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Development of a Software Module for Forecasting Malaria Outbreak based on an Equation Derived from Real-Time Parameters

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ABSTRACT
Malaria in India is one of the major public health problems. It is governed by many socio-ecological factors that exist in the system around. Hence forecasting the disease situation in a particular area necessitates observance of these micro factors. These factors upon identification and translation into a mathematical model can help understand and predict malaria situations at primary level. Attempts had been made in the past ever since its vector discovery by Sir Ronald Ross in 1897. As yet many of the models have faced difficulties in standardization of the variables inputed. We have made an attempt here to develop a model based on the results of our own earlier research from a real time situation of malaria in the desert area of Rajasthan, India. An equation of inter-relationship among five existing malaria components has been derived as an outbreak forecasting mathematical model. The equation has been converted into software. The software developed was tested for its predictive strength for simulated conditions of parameters as well as for real situation of five parameters. The software found to work efficiently and predicted the correct malaria situation.

Keywords
Malaria, software, forecasting module, malaria epidemiology, malaria equation.

1. INTRODUCTION
About 3.3 billion people-half of the world's population are at the risk of Malaria [1]. In north-western Rajasthan, India, which represents a desert ecosystem, Malaria appears as the seasonal outbreak of disease where every year the disease is introduced afresh through imported cases and 2-3 transmission cycles of disease then takes place with the help of local fauna of vector (*Anopheles stephensi* and *Anopheles culicifacies*). In this region, transmission system of Malaria depends primarily on number of active cases present in a particular human population and secondarily on population density of vector population and animal and human baits. Our earlier studies in 26 villages situated in irrigated and non-irrigated areas of desert Rajasthan have shown that transmission of Malaria in desert is primarily determined by number of active cases of Malaria along with population density of vector population, density of animal bait (cattle mainly) and human population density as secondary factors. Thus if a malaria affected village is taken as transmission area of disease where parasite *Plasmodium* (in form of active cases of Malaria), density of vector species and human and animal bait density participate to interact, most crucial of these components will be the number of active cases present at a point of time [2].

In present paper we attempted to formulate a mathematical equation based on outcome of our above study [2] to forecast an outbreak situation of Malaria in desert ecosystem. Further, this equation has been translated into a software programme and tested for simulated as well as real time conditions of malaria at village level. The software based on equation of relationship of malaria components has been found to predict correct malaria situation in simulated as well as observed malaria cases in the affected villages. Present paper reports the details of malaria epidemic forecasting module developed through our research.

2. MATHEMATICAL MODEL
2.1 Parameters Selected
Based on our earlier work [2], the following parameters were selected: per man hour density (PMH) of mosquito species such as *Anopheles stephensi, Anopheles culicifacies* (PMHs and PMHc respectively). The human and cattle density data for each village studied were taken from Government Census Book. The number of active cases of malaria at given point of time were recorded by conducting house to house survey in the study village.

2.2 Formulation Of The Mathematical Equation
An inter-relationship between parameters of transmission of malaria was formed:

$$TI = Ac(PMHs - Hd + PMHc - Cd)$$

Where,

TI = Transmission Index of malaria at village level

Ac = Active Cases of malaria at village level

PMHs = Per Man Hour density of *Anopheles stephensi*

Hd = Human density at village level

PMHc = Per Man Hour density of *Anopheles culicifacies*

Cd = Cattle density of village

(Density of mosquitoes was calculated in terms of their adult forms caught per man hour i.e. PMH which in case of *Anopheles stephensi* is denoted as PMHs and in case of *Anopheles culicifacies* is denoted as PMHc.)

If the value of TI comes less than 10, malaria will be SPORADIC only.

If value of TI comes more than 10 but less than 20, transmission will be of MODERATE level.

If value of TI comes more than 20, there would an EPIDEMIC of malaria.

2.3. Designing of Software

A software using Visual Basic 6.0 and Microsoft Access as backend database was developed from the above equation. The software developed is user friendly and has Graphic User Interface. A person with basic computer knowledge can operate this software and thus proves helpful for health workers. A self extracting archive and installation setup has been prepared and is made available as open source along with its source code at the URL http://code.google.com/p/malaria-transmission-prediction-software/. The source code has been licensed under Eclipse Public License 1.0 which is an Open Source Initiative (OSI) compliant license.

The software has three form modules. The 'New Prediction' form has the option to input parametric observations such as Active case (Ac), Per Man Hour Density- *Anopheles culicifacies* (PMHc) and Cattle Density (Cd) etc. As soon as the user inputs the values, the software predicts the expected prediction as 'Sporadic' or 'Moderate' or 'Epidemic'. The user also has the option to save the observations along with the details of the location of the area under consideration. The 'Open Prediction' form has the option to view the previously added observations. The user also has the options here to edit or delete the previously added observations.

The 'Graphic Prediction' form has the graphical interface which is developed using the Microsoft Chart Control 6.0 (SP4) (OLEDB) of Visual Basic 6.0. Here a user can change various parametric factors determining malaria transmission and can view the predictions in the form of a line graph. The user may fix any four variables out of the given five (i.e. Ac, PMHs, Hd, PMHc and Cd). The software immediately plots a line graph showing the effect of the fifth variable on malaria prediction based on the minimum and maximum values provided in the same form for that variable. The user also has the option to change the value of the fifth variable using a slider. As soon as the user slides the slider, the software displays a vertical bar in the above line graph, which further helps the user to identify the effect of the change of fifth variable for a given situation.

3. RESULTS AND DISCUSSION

3.1 Testing of Software Module

During the year 2008, malaria outbreak appeared in the Pokaran town, Jaisalmer district, India. The software developed was tested under field conditions for two areas Area I and Area II (Table 1). The observations were made with respect to the parameters included in the equation of transmission.

Table 1. Observations based on the equational parameters from Malaria affected areas.

Study Area	**Area I**	**Area II**
Date of 1st Study	9.8.2008	9.9.2008
Active cases (Ac)	3	5
Per Man Hour density (PMHs)	8.4	0
Human Density (Hd)	126	144
Per Man Hour density (PMHc)	13.6	42
Cattle density (Cd)	3	168
Software prediction (TI)	Sporadic	Sporadic
Date of 2nd Study	18.8.2008	19.9.2008
Real magnitude of Malaria seen then	Sporadic	Sporadic

When the values of these parameters were entered in software developed, a prediction of 'Sporadic' malaria was observed for Area I (figure 1). The software also has a provision to view the prediction in a graphical form. The data for Area I when entered in the 'graphical prediction' format also showed the same result (figure 2). Under real time conditions also, the area actually proved to have a situation of 'Sporadic' form during the said period (Table 1).

Similarly for Area II also a value of TI less than 10 was derived by the equation. Here the software predicted a 'sporadic' malaria situation for Area II. The follow up study made after 10 days also showed sporadic malaria situation (Figure 3 with its graphical prediction shown in figure 4).

Malaria incidence at a given point of time in a particular setting is the resultant interaction of five ultimate factors of malaria cycle viz; number of active malaria cases as contributors of parasites to available vector fauna feeding upon them, density of anthropophillic and zoophillic vector species, density of animal baits for zoophillic species and density of human bait for anthropophillic species.

We conceptualized that whatever could be the efficacy of a malaria control programme in an area and the status of drug resistance by malaria parasite within human host, what stands crucial for the malaria to be transmitted from a patient to a healthy host, is number of active cases available within the flight range of available vectors species in a geographical area of transmission. All other factors play a secondary role only. Hence our equation of transmission of malaria included active cases of malaria as the primary parameter.

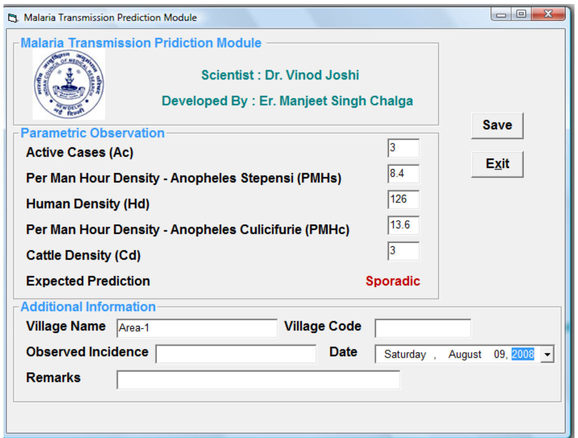

Fig 1: Plate showing malaria forecasting module with provision for inputing observed values of the 5 parameters for Area I. (When the parameters obtained from the study area are entered in the box provided, the 'expected prediction' according to the software developed will appear to be either Sporadic/moderate/epidemic)

Fig 2: Plate showing graphical prediction by the software for the type of Malaria possibility for Area I. (When the data are feeded in the 'Graphical prediction format', the graph plotted will indicate whether present condition is sporadic/moderate/epidemic)

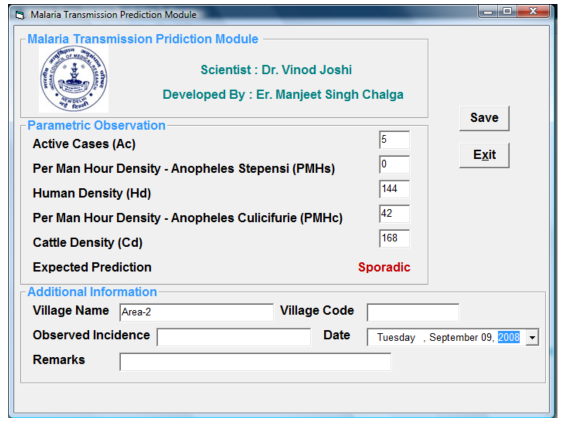

Fig 3: Plate showing malaria forecasting module with provision for inputing observed values of the 5 parameters for Area II.

Fig 4: Plate showing graphical prediction by the software for the type of Malaria possibility for Area II.

Similarly, whatever could be the insecticide resistance among malaria vectors in an area and there could be any status of ecological factors what matters is how much is the net density of a vector species which by option (preference) or by compulsion (due to less density of preferred bait), has to bite a human bait out of which few may happen to be malaria patients thus expediting disease transmission. We further hypothesized that risk of malaria transmission in an area will be depending upon the density of human population for an anthropophilic species such as *Anopheles stephensi*. If human population is more in a given transmission system (within flight range of a species), density of an anthopophillic species will have less chance to feed upon an infected human bait for later being dilutely present in a larger human population. Whereas, in contrary situation, if in a given transmission system, bait population is less than available vector population will have more probability of biting an infective human host. Similarly, if for a zoophillic species density of animals is more, this species will not prefer human bait and hence in this situation also more density of preferred bait will reduce transmission probability. For this reason, we have kept an inverse relationship between human/animal host density and density of respective vectors.

We have also perceived that whatever may be the density of vector species or bait population, if cases of malaria are not present, value of all these will be zero. Based on above concept which was partly proved by our earlier studies [2], in the equation of inter-relationship of malaria components active cases (Ac) have been kept in determining mathematical position in the equation. Earlier workers have reported anthropo-ecosystem of malaria, but these studies describe only qualitative or theoretical inter-relationship of direct and indirect factors which may influence a malaria transmission process in an area [3]. Our present studies represent a conclusive work which needs to be worked out. Garrett-Jones [4] has reported significance of human blood index of malaria vectors in epidemiological assessment. In fact this study has focused on interaction of vector and human host which has been mathematically worked out. Other workers have reported role of climatic factors on malaria [5-8], but again what climatic factors will determine is the availability of a vector population during a particular time in an area, and we have attempted to include the ultimate factor i.e. density of vectors. Many earlier workers have also attempted developing mathematical models of malaria forecasting based on entomological and parasitological variables [9], on meteorological variables [10] and on Geographical Information System [11]. Recently mathematical models have also been derived based on immune functions to intervene transmission reduction by Filipe et al combining epidemiological and immunological processes [12]. Gaudart on the other hand has very interestingly correlated the environmental effects acquired through remote sensing along with environmental factors important in forecasting the evolution of malaria epidemiology as observed in locality of Sudanese Savannah [13]. Introduction of vaccines at different stages in the malaria transmission cycle has been demonstrated in mathematical model designed by Smith et al [14]. At present, Malaria control operations in India are accompanied based on annual parasitic index of Malaria and total slide positivity rate observed for a particular setting. As such no predictive software model is forming the base of malaria control operations.

The present computer model based on real time and ultimate parameters of Malaria cycle will add significance to supplement to the strength of ongoing malaria control efforts.

4. CONCLUSION

Malaria is the major public health problem of India. About 2-3 million malaria cases have been reported in past two decades in the country [15]. It appears that if a predictive malaria forecasting system is developed we can plan to integrate parasite containment with vector control operations in high risk areas to achieve reduced disease transmission. Present study offers a mathematical relationship of malaria components for forecasting malaria epidemic and translation of equation into computer software. The data of all these parameters are being generated by the National Anti Malaria Programme, Government of India. Using these data, present forecasting module developed by us can be used to predict possible malaria situation at each village and at sub-centre level. We plan to share the utility of the software with State Health authorities to help them know the possible prospective situation of Malaria at village level. Through prediction generated by software the prioritization of prevention/control measures against malaria can be made.

5. ACKNOWLEDGMENTS

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