to such models, so as to determine the public places which act as reservoir of infected malaria vectors. The overall result will form a key resource for realistic vector control. Hence the idea is to be more proactive and offensive against malaria vectors, by locating the vectors in their hiding places, rather than human beings being located and bitten by the infected vectors. The emerging computational strategy discussed here is part of an ongoing research project in application of computational techniques towards eradication of malaria. This paper documents the result of an initial survey on malaria vector existence in public places.**

I. INTRODUCTION

A number of public places, such as bars and restaurants have been reported to close outdoor terraces or shut down completely as customers cannot sit outside because of what experts described as 100 billion mosquitoes invasion [1]. The importance of public places in disease transmission could be proved by referring to research by [2] and [3] which shows that contact rate between infectious and susceptible individuals could be reduced as much as 50% by closing some public places. While closing down public places is not the best solution, this finding however underlines the importance of public places in disease propagation. It has been shown that the number of individuals in a household drastically affects the size of disease outbreaks [2]. This implies that the more the number of people interacting in a place, the more the probability of disease transmission in that location. A recent literature survey carried out as part of this research revealed that the average household size for all the countries studied spans between 2.2 and 7.4. For instance Bangladesh [4] is 5.6, Norway [5] is 2.3, Switzerland [6] is 2.2, Japan [7] is 2.7, Afghanistan [8] is 7.4, Australia [9] is 2.6, China [10] is 3.7, Egypt [11] is 4.9, USA [12] is 2.57 and Canada [12] is 3.1. Since most public places (eg. schools, markets, airports etc) accommodate thousands of people, the probability of disease spread is very high in such places, and hence the need for studying malaria transmission in public places.

II. RESEARCH HYPOTHESES:

The hypotheses for this research experiment are:

Hypothesis1: Some public places where human beings visit for their daily socio-economic activities harbor malaria vectors.

Hypothesis2: These public places contribute to propagation of malaria due to blood sucking bites by mosquitoes in these locations.

Hypothesis3: The control of malaria resulting from human migration from location to location will remain very difficult to deal with, as long as malaria vectors thrive in public places.

Hypothesis4: Network Modeling can be used to study the dynamics of malaria transmission in public places.

Hypothesis5: Even if vectors are controlled effectively in the residential homes, malaria will still persist if the public places are not taken into consideration.

III. MATERIALS AND METHODS

A survey research was carried out in Sarawak State of Malaysia in June 2010 on vector existence in public places. A total of 525 valid responses were obtained from respondents drawn from ten countries, though the indigenes (Malaysian citizens) constituted a greater percentage. The foreigners involved were those who visited or were living in Malaysia at the time of this research. The aim of this survey is to determine previous experiences of mosquito bites in 16 carefully selected type of public places (see TABLE I). The respondents also had the option of indicating three most critical public places, and ranking them in the order of perceived degree of vector existence (or mosquito bites experiences), as well as suggesting other public places apart from the sixteen. The vector control strategies used in residential homes were also studied. Various modeling and data analysis techniques were applied to derive relevant outputs. The two popular correlation coefficients (Spearman and Pearson Correlation Coefficients) were applied for relevant validation of the research findings.

IV. DATA EXTRACTION

The VEXCount (vector existence count) table was built from the questionnaire data. This is the frequency distribution table which cumulates all the binary responses against each of the public places under consideration. This table is shown below as extracted from the experimental data. This implies that out of the 525 respondents, 398 experienced mosquito bites in a school, 156 in a football pitch, 317 in a bus stop, etc in that order.

TABLE I
VEXCOUNT TABLE

S/N	PublicPlace	Respondents Count
1	School	398
2	FootBallPitch	156
3	BusStop	317
4	Market	247
5	SwimPool	86
6	Restaurant	207
7	Airport	30
8	Road	226
9	BarbSaloon	26
10	River	442
11	Zoo	249
12	Mountain	283
13	Hotel	76
14	Office	60
15	CinemaHall	50
16	NightClubs	26

The distribution of respondents according to country of origin is shown in TABLE II.

TABLE II
RESPONDENT NATIONALITY TABLE

Country	Respondents Count
China	1
Germany	1
Indian	3
Indonesia	5
Korea	1
Libya	1
Nigeria	3
Pakistan	1
Palestine	2
Malaysia	507
TOTAL	525

Data analysis for respondents who have suffered from malaria revealed that vector controls were actually applied in their residential homes. The three tools indicated are *Bednets* (mosquito nets covering beds in the bed room), *Windownets* (nets that bar mosquitoes from entering through the windows), and *Insecticides*. The distribution of these tools is shown in TABLE III, with a total of five respondents indicating that they do not apply any measure in controlling mosquito vectors in their homes.

TABLE III
VECTOR CONTROL TOOLS TABLE

Tools	Respondents Count
BedNets	19
WindowNets	26
Insecticides	42
None	5

Also extracted is the multiple control strategy data which shows the distribution of how these respondents apply combination of vector control strategies in the residential homes. The result is TABLE IV with column codes *NoneSTRAT*, *SingleSTRAT*, *DoubleSTRAT*, *TripleSTRAT* representing 0,1,2, and 3 number of strategies in that order.

TABLE IV
MULTIPLE CONTROL STRATEGY TABLE

Combination of Strategies	Respondents Count
NoneSTRAT	5
SingleSTRAT	15
DoubleSTRAT	21
TripleSTRAT	10

The cumulative rank (*CUMRank*) table was built by extracting the three ranks (*Rank1, Rank2, Rank3*) assigned by the respondents to each of the public places under investigation, and then cumulating these ranks to get *CUMRank* score as shown in TABLE V.

TABLE V
THE CUMRANK TABLE

Public Places	Rank1	Rank2	Rank3	CUMRANK
AirPort	1	0	0	1
BuStop	30	50	54	134
Cinema	1	4	7	12
Football Pitch	13	28	19	60
Market	17	48	40	105
Mount	94	78	36	208
NightClub	2	0	1	3
Pool	11	0	7	18
Restaurant	10	15	29	54
River	200	110	44	354
Road	15	31	43	89
School	70	41	62	173
Zoo	31	47	72	150
Hotel	0	2	6	8
Office	0	0	3	3
Saloon	0	1	1	2

In order to study the variation between vector existence and top ranking, the *VEXCount* and *CUMRank* tables were merged giving rise to TABLE VI. This table was used for validation of the experiment through computation of correlation between the measure of vector existence and the cumulative ranking.

TABLE VI
MERGING CUMRANK & VEXCOUNT

S/N	PublicPlace	VEXCOUNT	CUMRANK
1	School	398	173
2	FootBallPitch	156	60
3	BusStop	317	134
4	Market	247	105
5	SwimPool	86	18
6	Restaurant	207	54
7	Airport	30	1
8	Road	226	89
9	BarbSaloon	26	2
10	River	442	354
11	Zoo	249	150
12	Mountain	283	208
13	Hotel	76	8
14	Office	60	3
15	CinemaHall	50	12
16	NightClubs	26	3

The experimental data was mined for information related to *vector bite without infection* (VBWO) and *vector bite with infection* (VBWI). The VBWO data displayed on the left side of TABLE VII shows respondents who visited public places and were bitten by mosquitoes, but did not suffer from malaria. The VBWI data on the right side of the same table shows the respondents who visited public places and were bitten by mosquitoes, and then got infected by malaria within the last two years. The common column "*PPCount*" stands for public place count and it represents the total number of public places where the respondents had mosquito bites. The total numbers of people involved are 474 and 51 for VBWO and VBWI categories respectively.

TABLE VII
VECTOR BITE WITH & WITHOUT INFECTION (VBWO & VBWI)

VBWO		VBWI	
Respondents	PPCount)	Respondents	PPCount
8	1	0	1
16	2	2	2
109	3	9	3
69	4	11	4
69	5	7	5
69	6	6	6
48	7	4	7
27	8	2	8
22	9	2	9
11	10	5	10
10	11	2	11
6	12	0	12
4	13	0	13
4	14	0	14
1	15	0	15
1	16	1	16
474		51	

TABLE VIII
RE-RANKED TABLE

S/N	PublicPlace	Re-rank of VEXCount (RV)	Re-rank of CUMRANK (RC)	RC-RC (d)	d^2
1	School	2	3	-1	1
2	FootBallPitch	9	8	1	1
3	BusStop	3	5	-2	4
4	Market	6	6	0	0
5	SwimPool	10	10	0	0
6	Restaurant	8	9	-1	1
7	Airport	14	15	-1	1
8	Road	7	7	0	0
9	BarbSaloon	15	14	1	1
10	River	1	1	0	0
11	Zoo	5	4	-1	1
12	Mountain	4	2	2	4
13	Hotel	11	12	-1	1
14	Office	12	13	-1	1
15	CinemaHall	13	11	2	4
16	NightClubs	16	13	3	9

V. DATA ANALYSIS AND VALIDATION

The extracted data was analyzed for correctness, and various outputs like histograms, pie charts and graphs were generated. The Pearson Product Moment method was used to calculate the correlation coefficient of the survey data, with particular attention on the relationship between vector existence and top ranking. This validation is necessary since *vector existence* does not automatically qualify a public place as *top ranked*, but the reverse is always true, as every *top ranked* public place automatically qualifies as having *vector existence*. A high correlation coefficient between vector existence and top ranking could therefore be used as a basis for validation of the survey. The Pearson Product Moment Correlation coefficient is given by:

$$r(x,y)=\frac{\mathrm{N}\sum xy-(\sum x)(\sum y)}{\sqrt{\mathrm{N}\sum x^2-(\sum x)^2}\,\sqrt{\mathrm{N}\sum y^2-(\sum y)^2}} \qquad (1)$$

where x is the CUMRANK and y is the VEXCount (from TABLE VI). The terms in equation (1) can be calculated as:

$$\sum x = 2879,\quad \sum y = 1374,\quad \sum xy = 433697,$$

$$\sum x^2 = 797141,\quad \sum y^2 = 264982,\quad \mathrm{N} = 16 \quad .$$

Therefore, *r(x,y)* is evaluated to be:

$$\frac{16(433697)-(2879)(1374)}{\sqrt{16(79741)-(2879)^2}\sqrt{16(264982)-(1374)^2}}$$

Hence r(x,y) = 0.92059.

To calculate the Spearman's Rank Correlation Coefficient on the experimental data, the *VEXCount* and *CUMRANK* were both re-ranked in order of magnitude as 1^{st}, 2^{nd}, 3^{rd},.. 16^{th} , giving rise to TABLE VIII which was then used for correlation analysis. The Spearman's Rank Correlation Coefficient is given by:

$$R = 1-\frac{6\sum d^2}{\mathrm{N}(N^2-1)} \qquad (2)$$

where *d* = RV-RC (see TABLE VIII)

$$R = 1-\frac{6 \text{ x } 29}{16(16^2-1)} \qquad \textit{Hence } R = 0.95735$$

The calculated values of both correlation coefficients are very high, therefore validating the experiment.

VI. RESULTS

Various scenarios were analyzed using the extracted tables. The key visual outputs are shown in the following diagrams, and their significances discussed in relevant sections of this paper.

The vector existence histogram was plotted as shown in Fig 1 visualizing the relationship between the public places and number of respondents who experienced mosquito bites in such places. Furthermore, the pie chart in Fig 2 was also plotted to visualize the experimental data. The result indicated that "Rivers", "Schools", "Bus Stops", "Mountains" in that order are the topmost reservoirs of malaria vectors.

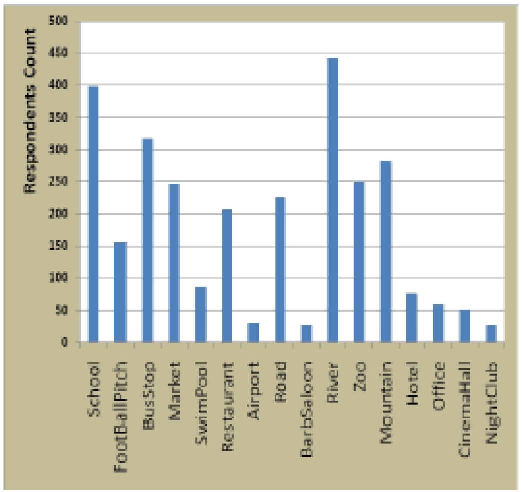

FIG 1: HISTOGRAM OF VECTOR EXISTENCE IN PUBLIC PLACES

One important deduction from Fig 1 and Fig 2 is that there are malaria vectors in public places.

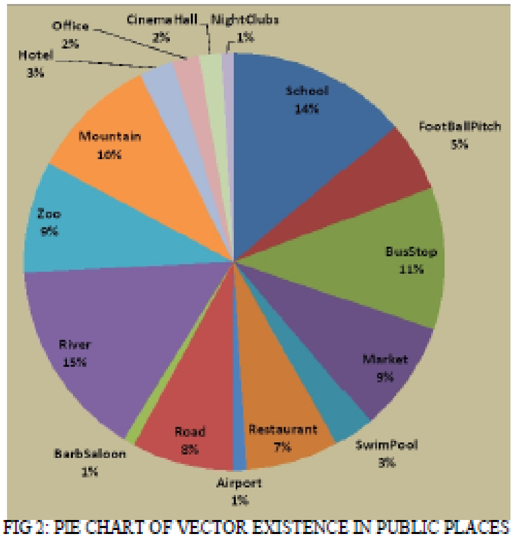

FIG 2: PIE CHART OF VECTOR EXISTENCE IN PUBLIC PLACES

In the research survey, each of the respondents were required to indicate the three public places perceived as most infested with malaria vectors, based on their past experiences of mosquito bites. The result of this is the graph in Fig 3 with the corresponding indicators "Rank3","Rank2' and "Rank1" clearly shown. The same data was used to generate the histogram in Fig 4.

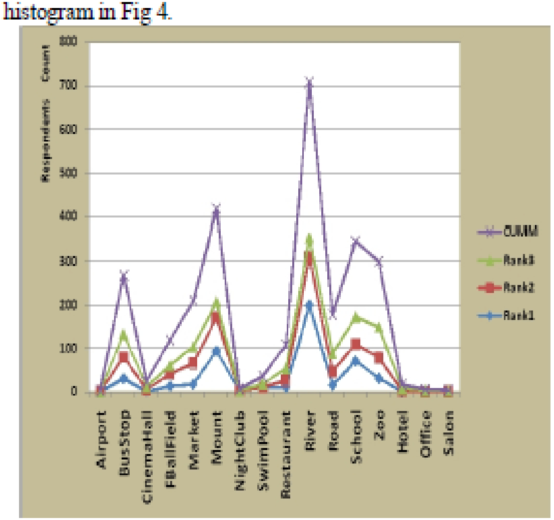

FIG 3: GRAPH OF RANKING OF VECTOR EXISTENCE

The fourth plot in Fig 3 with indicator "CUMM" is the cummulative rank, derived by summing up the three top ranks for each of the respondents. This derivative plot is of key significance.

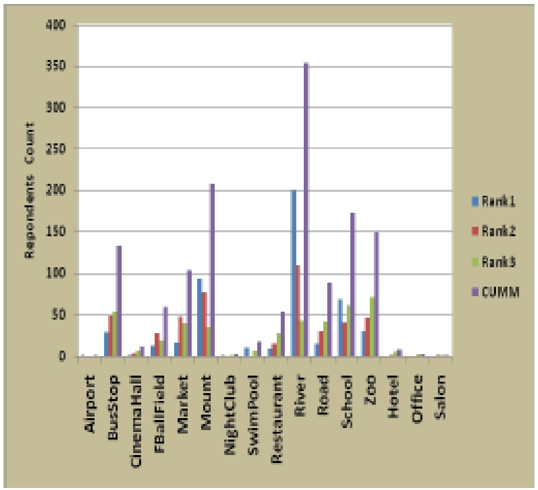

FIG 4: HISTOGRAM OF VECTOR EXISTENCE RANKING

First is that it could be used to derive the mean rank by simply dividing the cummulative rank by 3. Secondly, it acts as a visual validator, since it is expected to superimpose on top of the other three top rank plots. This is in line with the result of the numerical validation done using correlation coefficients as earlier stated.

The result of analysis on vector control tools used by respondents in their residential homes is Fig 5.

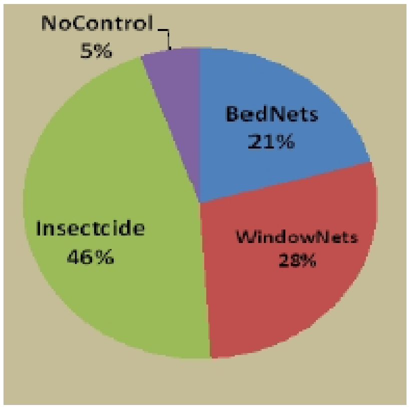

FIG 5: VECTOR CONTROL TOOLS CHART

As already mentioned in the data exctraction section and shown in TABLE III, the target group represented by this figure are the respondents who have suffered from malaria.

As much as 95% of the respondents use vector control tools in their residential homes, while only 5% live without vector controls. It is therefore very interesting to note that even at this, these respondents still suffered from malaria. The pertinent question is, "Why then do they still suffer from malaria?". The quest to answer this led to further analysis on combination of vector control strategies. Fig 6 clearly shows that as much as 62% of these respondents use a combination (of either double or tripple) vector control strategies but still suffered from malaria. Since it is assumed that the respondents are not naïve in the use of vector control tools, there is one way to account for why they still suffer from malaria even after applying vector controls in their residential homes. That is the fact that they must have contacted the malaria from the public places rather than in their residential homes.

The result of this experiment also supported the fact that not all mosquito bites led to malaria. For instance, of all the 525 respondents who have had mosquito bites at one time or the other, only 51 of them had malaria (within the last 2 years). Since malaria transmission is through bites by infected mosquitoes, this scenario can only be explained by deducing that the rest of the people who did not suffer from malaria must have been bitten by non-infected mosquitoes. The graph of bites with infection and bites without infection are shown in Fig 7 and Fig 8 respectively. In each of these graphs, the number of respondents was plotted against the number of public places where these respondents visited and experienced mosquito bites.

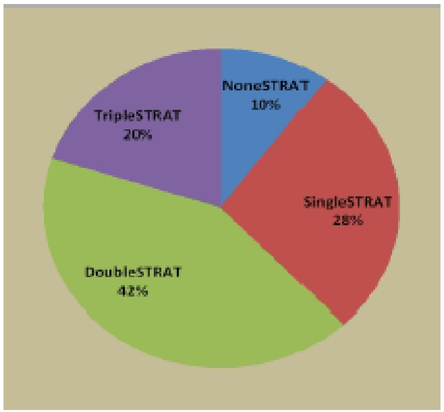

FIG 6: COMBINATION OF VECTOR CONTROLS CHART

A closer look at the shapes of Fig 7 and Fig 8 reveals a fairly common trend. For instance, both graphs rise up steadily, reach a peak, and then descend. Many facts can be deduced from these graphs. First is that there must be a public place or a combination of public places that account for the highest vector density, otherwise there would not have been any peak point on these graphs as observed. Secondly, there is a limit to number of places people can effectively visit and be bitten by mosquitoes. For instance a larger percentage of respondents visited and were bitten by mosquitoes in 1 to 6 public places, while very negligible number were able to visit between 11 to 16 places.

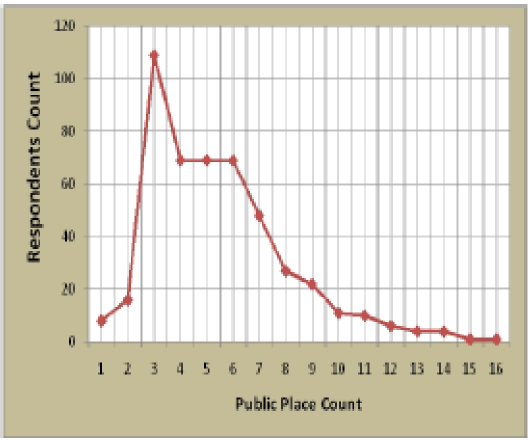

FIG 7: GRAPH OF BITES WITHOUT INFECTION

The fact that each of the respondents could accurately recollect the public places where they experienced mosquito bites is a clear indication that networks of human hosts and public places can be constructed for modeling malaria transmission.

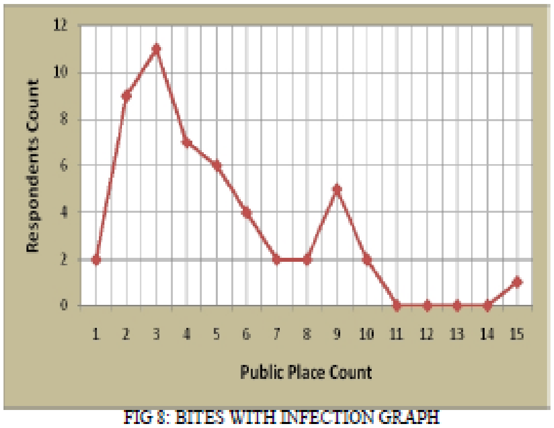

FIG 8: BITES WITH INFECTION GRAPH

VII. DISCUSSIONS ON RESEARCH OUTCOMES AND HYPOTHESIS

The result of this research has shown that there is indeed vector existence in public places. For instance, every of the 525 respondents mentioned at least one public place where they have had mosquito bites, with up to 2 respondents experiencing bites in all the 16 public places under investigation. It can also be deduced that the concept of vector existence in public places is not limited to Malaysia alone, since respondents were drawn from 10 countries. Result of this experiment also clearly proves that even if vectors are effectively controlled in residential home, malaria will still persist as long as the public places still harbor by malaria vectors.

The research also shows that it is possible to rank the degree of existence of vectors, though the present scope only gives an idea of type of public places of serious concern, rather than the exact location of those places. Prediction of the exact public places is the work in progress task of this ongoing research.

The concept of malaria vector bites without infection underlines the need to focus computational efforts on discovering the hotspots for infected vectors. Without achieving this, policy makers could waste limited vector control resources on areas of less immediate concern. In line with the hypothesis, it is clear that malaria resulting from human migration to other countries cannot be stemmed without effective vector control in public places. For instance, when a traveler enters a foreign country, the first point of interaction is the public places like airports, hotels, etc. If mosquitoes thrive in such public places, they bite the infected foreigner and subsequently bite the citizens of the host country to infect them. Malaria is therefore propagated. In the same way, while leaving the host country, the foreigner could also contact malaria and take back home to spread in his/her home country.

VIII. CONCLUSION

The entire hypothesis put forward can be seen to hold based on the results of this experiment. Though this experiment does not pinpoint the particular public places (or exact locations), it gives clues to types of public places of serious concern. It can therefore be concluded that research on malaria transmission through public places is a necessity for complete eradication of malaria. This research has revealed that malaria vector reservoirs could be further classified into natural (eg. river) and man-made habitats (eg. school, hotel). Such an understanding will definitely be useful in vector control, since the man-made reservoirs could be much easier to deal with than the natural reservoirs.

IX. FUTURE RESEARCH:

Work is currently in progress on building realistic network models and applying relevant computational techniques to determine the specific public places of serious concern.

ACKNOWLEDGMENT

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