MODELLING OF VECTOR PREVALENCE VIS-A-VIS ITS VULNERABILITY TO CLIMATE CHANGE

SUDESH KUMAR SOHANI

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

APRIL 2015

MODELLING OF VECTOR PREVALENCE VIS-A-VIS ITS VULNERABILITY TO CLIMATE CHANGE

by

SUDESH KUMAR SOHANI

Department of Civil Engineering

Submitted

In fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

NEW DELHI, INDIA

APRIL 2015

CERTIFICATE

This is to certify that the thesis entitled ***Modelling of Vector Prevalence vis-a-vis Its Vulnerability to Climate Change*** submitted by **Mr**. **Sudesh Kumar Sohani** to the **Indian Institute of Technology Delhi**, for the award of the degree of **Doctor of Philosophy**, is a record of the original bonafide research work carried out by him under our guidance and supervision. The thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

Dr. A. K. Nema
Professor
Department of Civil Engineering
Indian Institute of Technology Delhi
Hauz Khas, New Delhi 110016

Dr. B. R. Chahar
Professor
Department of Civil Engineering
Indian Institute of Technology Delhi
Hauz Khas, New Delhi 110016

ACKNOWLEDGEMENTS

I want to take this great opportunity to express my deep gratitude to all those great people who directly or indirectly supported me and contributed during the course of my PhD thesis work.

With high regards, I express my sincere gratitude and appreciation to my supervisors, Prof. B. R. Chahar, Department of Civil Engineering and Prof. A. K. Nema, Department of Civil engineering, Indian Institute of Technology Delhi for their expert guidance, constant encouragement, unconditional trust, support and constructive criticism during the course of my research work. I am deeply indebted to them for their suggestions during the preparation of the manuscript of this thesis and help to achieve my goal.

I express my special regards and thanks to my Student Research Committee members Prof. Mukesh Khare, Prof. S. V. Veeravalli and Dr. D. R. Kaushal for their critical review, valuable suggestions and support. Their suggestions helped me a lot to come through this research work.

I express my sincere thanks to the Authorities of IIT Delhi in general, and the Department of Civil Engineering in particular for providing facilities to carry out the research work.

I gratefully acknowledge the help of the faculty members Prof. A. K. Gosain, Prof. Shashi Mathur, Prof. A. K. Jain, Dr. Anushree Malik, Dr. Dhanya C. T. for their support, teaching and encouragement. I am especially grateful to my fellow research scholar and presently a Project Scientist at IIT Delhi Dr. Sudheer Ch. for his unconditional cooperation and diligent guidance throughout this journey of my research work.

I am thankful to the Authorities of National Institute of Malaria Research (NIMR, Indian Council of Medical Research), New Delhi for providing the study data. I express my gratitude to Dr. R.C. Dhiman for sharing his expertise and providing specific data for the study. His constant encouragement and guidance helped me to decide appropriate line of action for my study. I wish to thank Dr. V.P. Sharma for his kind initial enlightening discussions and for interacting with me time to time, in turn, helping me to understand the concept of the vector borne diseases. I am thankful to the Authorities of CRDT, IIT Delhi for providing the required facilities for the study, I specially wish to thank Dr. Anushree Malik for the encouragement and for extending all the help.

My special thanks are due to my well-wishers, mentor and sponsorer Er. Ashok Sojatia, Chairman (BOG) and Er. Ashish Sojatia, Group Chairman, Acropolis Group of Institutions for encouraging me to pursue higher studies and providing me necessary support.

This acknowledgement will remain incomplete unless I thank my fellow research scholars: Raktim Haldar, R Maheswaran,Deepak Kumar, Jayshri Patel, Boini Narsimlu, Pratiksha Pandey, Shailendra Jain, Aniket Chakravorty, Jatin Anand, Sridebi Basu, Pawan Kumar Rai, Jyoti, Pankaj Prajapati, Ashwani Soni and the staff members: Mr. Rajbir Agrawal, Mr. N. R. Gehlot, Mr. Vikram Chand, Mr. Rajiv Sharma, Mr. Amit Bundela, Mr. Chakresh, for their utmost cooperation at every stage, and for good ideas and humour to keep the study period pleasant.

I am indeed lucky to live in a joint family of we three brothers, my elder Dr. Susheel Sohani, younger Mr. Sanjeev Sohani, and parents. I do not find words to express my gratitude to every single member of my big family, my mother, my wife Alpana and son Shivam for their all-out support who also accepted my challenging task at this stage. My late Father and the almighty GOD shall remain the ideal to take all the credit.

New Delhi, April 2015 Sudesh Kumar Sohani

ABSTRACT

Malaria is one of the most dangerous vector borne diseases, causing more than one million deaths every year. Many researchers envisioned the control and elimination of malaria by inventing new drugs, developing newer strategies and by developing various models. In the process, many new concepts and complexities have been introduced. Still these inventions and new models are like tip of the iceberg compared to the existing complexities involved in malaria.

In India, malaria is a major public health problem and it contributes significantly to the overall malaria burden in Southeast Asia. To find a solution to the problem, mathematical models do help explain the dynamics of such infectious disease and can facilitate comparisons among competing control strategies that can inform policy decisions. Further to strengthen the prevention and control measures, this study has been carried out in order to develop appropriate modelling approaches of forecasting malaria transmission.

The study specifically has been aimed to develop three possible approaches to model and forecast the propagation of malaria with respect to the climate change variables. The first approach is to predict the variation in vector density with respect to climate variables in the subtropical climatic zones of lower Himalayan regions having increasing altitudes using Genetic Programming (GP). The study is done at three locations namely Raikhalkhatta, Bhorsa and Jyadi. Models have been developed based on the vector density as indicator. Calibration and validation of the simulated vector density indicated very good significance levels. To assess the impact of temperature and rainfall on the

vector density sensitivity analyses also have been done for all the locations. The analyses showed the variation in vector density on increasing and decreasing the temperature.

The second forecasting model has been developed through another novel approach by coupling the Fire Fly Algorithm (FFA) and Support Vector Machines (SVM) to determine the malaria transmission at two locations in the plains of Rajasthan under arid and semi-arid climatic zones. The performance of SVM models depend upon the appropriate choice of SVM parameters. In this study FFA has been employed for determining the parameters of SVM. In addition, three more forecasting approaches are developed by employing Support Vector Machines (SVM), Artificial Neural Network (ANN) and Auto Regressive Moving Average (ARMA). At both stations malarial incidences have been computed using SVM-FFA, SVM, ANN and ARMA models. Simulated and actual malaria incidences values are compared. SVM-FFA model performed best out of four models, and showed very good significance level for the simulated malaria incidences on comparing it with the actual incidences. Box and Whiskers Plot has been used to find out the normalized residual errors to compare all the above algorithms. Sensitivity analyses also have been done which showed that there is variation in incidences on increasing and decreasing the temperature.

The Anopheles mosquito is one of the major vectors of malaria. Anopheles culicifacies species play a major role in spreading malaria in Asian countries, especially in Indian subcontinent. Hence, thirdly a mathematical model has been worked out to understand interactions of entomological and climatic parameters of malaria transmission. MATLAB has been used to develop this deterministic model, in the process three major steps are followed. First of all the endogenous variables, which have significant influence on the parasite transmission cycle, are identified and their relationship as a function of temperature is determined. Secondly, vector ecology, and entomological parameters are identified in order to determine exogenous parameters, which have direct influence on the malaria transmission. Finally a set of Coupled Ordinary Differential Equations is solved in order to determine the malarial incidences using Fourth Order Runge-Kutta Methods. The developed model is validated using already published data. Results match quite well with the data.

- - -

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND NOTATIONS

The following listed symbols and notations are used in the Thesis

Symbol	**Definition**
ANN	Artificial Neural Network
ARMA	Auto Regressive Moving Average method
EIR	Entomological Inoculation Rate
FFA	Fire Fly Algorithm
GP	Genetic Programming
HBI	Human Blood Index
HUF	Infectious Human
HUI	Infected Human
HUM	Recovered Human
HUS	Susceptible Human
Ma	Human Biting rate
N	Sporogonic Cycle
P_{hu}	Total Human Population
PSO	Particle Swarm Optimization
R	Rainfall /precipitation
R^2	Coefficient of determination
RH	Relative humidity
R_{mo}	Mortality rate
RMSE	Root Mean Square Error

R_{na}	Natality rate
SVM	Support Vector Machine
Temp	Temperature
VC	Vectorial Capacity
VF	Infectious Vector
VI	Infected Vector
VS	Susceptible Vector
μ_m	Natural Mortality rate
α_m	Induced Mortality Rate