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MASTERS' THESIS

Study Title: Influence of Climatic Factors on the Emergence of Dengue

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DECLARATION

This thesis, *"Influence of climatic factors on the Emergence of Dengue"*is the result of my independent investigation of the existing literature. Where my work is indebted to the work of others, I have made appropriate acknowledgements.

I declare that this study has not already been accepted for any other degree nor is it currently being submitted in candidature for any other degree.

Date and candidate's signature:

Dr. Shiraz Sheriff

Total word count (excluding the *Bibliography* section and *Annexes*): 8,662 words.

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1. ABSTRACT

Influence of Climatic Factors on the Emergence of Dengue -A Systematic review

By Shiraz Sheriff

Background: The impact of deadly Dengue incidence worldwide has been surmounting and this study will look at the climatic factors that influence the increase of Dengue infections worldwide.

Objectives: The overall aim of this systemic review is to review the available literature and determine whether Climatic Factors contribute to an epidemic emergence of Dengue.

Methods: A detailed search of electronic databases, articles published, web sites and cross references were made to obtain and collect pertinent primary studies which were systematically abstracted and analysed.

Results: The review of the papers revealed 13 studies associated temperature to be associated with Dengue emergence, 6 studies associated rainfall to Dengue emergence, 4 studies associated relative humidity to dengue emergence and 3 studies each associated precipitation and vapour pressure to dengue emergence. One paper showed there was an association of three variables namely temperature, rainfall and humidity and a combination of these led to a Dengue emergence.

Conclusions: The risk of Dengue infection is increasing and an understanding of the changes in climatic variables more than normal should be taken into account when developing early warning systems and assessing epidemic potential in detail all over the world.
The changes are seen more in areas where there have not been previous epidemics like cooler regions and higher altitudes where Aedes aegypti proliferation is taking place due to warmer temperatures. Conditions like drought areas are potential epidemic points from where the disease can set in and cause a severe epidemic if climatic factors affecting Dengue emergence are not taken into consideration.

2. Introduction

There are many deadly diseases occurring world wide and vector borne diseases constitute a major part of the morbidity and mortality profiles all over.

In this context it is interesting to see the emergence of Dengue Fever as a major killer disease sweeping most parts of the world in tropical and arid countries.

Dengue fever first emerged as a major public health problem in South East Asia but the disease has since spread throughout the tropical and subtropical regions of the world(1).

According to the WHO, Dengue affects around 2.5 billion people in the tropical and sub tropical countries around the world and it is seen as one of the most important vector borne viral disease(2).

Each year within the' dengue belt', which runs between latitudes of 35 N and 35 S, there are an estimated 50 million–100 million cases of DF and approximately 500,000 cases of dengue haemorrhagic fever (DHF) or dengue shock syndrome (3,4,5).

The risk factors for transmission are associated with an 'epidemiological triad' — the vector (*Aedes aegypti*), the dengue virus (of serotypes 1, 2, 3 or 4), and susceptible hosts (4).

Much of the re-emergence of Dengue as a killer disease can be attributed to the fact that the widespread presence of the mosquito vector and the circulation of all four of the distinct but closely related viruses or serotypes (6). While infection by one dengue virus provides lifelong immunity to that serotype, it increases the risk of severe illness when an individual is later infected by any of the other dengue serotypes. As a result, hyperendemicity – the circulation of multiple serotypes – produces more DHF cases and more deaths (6).

The risk of an epidemic is of course closely related to the adult vector biological and ecological factors (7): the life expectancy, the blood meal frequency, the extrinsic incubation period and the abundance. After the emergence, all biological processes are dependent on temperature and, for survival, on humidity (8, 9).

Abundance is supplied by the emergence of new adults and then is related to the immature stages of the mosquitoes: egg hatching, larval and pupal survival. These processes are related both to the human environment and to the climate. Indeed, Aedes. Aegypti is a domestic mosquito, which lays eggs preferentially in artificial containers left indoors and outdoors by people (10). Once embryonated, these eggs can survive up to 1 year until they are flooded and they hatch (11, 12)

Aedes *Aegypti* is a peridomestic mosquito that can live in and around houses. It is primarily a day-biting mosquito and feeds preferentially on human blood. It has a holometabolous lifecycle that makes it undergo complete metamorphosis through its egg, larval, pupal and adult stages (13).

Development and survivorship of the mosquito is greatly dependent on the climatic variables like temperature and precipitation. (13).Increasing Global temperatures and other different climate change phenomenons have seen to affect Aedes *Aegypti* populations as they modify its geographical range and epidemic potential. (13). Changes in elevational distribution of Aedes Aegypti have been observed in Colombia for example where previously the Aedes mosquito was found at 1500 m ,it has been recently found to be present at 2200m most probably due to temperature increase(14). Unaffected higher altitudes in Mexico have seen a surge in Dengue cases recently (15).

Koopman et al. (1991) found that the average temperature during the rainy season related strongly to the estimated risk of dengue infection to a community in Mexico and that there was a significant association between humidity and infection (16). It has also been found that the hatching of the mosquito varies dramatically according to precipitation and humidity (17).

Rueda et al. (1990) had shown that temperature has been shown to affect population biology in the laboratory (18), while models based on precipitation, temperature and atmospheric moisture explain much of the intra-annual variation in Aedes abundance (19) and dengue incidence (20). Studies conducted in the countries like Brazil, Indonesia and Venezuela, where Dengue Infection is present either in epidemic or endemic form have suggested a correlation between weather and pattern of Dengue Incidence. Rain, temperature and relative humidity are suggested as important factors attributing towards the growth and dispersion of this vector and potential of dengue outbreaks (21-23).

The direct impacts of climate on the incidence of dengue infections worldwide have to be ascertained and studies have not been partial enough to primarily focus on climatic variables often tending to limit and conclude with vector surveillance, vector density control, breeding habitat control and human environmental practices.

In this context it would be necessary to look at the available literature around and see the influence of climatic variables on the emergence of Dengue infections worldwide.

3. Objectives

The overall aim of this systemic review is to review the available literature and determine whether Climatic Factors contribute to an epidemic emergence of Dengue.

4. Methods

A search of different databases and virtual libraries was done and appropriate inclusion and exclusion criteria were applied on the collections.

The process underwent was:

1. Identifying relevant literature from databases and journals
2. Excluding duplicate articles
3. Selecting relevant articles for further review
4. Reading through and building a grading scale to assess the quality of each article.
5. Identifying and extracting relevant data from articles.
6. Interpretation and description of review results.

4.1. Search Strategy

Electronic databases like PubMed, Scopus, Embase and Medline were searched thoroughly using various combinations of key words and medical subject heading (MeSH) terms. For e.g.: *dengue*, climatic *factors, temperature, rainfall, humidity, precipitation.*

The search results produced relevant papers which were extracted for further reading and inclusion. Other sources like Journals, web published articles, bulletin posts of presentations and papers presented in conferences were also looked into and it was difficult to include any grey literature as they did not fulfill the selection criteria.

There was no specific time frame defined for the period of publications. Only articles published in English were taken into consideration.

4.2. Inclusion Criteria

The Study literature selected should address the relationship between Dengue to the influence of any of the climatic variables. For e.g. Temperature, Rainfall, Relative Humidity, Vapour pressure, Precipitation

There has to be pertinent objectives and defined study period to correlate the relationship and there should be proper results and conclusions discussed in the articles from the authors.

4.3. Exclusion Criteria

Articles which are irrelevant to topic, literature reviews and containing only abstracts were excluded from the analysis.

4.4. Data Extraction and Method of Data Synthesis

A standard data extraction form was formulated detailing the basic identification details of the publications and period of publication. The eligibility, background descriptions, study settings, methods, outcome measures and results were used to abstract relevant information from the publications included in this systematic review. Data synthesis tables were used to blend the results to make comparison among studies possible and tabulate a comprehensible conclusion. All the data was entered in Microsoft Excel and presented in the form of Tables for detailed comprehension. The data extraction form is listed below in Table 1.

Data Extraction Form

Code No.
Title
Journal
Published Year
Author
Type of literature: □*Published article*□*Report* □*Book/chapter*
□*Other………*

General Description and Methods

Study Type
Study Objectives
Study Hypothesis
Study Setting (Country /Place)
Study Population
Study Time Period
Climatic Variables Measured
Entomological Variables Measured
Source of Data(Dengue/Climatic Variables)
Statistical Methods

Results and Conclusions

Main Results
Other Results
Conclusions of the Authors
Conclusions of the Reviewer

Quality assessment. □*Good* □*Medium* □*Low*

Table 1.Data Extraction Form

4.5 Quality Assessment

Each paper was subjected to a quality grading scale where the measures were based on five questions to asses the quality of each paper.

The gradients applied were:

1. Did the study have a clear objective?

2. Did the study measure all variables described in the objective?

3. Did the study follow a standard in measuring Dengue cases?

4. Was the climatic variables measured and analysed properly?

5. Were results and conclusions comprehensively discussed by authors?

The grading scores were applied to each papers and were scored

A if all or most of the terms were entirely followed it was graded Good

B if there was sufficient description yet reasonable shortcomings it was graded Medium

C if there was drastic shortcomings and it was deemed Insufficient or Low.

4.6. Definitions

Breteau Index: The number of positive containers containing Aedes *aegypti* larvae per 100 premises inspected**.**

Container index: percentage of containers positive for Aedes breeding.

House index: percentage of houses positive for larvae of Aedes.

5. Results

The searches with different combinations of key words brought out a total of 296 papers. (Fig 1) .There was 26 duplications found during these searches and was excluded from the review. 17 studies were then selected finally from the search having a tangible relation for the study review. The search flow diagram process is described below.

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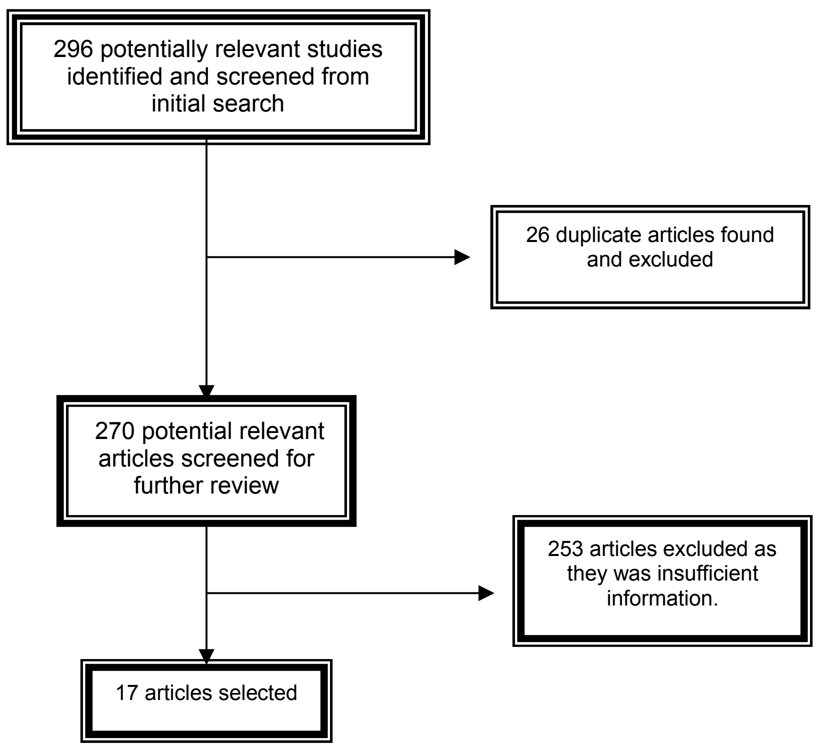


Fig. 1: Flow chart indicating the selection process of articles for the review work

The 17 selected papers were analysed in depth for all the study objectives.1 paper was published before 2000 and the other sixteen were published after the year 2000.

At the end of the Quality assessment, 14 studies were found to be Good, 2 studies were found to be Medium and 1 study was found to be Insufficient or Low.

The table below describes the studies selected for this review and their grading scores.

ID	Name of Study	First Author	Journal	Year of Publication	Language	Q 1	Q 2	Q 3	Q 4	Q 5	Overall
CF1 Ref # 36	An information value based analysis of physical and climatic factors affecting dengue fever and dengue haemorrhagic fever incidence	Nakhapakom et al	Intl Journal of Health Geographics	2005	English	A	A	A	A	A	A
CF2 Ref #53	The Climatic Factors Influencing The Occurance of Dengue Haemorrhagic Fever in Thailand	Suwich et al	Southeast Asian Journal of Tropical Medicine and Public Health	2005	English	A	A	A	B	A	A
CF3 Ref #55	Climatological Variables And The Incidence of Dengue Fever In Barbados	Depradine et al	International Journal of Environmental Realth Research	2004	English	A	B	A	B	A	A
CF4 ref #27	Climate, mosquito indices and the epidemiology of dengue fever in Trinidad (2002–2004)	D.D Chadee et al	Annals of Tropical Medicine & Parasitology	2007	English	A	A	A	A	A	A
CF5 Ref #28	An Outbreak Of Dengue Fever In Periurban Slums Of Chandigarh, India, With Special Reference To Entomological And Climatic Factors	R.K Ratho et al	Indian Journal of Medical Sciences	2005	English	A	A	A	B	A	A
CF6 Ref #13	Global Scale Relationships Between Climate And The Dengue Fever Vector ,Aedes Aegypti	Hopp et al		1998	English	A	A	A	A	B	A

CF8 Ref #29	Weather As An Effective Predictor For Occurrence Of Dengue Fever In Taiwan	Pei-Chih Wu et al	Acta Tropica	2007	English	A	A	A	A	A	A
CF8 Ref #30	Climatic And Social Risk Factors For Aedes Infestation In Rural Thailand	Nagao et al	Tropical Medicine and International Health	2003	English	A	A	A	A	A	A
CF9 Ref #40	Drought Associated Chikungunya Emergence Along Coastal East Africa	Chretien et al	The American Society of Tropical Medicine and Hygiene	2007	English	B	C	A	B	B	B
CF10 Ref #32	Eco-epidemiological Analysis Of Dengue Infection During An Outbreak Of Dengue Fever In India	Chakravarti et al	Virology Journal	2005	English	A	B	A	A	A	A
CF11 Ref #61	Factors Influencing The Population structure of Aedes aegypti from the main cities in Cambodia	C.Paupy et al	Heredity	2005	English	B	C	B	B	C	C
CF12 Ref #38	Short Communication: Impact Of Climate Variability On The Incidence Of Dengue in Mexico	M.Hurtado-Diaz et al	Tropical Medicine and International Health	2007	English	A	A	A	A	A	A
CF13 Ref #39	Nonstationary Influence Of El Nino on the Synchronous Dengue Epidemics in Thailand	Cazelles et al	PLoS MEDICINE	2005	English	A	A	A	A	A	A
CF14 Ref #34	Larval Occurrence and Climatic Factors Affecting DHF Incidence in Samui Islands,Thailand	S Wongkoon et al	Proceedings Of World Academy Of Science, Engineering And Technology	2007	English	A	A	A	B	A	A

CF15 Ref #37	Dengue fever epidemic potential as projected by general circulation models of global climate change.	Patz et al.	Environmental Health Perspectives	1998	English	A	A	B	A	A	A
CF16 Ref #41	Texas Lifestyle Limits Dengue Infection	Reiter et al	Emerging Infectious Diseases Online Journal	2003	English	A	B	B	B	B	B
CF17 Ref #35	Climatic Factors Associated With Epidemic Dengue in Palembang,Indonesia	Bangs et al	Southeast Asian Journal of Tropical Medicine and Public Health	2006	English	A	A	A	B	A	A

5.1 Findings

The papers selected highlighted the risk of Dengue incidence with climatic factors. After the final selection of papers included for this study it is interesting to see that there are 5 studies alone undertaken in Thailand itself. The other areas represented in this review are 2 studies from India, 2 Global studies and one each from Barbados, Trinidad, Mexico, USA, Kenya, Taiwan, Indonesia and Cambodia.

Most articles discussed climatic factors and Dengue where as 1 article described Chikungunya emergence and Drought. It was included as the vector Aedes Aegypti is common for spreading these two diseases and it was interesting to find the association between Drought and the principal vector.

The population studied was described in 10 articles while 7 articles did not describe the population.

The Study periods varied mostly from one year or less than one year(5 papers)to 3 years (1 paper),4 years(1 paper),5 years(2 papers),7 years(1 paper),8 years(1 paper)14 years(1 paper),15 years(1 paper) and 30 years(2 papers).

Dengue case numbers were measured in 1 article and incidence rate was described in 1 article.Vectoral indices like Breteau Index and Aedes House Index was measured in 5 articles and Container Index was measured in 3 articles. Larval density index was measured in 1 article.

Of the Climatic variables, Air temperature was measured in 15 articles, Rainfall was measured in 7 articles and Relative Humidity was measured in 5 articles, Precipitation in 3 articles and Vapour pressure in 1 article. The other variables measured concurrently with Dengue were Land Use, Land Cover, Solar Radiation, Sea Surface Temperature and Drought. One study also associated Noise while another study demonstrated the effects of herd immunity in reducing Incidence of Dengue cases.

Most studies carried out a retrospective method in carrying out the study and 4 studies implemented time series analysis as it provided a way to establish the relationship between changes of weather parameters, environmental factors and occurrence of infectious diseases which could be utilized for forecasting future changes according to model-based scenarios developed for different regions. (24, 25).

Most studies have been done in different geographical settings and the diversity of these studies at different time periods and location show factors that influence the incidence of Dengue with Climatic factors. Of the 17 articles reviewed, 15 articles found associations between climatic factors and Dengue incidence.1 article assumed there was an association.

The results of the studies selected are highlighted below in a table

Published Year	First Author	Study Period	Country	Main Results	Statistical method	Climate Variable	Dengue Variable
2005 Ref #36	Nakhapakom	1998	Thailand	Analysis of the climatic factors such as rainfall, temperature and humidity with the dengue incidences has revealed that dengue generally occurred when average temperature rose above normal as found during the El-nino in 1998. It also occurred when the rainfall was comparatively lower and humidity was higher than average.	Multiple Regression Analysis	Monthly rainfall, Temperature and Relative humidity	Incidence Rate
2005 Ref #53	Suwich	1978-1998	Thailand	Increase of Temperature was associated with a rise in the incidence of DHF in 9 provinces.Increased Rainfall was associated with decreased incidence of DHF in 7 provinces	TimeSeries Analysis	Monthly Rainfall, Monthly Average Temperature and Average Relative Humidity.	Incidence Rate
2004 Ref #55	Depradine	1995-2008	Barbados	Rainfall is an obvious primary factor in the incidence of dengue cases.Vapour pressure, which unlike the relative humidity, is a measure of the actual water vapour content of the atmosphere, has a stronger relationship with the incidence of the dengue cases.The maximum incidence occurs at an average temperature of 278C and at vapour pressures of (30 – 31) mb. This combination of meteorological variables would suggest that large outbreaks of dengue appear to depend on a combination of these variables	Cross Correlation	Rainfall, Temperature, Vapour Pressure, Relative Humidity and Wind Speed	Incidence Rate

2007 Ref #27	Chadee	2002-2004	Trinidad	Most (80%) of the DF cases recorded during the present study were reported during the rainy season when the BI for Ae. aegypti ranged between 20 and 46 —that is, four to nine times higher than the BI of 5 thought to represent the threshold for dengue transmission (Macdonald, 1956)	Chi Square	Rainfall, Temperature	Incidence Rate,Breteau Index
2005 Ref #28	Ratho	2002	India	High rainfall and humidity with the temperature range from 21*C to 33*C during the months of August and September *might have* favored the breeding of mosquitoes, thus leading to an increase in the number of dengue cases in October and November, 2002	Chi Square	Average Temperature,Rainfall and Humidity	Incidence Rate
2001 Ref #13	Hopp	Not Clear	Global Scale	Climate may affect the Aedes aegypti mosquito, the principal vector for yellow fever and dengue, since increasing global temperatures and other associated climate changes may modify the mosquito's geographic range	Model Based	Precipitation, Temperature, Relative Humidity and Solar Radiation.	Incidence Rate
2007 Ref #29	Pei-Chih Wu	1998-2003	Taiwan	Temperature and relative humidity have been found to be statistically associated with the incidence of Dengue fever.	Time Series Analysis	Temperature,Rainfall and Relative Humdidty	Incidence Rate

2003 Ref #30	Nagao	1994-1998	Thailand	The associations with the different temperature variables confirm that Aedes populations are generally favoured byhigher temperatures (shown by the positive relationship with minimum temperature), provided they do not exceedharmful upper limits (defined by the optimum maximum temperatures of 33.2–34.2 _C for the various entomological indices)	Multi Variate Analysis	Temperature and Precipitation	Breteay Index,House Index and Container Index
2007 Ref #40	Chretien	1995-2000	Kenya	Climatic effects particularly elevated temperature, on virus development in vector mosquitoes also could have enhanced transmission efficiency. Interestingly, Epidemic dengue-3 emergence in East Africa has also coincided with severe drought.	Not Specified	Rainfall Temperature	Incidence Rate
2005 Ref #32	Chakravarti	2005	India	An in-depth analysis of these three factors thus led to a proposal that optimum temperature with high relative humidity and abundant stocks of fresh water reservoirs generated due to rain, developed optimum conditions conducive for mass breeding and propagation of vector and transmission of the virus	Not Specified	Rainfall,Temperature and Relative Humidity	Incidence Rate
2005 Ref #61	Paupy	2001	Cambodia	Climatic factors such as rainfall are important in generating breeding sites. The severe and periodic rainfalls in Kampong Som (Sihanoukville) could fill containers, which accumulate at the vicinity of houses.. The abundance of breeding sites could enhance	Not Specified	Rough asumptions	Not defined well

				Ae.aegypti movement and genetic exchange and reduce genetic differentiation			
2007 Ref #38	Hurtado-Diaz	1995-2003	Mexico	This study shows that an increase in SST, minimum temperature and precipitation is associated with an increase of dengue transmission cycles in the coastal municipalities of the Gulf of Mexico.	Time Series Analysis	Temperature and Precipitation	Incidence Rate
2005 Ref #39	Cazelles	1983-1997	Thailand	In most countries, dengue is most prevalent in the wet season, yet on an interannual scale, dengue epidemics have also been associated with drought. In countries with high rainfall, drought can cause normally fast-flowing rivers to recede into a series of stagnant pools, ideal for mosquito breeding. Dengue and climate might be driven by temperature, rather than rainfall.	Wavelet Method	Temperature and Precipitation	Incidence Rate
2007 Ref #34	Woongkon	2006	Thailand	Warmer temperature increases DHF incidence in Samui,Thailand.l The transmission of dengue viruses is climatic sensitive for several reasons. First, temperature changes affect vector-borne disease transmission and epidemic potential by altering the vector's reproductive rate, biting rate, the extrinsic incubation period of the pathogen, by shifting a vector's geographical range or distribution and increasing or decreasing vectorpathogen- host interaction and thereby affecting host susceptibility. Second, precipitation affects adult female mosquito density. An increase in	Pearson Correlation Coefficient Test	Rainfall,Vapour Pressure,Relative Humidity,Temperature and Wind Speed.	House Index,Container Index Index and Breteau Index.

				the amount of rainfall leads to an increase in available breeding sites which, in turn, leads to an increase in the number of mosquitoes. An increase in the number of adult female mosquitoes increases the odds of a mosquito obtaining a pathogen and transmitting it to a second sensitive host.			
1998 Ref #37	Patz	Not Clear	Global Scale	Epidemic potential increased with a relatively small temperature rise, indicating that fewer mosquitoes would be necessary to maintain or spread dengue in a vulnerable population	Not Specified	Temperature	Incidence Rate
2003 Ref #41	Reiter	Not Clear	USA	If the current warming trend in world climates continues, air-conditioning may become even more prevalent in the United States, in which case, the probability of dengue transmission is likely to decrease due to Human behaviour of staying indoors and reduced efficacy of breeding of Aedes Aegypti Indoors when Air-conditioning provides a drier artificial atmosphere lowering their survival rate and the cool temperature extends the extrinsic incubation period, reducing the likelihood of transmission.	Multivariate Analysis	Temperarure	Breteau Index,House Index
2006 Ref #35	Bangs	1997-1998	Indonesia	Elevated temperatures contributed to the high incidence of Dengue Incidence.	Multivariate Analysis	Temperature	Breteau Index,House Index,Container Index

5.2 Relationship between Climatological Variables and Dengue

Based on the results interpreted from the review of literature of 17 articles, 13 studies found temperature having a significant association with Dengue Incidence.

Rainfall was found to contribute to Dengue Incidence in 6 studies and Relative Humidity was a contributing factor in 4 studies.

Precipitation was another factor closely associated with Dengue Incidence in 3 studies.

The other notable relationships found were Drought (1 study), Vapour Pressure (1 study), Solar radiation (1 study) and Sea Surface temperature (1 study).

Suwich et al. (2005) in their study in Thailand found that increase of Temperature was associated with a rise in the incidence of DHF in 9 provinces. They had analysed a time series model with trends, cyclical patterns and climatic variables. Here the figure below describes the temperature correlation.

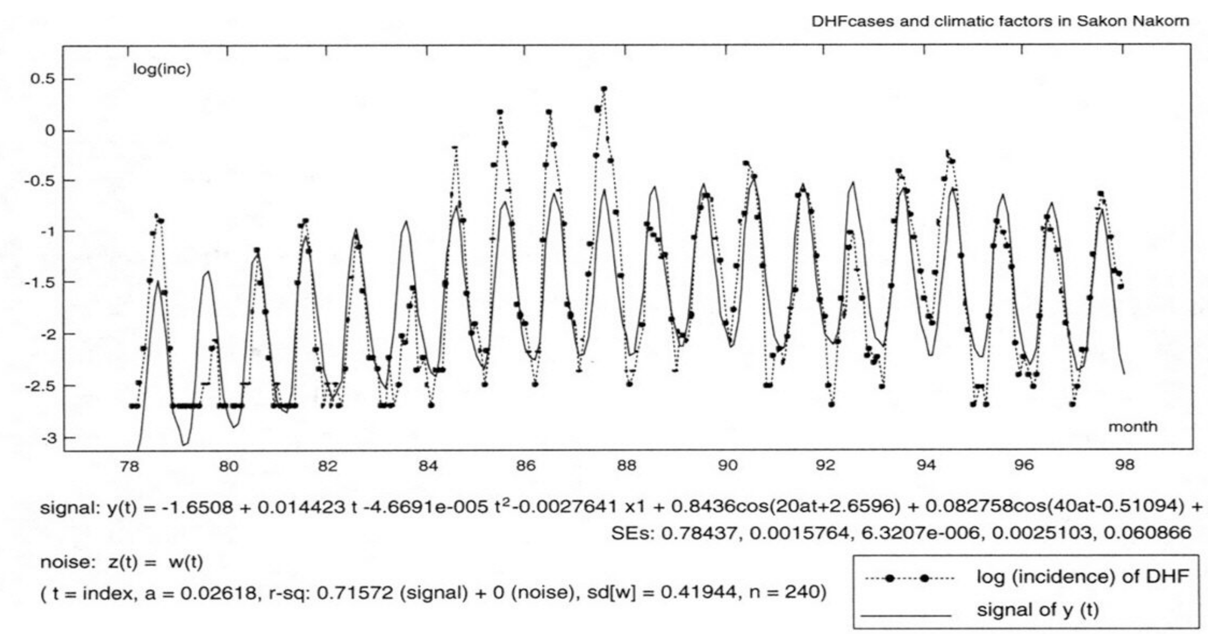


Fig 1.The model with trends, cyclical patterns and climatic variables (maximum temperature) Suwich et al. (2005) From: Suwich.2005. Climatic Factors Influencing The Occurance of Dengue Haemorrhagic Fever in Thailand. Southeast Asian Journal of Tropical Medicine and Public Health; Jan 2005; 36, 1;

Colin et al (2004) analysed climatological variables and Dengue incidence in Barbados and incurred that rainfall is an obvious primary factor in the incidence of dengue cases. The study also revealed Vapour pressure which unlike relative humidity is a measure of the actual water vapour content of the atmosphere has a stronger relationship with the incidence of the dengue cases (54). The maximum incidence occurs at an average temperature of 27C and at vapour pressures of 30 – 31 mb. This combination of meteorological variables suggested that large outbreaks of dengue appear to depend on a combination of these variables (54). The Figure below denotes the Percentage of Dengue Cases in relation to Vapour pressure and temperature during the study period from 1995-2000.

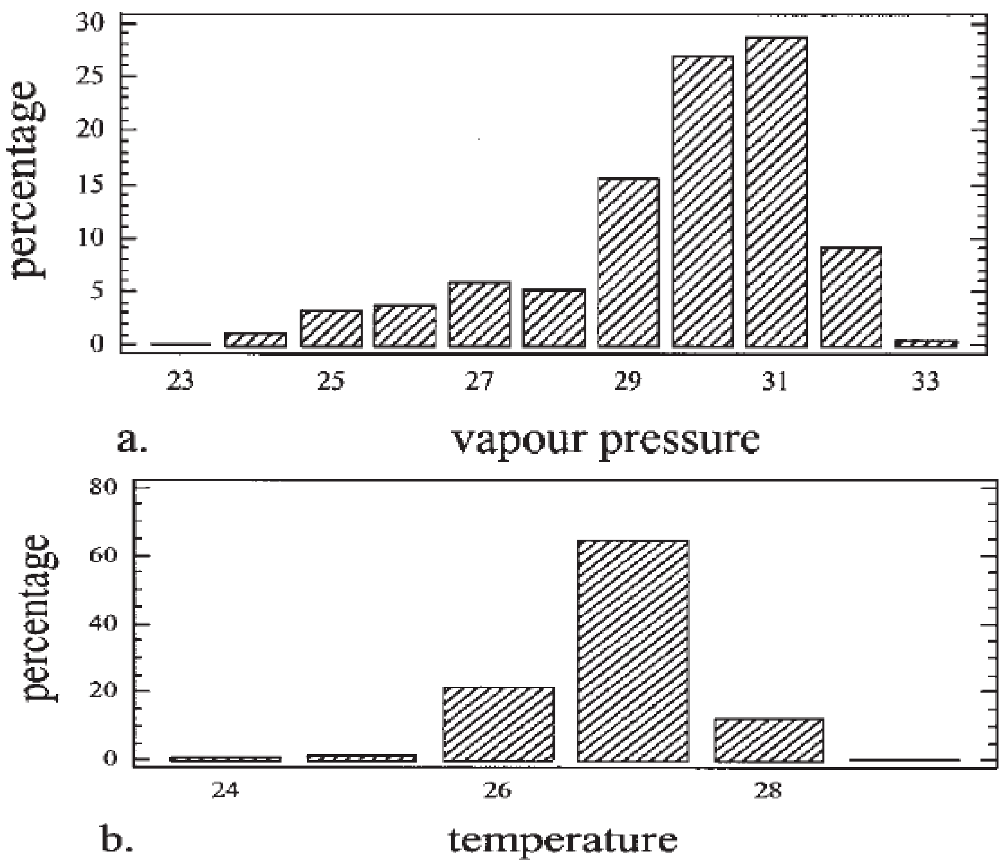


Fig. 2 Percentage of dengue cases occurring at (a) vapour pressures and (b) average temperatures for the period (1995 – 2000) in Barbados. (Colin et al 2004)
From: Colin A. Depardine and Ernest.H. Lovell.2004. Climatological variables and the incidence of Dengue fever in Barbados. International Journal of Environmental Health Research 14(6), 429 – 441

Chadee et al. (2007) in their study in Trinidad over a two year period using entomological indices of Aedes and climatic factors opined that around 80% of the Dengue Fever cases recorded during the study were reported during the rainy season when the Breteau Index for Aedes. *aegypti* ranged between 20 and 46 that is four to nine times higher than the Breteau Index of 5 thought to represent the threshold for dengue transmission (26).

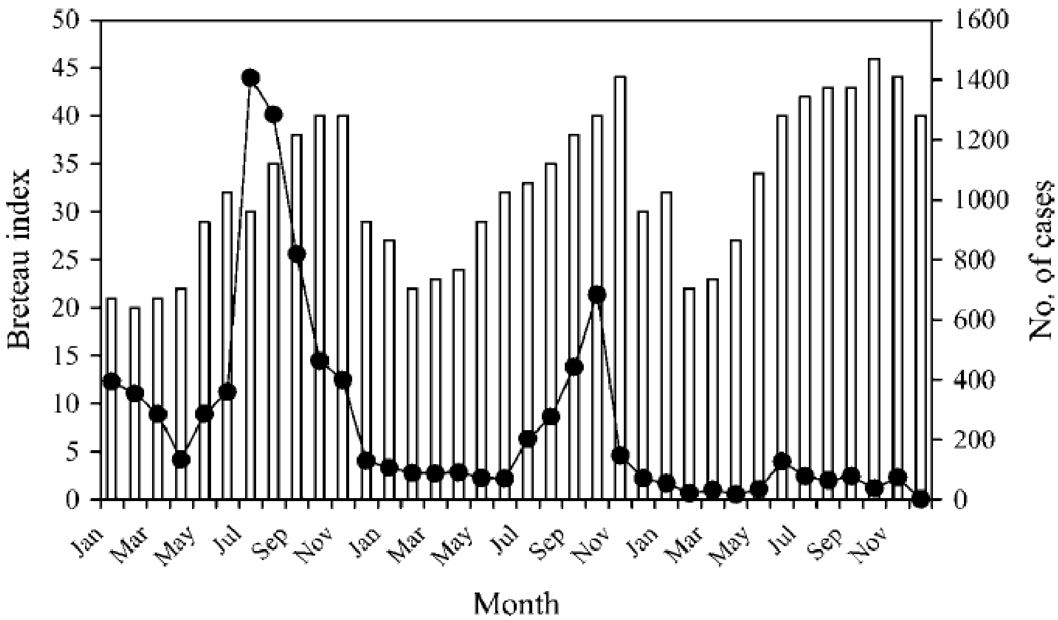


Fig.3 The monthly Breteau indices for Aedes aegypti (%) and numbers of cases of dengue fever (N) recorded in Trinidad between January 2002 and December 2004.
From: D. D. Chadee, B. Shivnauth, S. C. Rawlins and A. A. Chen,2007.Climate, mosquito indices and the epidemiology of dengue fever in Trinidad (2002–2004). Annals of Tropical Medicine & Parasitology, Vol. 101, No. 1, 69–77 (2007)

The majority of DF cases recorded in each study year i.e. 2002, 2003 and 2004 occurred during the rainy season, with incidence significantly higher during the months of June, July, August, September and October than at other times of the year. (27).

A study carried out in India by Ratho et al (2005) during the dengue epidemic outbreak in 2002 found that high rainfall and humidity with the temperature range from 21

Degrees C to 33 Degrees C during the months of August and September might have favored the breeding of mosquitoes, thus leading to an increase in the number of Dengue cases in October and November,2002(28) The Figure below shows the incidence of suspected dengue cases, mean atmospheric temperature, rainfall and humidity during the months of January to December in the epidemic year 2002.

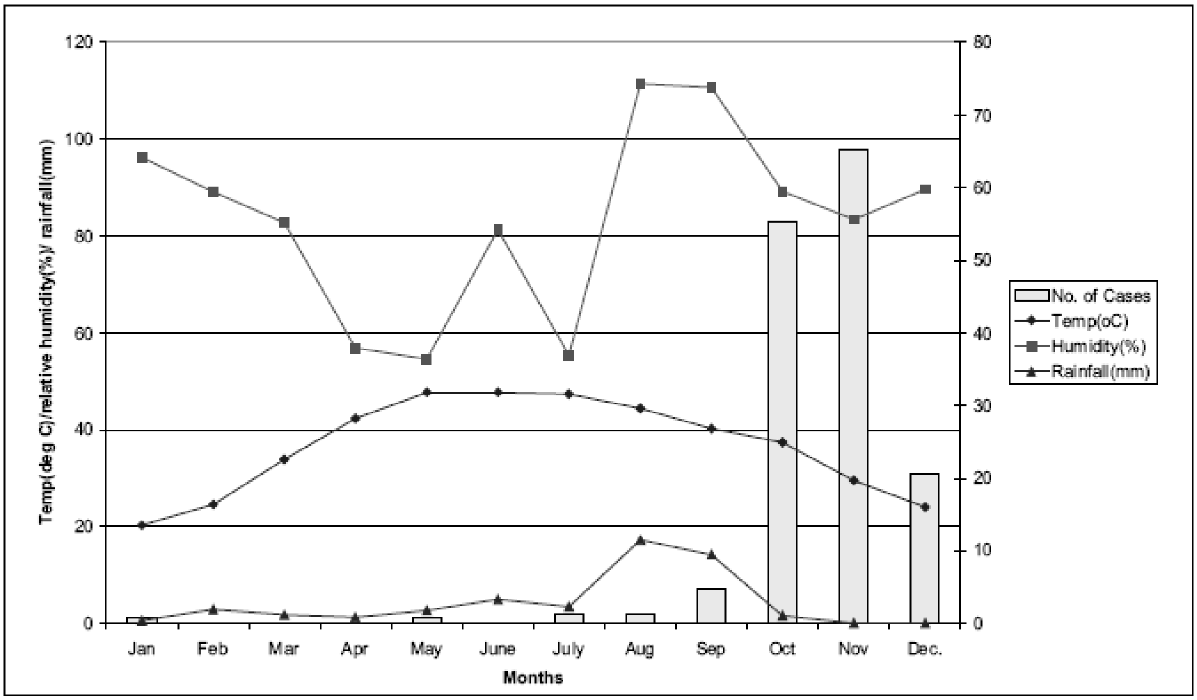


Fig.4 Dengue cases, mean atmospheric temperature, mean relative humidity and average seasonal rainfall during the months of Jan—Dec, 2002
From: R. K. Ratho, B. Mishra, J. Kaur, N. Kakkar, K. Sharma.2005. An Outbreak of Dengue Fever in Periurban Slums of Chandigarh, India, with Special Reference to Entomological and Climatic Factors.

The maximum number of patients was seen in October and November and when the mean maximum and minimum atmospheric temperatures were 29.4 degrees Celsius and 15.2 degrees Celsius respectively. The average rainfall and relative humidity during these months were 0.5% and 57.5% respectively. (28)

Pei Chi Wu et al (2007) in their study of weather as an effective predictor for the occurrence of Dengue fever in Taiwan observed that Temperature and relative humidity have been found to be statistically associated with the incidence of Dengue fever.

Weather Variables were measured with Incidence of Dengue fever using cross-correlations. The most significant associations, based on the value of *r*, for maximum monthly temperature ($r = 0.24$, $p < 0.05$), minimum monthly temperature ($r = 0.23$, $p < 0.05$), relative humidity ($r = 0.20$, $p < 0.05$), and monthly rainfall ($r = 0.18$, $p < 0.05$) were found at a lag of 2 months. (29)

Time-lag (months)	Maximum temperature	Minimum temperature	Relative humidity	Rainfall	Frequency of BI ≧ 5[a]
−5	0.072	0.051	−0.001	−0.018	−0.118
−4	0.161*	0.149	0.078	0.032	−0.050
−3	0.211*	0.200*	0.159*	0.142	−0.052
−2	0.239*	0.233*	0.202*	0.180*	−0.095
−1	0.205*	0.210*	0.169*	0.142	−0.140
0	0.099	0.099	0.010	0.006	−0.211

[a] Available monthly vector surveillance data (January 1998 to December 2003).
* Statistical significance.

Fig.5 Cross-correlation coefficients between climate variables, recovery of vector and incidence of Dengue Fever in Kaohsiung, Taiwan (July 1988-December 2003)
From: Pei-Chih Wu , How-Ran Guo, Shih-Chun Lung, Chuan-Yao Lin , Huey-Jen Su.2007, Weather as an effective predictor for occurrence of dengue fever in Taiwan. Acta Tropica 103 (2007) 50–57

Yoshiro et al (2003)in another study carried out in rural Thailand from 1994-1998 using atmospheric temperature and precipitation with Entomological Indices observed the associations with different temperature variables denote that Aedes populations are generally favoured by higher temperatures (shown by the positive relationship with minimum temperature), provided they do not exceed harmful upper limits (defined by the optimum maximum temperatures of 33.2–34.2 degrees Celsius for the various entomological indices)(30). Indices were positively associated with minimum temperature, and the increase in precipitation from 2 months to 1 month before. Differentiation of the expression combining the linear and quadratic temperature terms (31) indicated the various indices reached maximum at very similar temperature values: 33.2 degrees Celsius for House Index; 33.2 degrees Celsius for Container Index and 34.2 degrees Celsius for Breteau Index (30).

Anita et al(2005)analysed Rainfall, Temperature and Relative Humidity in an eco epidemiological analysis of Dengue infection during an outbreak of Dengue in India in 2005 and came to the conclusion that an in-depth analysis of these three factors led to a proposal that optimum temperature with high relative humidity and abundant stocks of fresh water reservoirs generated due to rain, developed optimum conditions conducive for mass breeding and propagation of vector and transmission of the virus.(32)

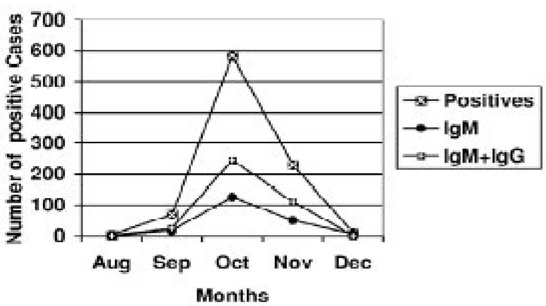
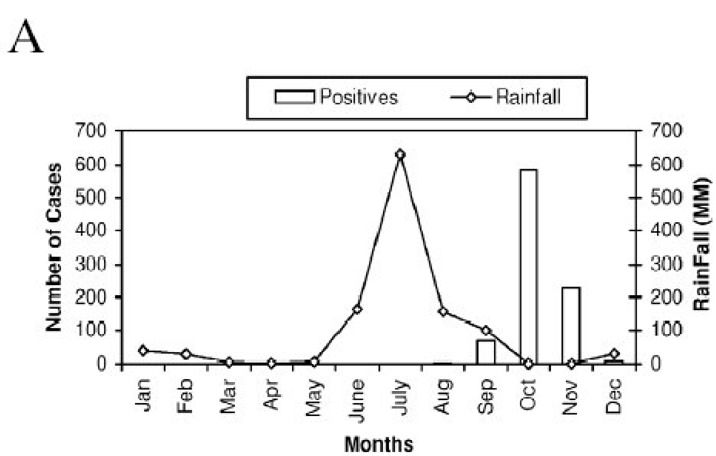
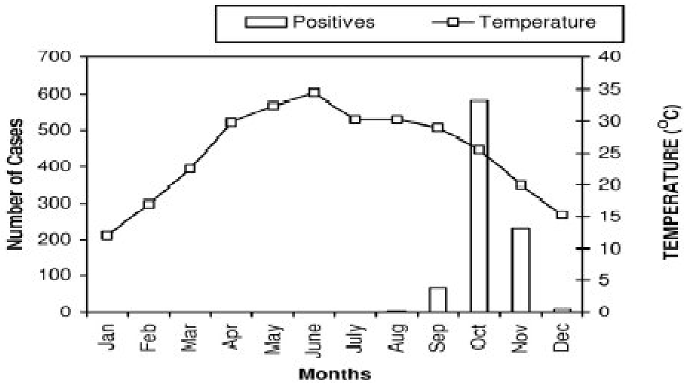


Fig.6 Month wise distribution of serogically positive cases during an outbreak in the year 2003.



B



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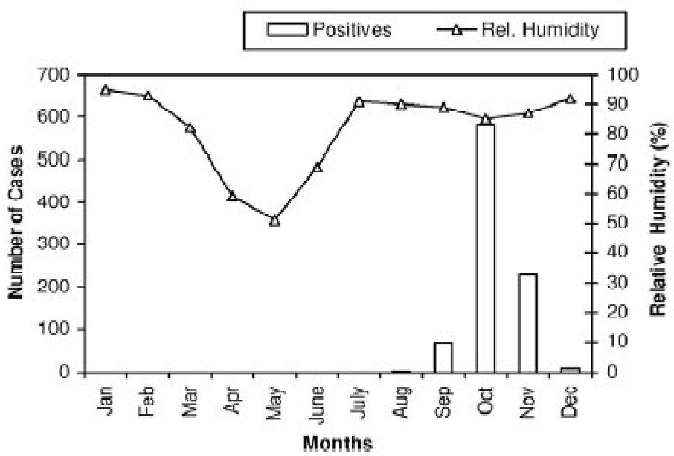

Fig 7A: Month wise distribution of serologically positive cases of dengue fever /dengue hemorrhagic fever and rainfall in Delhi for the year 2003 B: Month wise distribution of serologically positive cases of dengue fever /dengue hemorrhagic fever and temperature in Delhi for the year 2003 C: Month wise distribution of serologically positive cases of dengue fever /dengue hemorrhagic fever and relative humidity in Delhi for the year 2003

From: Anita Chakravarti and Rajni Kumaria.2005. Eco-epidemiological analysis of dengue infection during an outbreak of dengue fever, India. *Virology Journal* 2005, 2:3

Fig. 7A indicates that outbreak coincided mainly with the post monsoon period of subnormal rainfall (Cumulative rainfall = 30.3 mm) from October to December 2003 and was followed by relatively heavy rainfall during the monsoon period; from June to September 2003. The difference in the rainfall and temperature between three seasonal periods was found to be significant ($p < 0.05$) (Fig. 7A &7B). Mean ambient temperature was 25.4°C during the pre monsoon period, which increased to 30.9°C during the monsoon period; the period preceding the outbreak and decreased to 20.3°C (Mean temperature from October to December) in the actual outbreak months during the post monsoon period. The difference between relative humidity during the three periods was not significant. The mean relative humidity was 71.2% during the pre monsoon period. It increased during the monsoon period to 85% and increased further during the post monsoon period to 90% (Fig. 7C) (32).

Woongkon et al.2007 in their study showed warmer temperature increased the incidence of Dengue Fever in Samui, Islands, Thailand. The two figures below were used to justify and correlate the relationship during a period from 1999 to 2006(34).

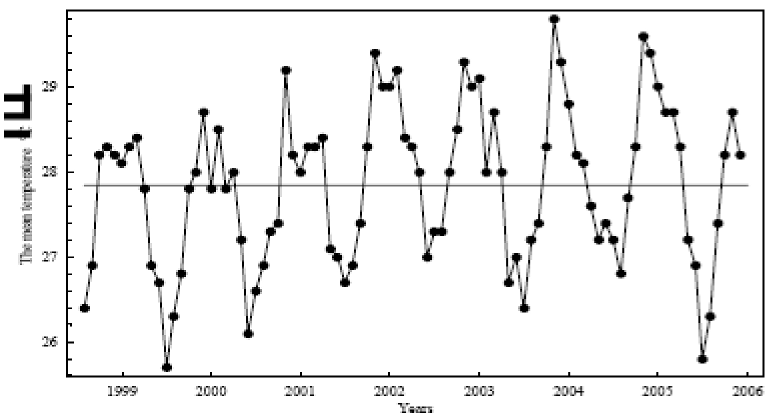

Fig 8.The mean temperature at Samui Islands from 1999-2006

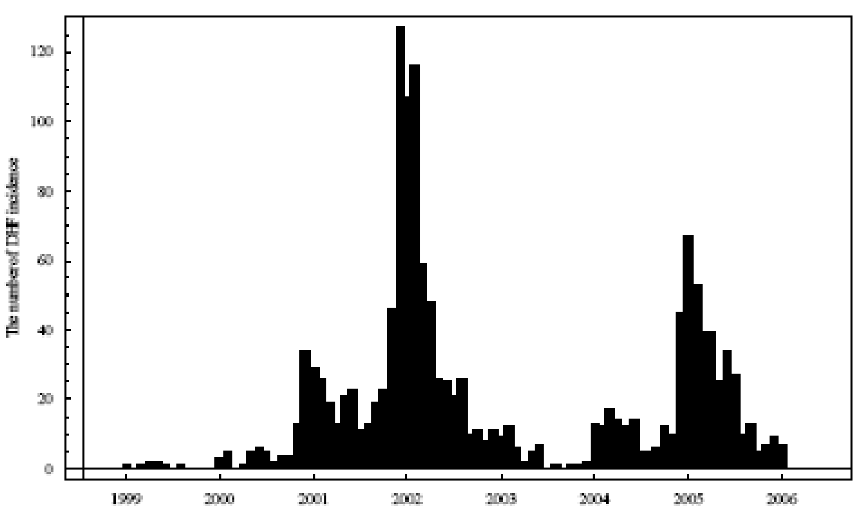

Fig 9.The number of monthly DHF incidences at Samui Islands from 1999–2006

Fig 8&9 From: S. Wongkoon, M. Jaroensutasinee, K. Jaroensutasinee, W. Preechaporn, and S. Chumkiew.2007. Larval Occurrence and Climatic Factors Affecting DHF Incidence in Samui Islands, Thailand. Proceedings of the world academy of science, engineering and technology, Volume 21, January 2007

The relationship between the mean temperature and the transmission of DHF at Samui Islands between 1999–2006 were shown in Fig. 8 and Fig. 9. Promprou *et al.* (33) studied climatic factors affecting DHF incidence in Southern Thailand and found that the significant variables were minimum temperature, the number of rainy days, and relative humidity on the Gulf of Thailand side. (34).

A study in Indonesia by Michael et al (2006) for a period of ten years from 1997-1998 comparing temperature with Larval indices found that elevated temperatures contributed to the high incidence of Dengue Incidence(35). Quarterly Aedes mosquito surveillance and control activities between April 1997 and September 1998 found variable combined House index measures ranging from 58% to 12.9%.The ENSO quarterly composite House index remained above 23% for all 4 epidemic quarter periods. The average ambient temperatures were above normal (+0.6-0.9 Degree Celsius) for the pre epidemic periods of August to November 1997 and remained above normal (+0.7-1.2 Degree Celsius) from December 1997 to April 1998(35).

An Information value based analysis of physical and climatic features affecting Dengue fever incidence studied by Kanchana et al (2005) in Thailand studied the climatic factors such as rainfall, temperature and humidity with the dengue incidence and revealed that dengue generally occurred when average temperature rose above normal as found during the El-Niño in 1998. It also occurred when the rainfall was comparatively lower and humidity was higher than average. (36). Multiple regression analysis is employed to develop an empirical model to predict the dengue incidences. The independent variables were used to predict changes in the dependent variable in the rainy and non-rainy seasons. Number of peoples affected by DF/DHF was used as the dependent variable and the rainfall(R), temperature (T) and relative humidity (H) were considered as the independent variables (36). Multiple regression analysis was carried out for each of the observations of the occurrence of DF/DHF cases and monthly climatic data of 5 years (1997–2001) as shown in the graph in Figure below:

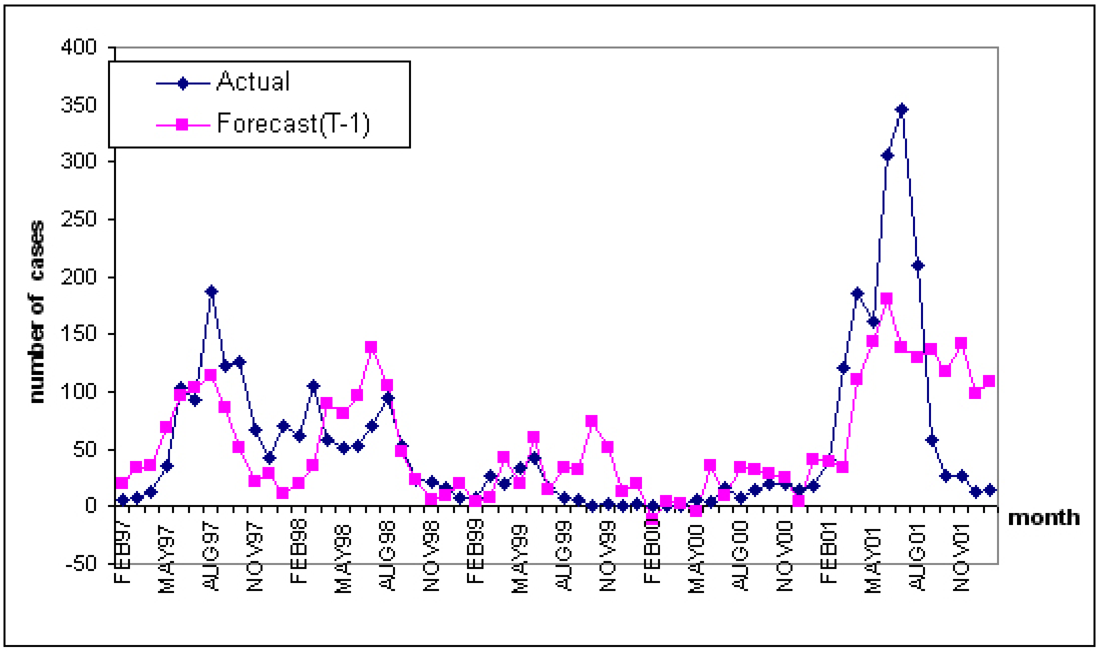

Fig 10. Relationship between actual and forecasted Dengue cases in Sukothai, Thailand.
From: Kanchana Nakhapakorn and Nitin Kumar Tripathi.2005. An information value based analysis of physical and climatic factors affecting dengue fever and dengue haemorrhagic fever incidence. *International Journal of Health Geographics* 2005, 4:13

Marianne et al (2001) studied Global scale relationships between climate and the dengue vector Aedes aegypti analyzing Precipitation, Temperature, Relative Humidity and Solar Radiation data on a global scale model and found that Climate may affect the Aedes aegypti mosquito, the principal vector for yellow fever and dengue, since increasing global temperatures and other associated climate changes may modify the mosquito's geographic range (13).

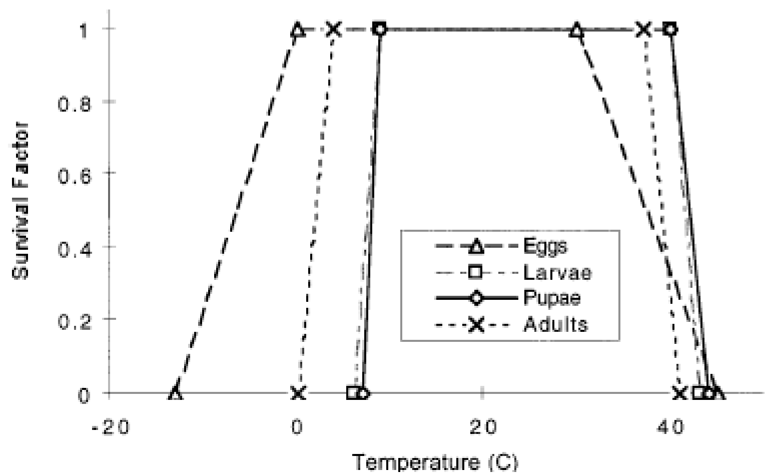

Fig 11. Temperature dependent survivorship for the life stages of Aedes Aegypti Mosquito.
From: Marianne J. Hopp and Jonathan A. Foley (2001) Global-Scale relationships between climate and the dengue fever vector Aedes Aegypti , Climatic Change, Volume 48, Numbers 2-3

Another Global scale Study Conducted by Patz et al (1998) looked at temperature and Dengue incidence rate and designed a global epidemic potential model .They found that the epidemic potential increased with a relatively small temperature rise, indicating that fewer mosquitoes would be necessary to maintain or spread dengue in a vulnerable population(37). Figure 12 describes the assumptions used in developing a Global Epidemic Potential Model and Fig 13 describes the annual Epidemic Potential in (A)Bangkok, Thailand;(B)San Juan, Puerto Rico;(C)Mexico City, Mexico;(D)Athens, Greece and (E) Philadelphia,Pensylvania.

Table 1. Assumptions used in the Dengue Epidemic Potential Model

Parameter (temperature dependent)	Default value	Contributing factors	Reference
Mosquito survival probability	0.89/day[a]	Temperature, humidity, and food availability	(26,49–51)
EIP	6–39 days	Very temperature dependent. Based on temperature-dependent enzyme kinetic model	(12,52,53)
Probability of mosquito infected from viremic human blood meal	0.45	Viral titer in blood meal[b] (viral titer contributes to EIP)	(12,20)
Biting rate on humans, based on:			
Duration gonotropic cycle	74–250 hr[c]	Very temperature dependent. Based on blood meal digestion rate at 25°C determined by enzyme kinetics model	(42,54–56)
Number blood meals per cycle	1.1–2.0	Inversely related to female wet weight and directly related to larval development rate, e.g., faster development yields smaller adults[d]	(16,57)
Alternate host per feeding attempt	2.8 persons[e]	Based on four attempts per replete feed × 0.6 probability of different human host per attempt	(20)
Blood meals	90% human	*Aedes aegypti* is extremely homophilic	(58)

EIP, extrinsic incubation period.
[a]Within the viable temperature range of 6°C and 40°C (16,59).
[b]Assumes infectious period of host to approximate 5 days (3,47).
[c]Subsequent cycles are only 0.58 duration of first cycle (25).
[d]Adult female wet weight derived from multiplying larval weight by 1.655 (16).
[e]Calculated as 1.0, for first human encounter, plus three more attempts with 0.6 probability of bitting different human host each time.

Fig 12.Assumptions used in Dengue Epidemic Potential Model

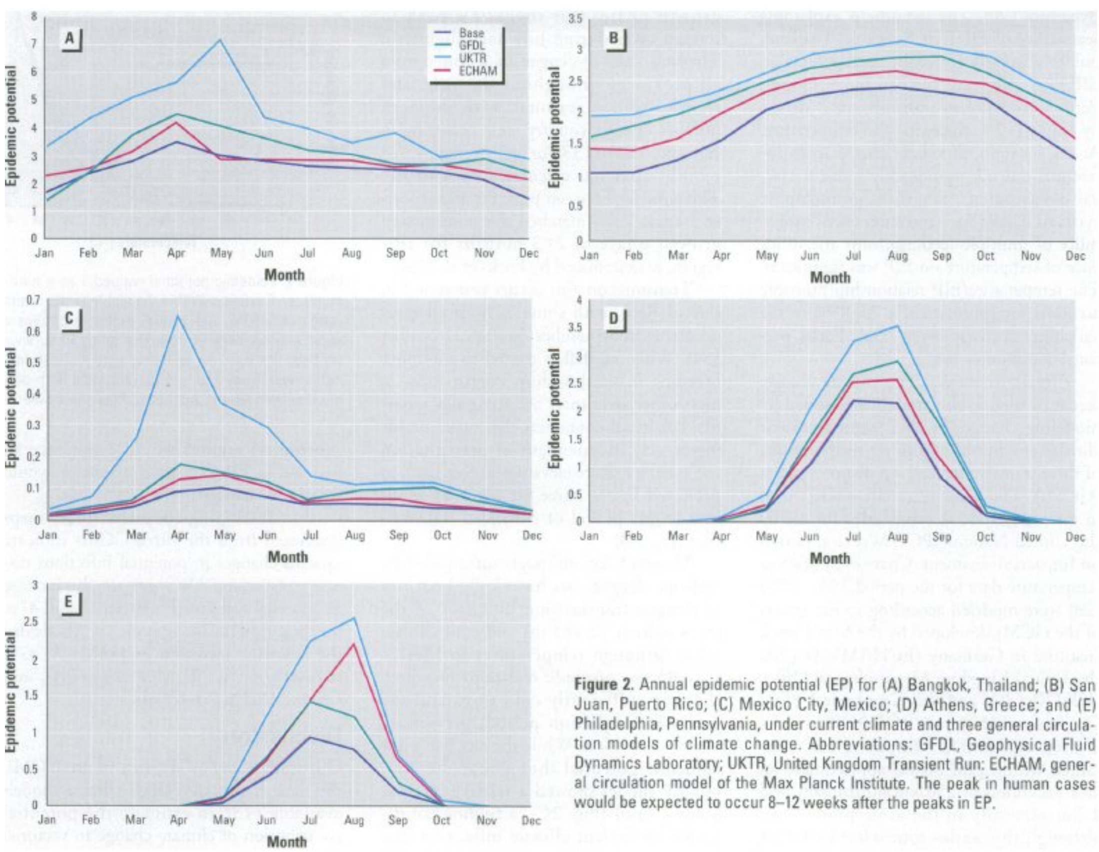

Figure 2. Annual epidemic potential (EP) for (A) Bangkok, Thailand; (B) San Juan, Puerto Rico; (C) Mexico City, Mexico; (D) Athens, Greece; and (E) Philadelphia, Pennsylvania, under current climate and three general circulation models of climate change. Abbreviations: GFDL, Geophysical Fluid Dynamics Laboratory; UKTR, United Kingdom Transient Run: ECHAM, general circulation model of the Max Planck Institute. The peak in human cases would be expected to occur 8–12 weeks after the peaks in EP.

Fig 13.Annual Epidemic Potential in various Cities based on the Model
Fig 12&13 From: Jonathan A. Patz, Willem J.M. Martens, Dana A. Focks, and Theo H. Jettend.1998. Dengue Fever Epidemic Potential as Projected by General Circulation Models of Global Climate Change. Environmental Health Perspectives * Volume 06, Number 3, March 1998

The study addresses transmission potential of a given mosquito population size. Epidemic Potential is sensitive to temperature and is derived directly from vectorial capacity equations to determine the efficacy by which a given number of mosquitoes can transmit dengue, maintaining endemic transmission (37).

Hurtado Diaz et al. (2005) studied the impact of climate variability on the incidence of Dengue in Mexico from 1995-2003 using temperature and precipitation in relation to Dengue incidence and highlighted that an increase in sea surface temperature, minimum temperature and precipitation is associated with an increase of Dengue transmission cycles in the coastal municipalities of the Gulf of Mexico. In San André's Tuxtla, adjusted auto-regressive models (Table 1) showed that the weekly number of dengue cases – with a lag of 16 weeks – increased by 46% for every increase of 1 degree C of SST; by 3.8% for every increase of 1 degree C in minimum temperature during the same week; and by 1.3% for every increase of 1 cm of precipitation with a lag of 2 weeks. In Veracruz, the number of dengue cases – with a lag of 20 weeks – increased by 42% for every 1 degree C increase in SST; by 4.8% for every 1 degree C increase in minimum temperature the same week; and by 2.1% increase of cases for every 1 cm of precipitation with a lag of 3 weeks (38).

Climate variable	San Andrés Tuxtla β 95% CI	Veracruz β 95% CI
Minimum temperature (°C)	0.044 (0.003, 0.084)	0.058 (0.018, 0.098)
Precipitation (cm)*	0.022 (0.001, 0.038)	0.022 (0.008, 0.037)
Sea surface temperature (°C)†	0.510 (0.247, 0.774)	0.453 (0.184, 0.723)
Population‡	0.179 (−0.963, 1.321)	0.110 (−0.072, 0.292)
Constant	−16.08 (−34.10, 1.95)	−16.93 (−28.809, −5.068)
AR(1)§	0.450 (0.373, 0.528)	0.397 (0.303, 0.490)
AR(2)§	0.226 (0.147, 0.305)	0.341 (0.247, 0.435)
AR(3)§	0.087 (0.006, 0.169)	0.083 (−0.012, 0.178)

CI, confidence interval.
*Lags of 2 and 3 weeks for San Andrés Tuxtla and Veracruz, respectively.
†Lags of 16 and 20 weeks for San Andrés Tuxtla and Veracruz, respectively.
‡Rate per 10 000 inhabitants.
§AR(n) Autoregressive terms with a lag of n weeks.

Table: Adjusted coefficients between natural logarithm of weekly Dengue cases in climate,weather and population variables,San Andres Tuxtla and Vera Cruz Municipalities ,1995-2003.

From: M. Hurtado-Dı´az, H. Riojas-Rodrı´guez, S. J. Rothenberg, H. Gomez-Dante´s and E. Cifuentes.2007. Short communication: Impact of climate variability on the incidence of dengue in Mexico. Tropical Medicine and International Health. Volume 12 no 11 pp 1327–1337 November 2007.

Bernard et al. (2005) pointed out that drought too indeed had some role to play in Vector dynamics as countries with high rainfall; drought can cause normally fast-flowing rivers to recede into a series of stagnant pools, ideal for mosquito breeding. Dengue and climate might be driven by temperature, rather than rainfall (39).

Jean Paul et al. (2007) did a study on Aedes Aegypti in Kenya from 1995-2000 and observed that climatic effects particularly elevated temperature, on virus development in vector mosquitoes also could have enhanced transmission efficiency. Interestingly, Epidemic dengue-3 emergence in East Africa has also coincided with severe drought (40).

6. Discussion

The risk of Dengue infection is beset by a number of factors. The role of climatic factors influencing an outbreak have been analysed by the authors and described. Various methods have been utilized to ascertain this association and the study settings and study periods have been diverse.

Kanchana et al. (2005) employed a spatial relationship model in Thailand (for e.g. conditional analysis) to see the probabilistic relationship between relevant factors affecting Dengue and Environmental factors before employing statistical methods. This helped to explore the influencing factors in an epidemic of Dengue (36).

6.1 Vector Biology

The first line of operation is to look at the vector biology cycle to understand the different stages of mosquito development and the influence of temperature or other climatic factors on its development process.

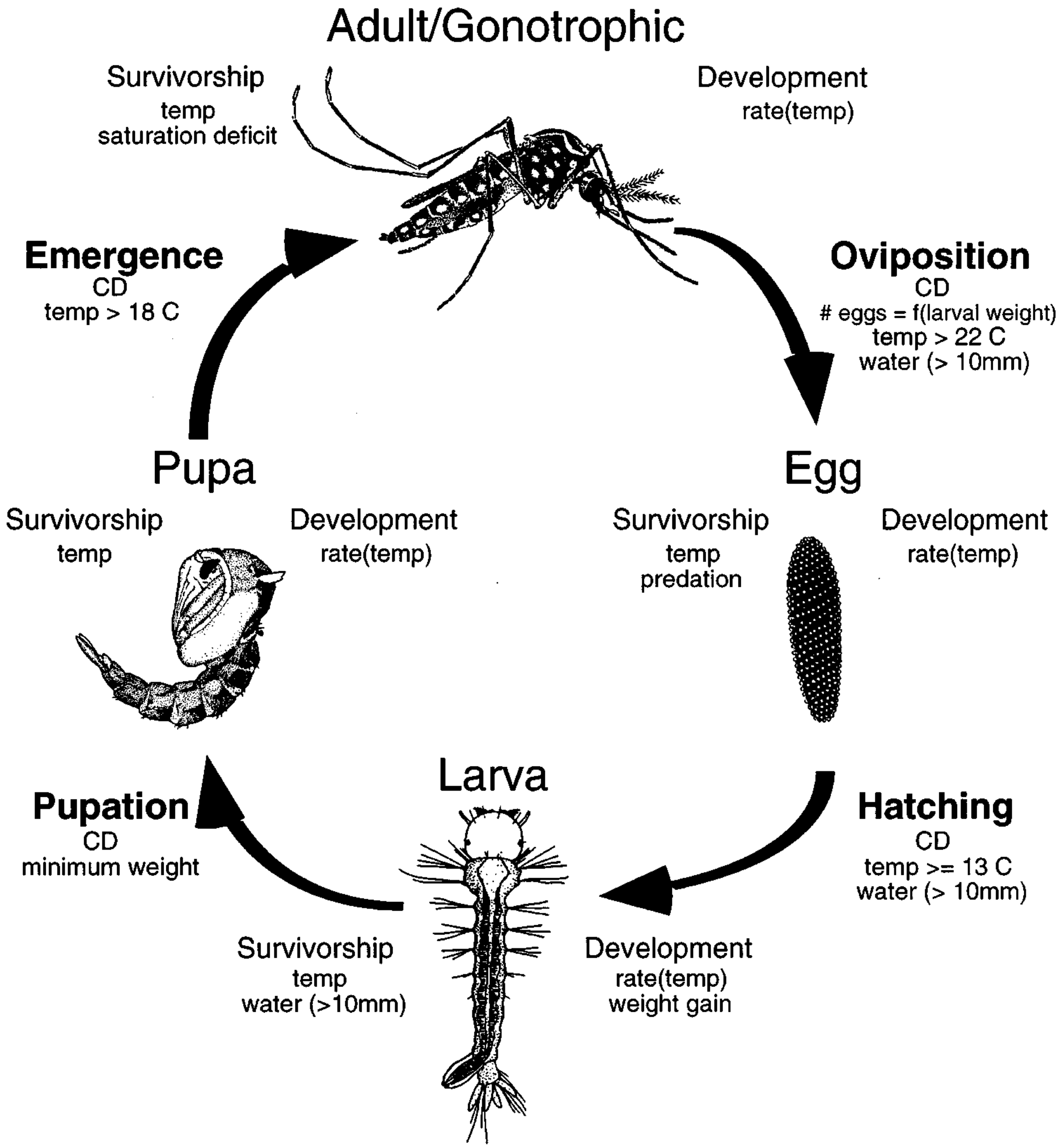

Fig.14.Development rate and Survivorship calculation stages

From: Marianne J. Hopp and Jonathan A. Foley (2001) Global-Scale relationships between climate and the dengue fever vector Aedes Aegypti , Climatic Change, Volume 48, Numbers 2-3

At every stage there is temperature dependent gradient present to allow proper development of the egg from to adult mosquito. One study calculated each day the rate of development and survivorship. It is proven by Christopher et al. (1968) that Survivorship and development requirements are life stage-dependent. Metamorphosis is dependent on daily cumulative development (CD) and other life stage-specific factor (42).

The female mosquito has an average lifespan of about 8–15 days and it can fly for about 30–50 m per day on an average. That shows that on a rough estimate the female mosquito would travel around 240–600 m range in its lifetime (43).

The development period from egg to human disease shows a time lag of about one month that leads to Dengue Fever or Dengue Haemorrhagic Fever and the cases occur during 7 – 45 days. The duration of larvae stages to adult is 7 to 12 days and the lifespan of for female mosquito is about 8 to 15 days (44).In the meantime, the virus develops in the mosquito for a period of 8–10 days. When a person gets infected with fever, the infection has a high probability of being widely disseminated to other people. The virus usually is found in the serum, plasma, circulating blood cells and in selected tissues, especially those of the immune system, for approximately 2–7 days, roughly corresponding to the period of fever (36).Thus it can be deduced that if there was a case discovered in June, there was already enough virus circulation happening around a month before and other factors like vector life cycle and virus development has to be delved deeper into for any control.

6.2 Vector Habitat and Extent

Breeding foci are good habitats for the Aedes *aegypt*i larvae to grow .There are two types namely primary and secondary breeding foci. During the pre monsoon period, the mosquitoes depend on the primary breeding foci as the mother foci to grow. Discarded tires, desert coolers, containers which collect fresh water during the monsoon period then serve as secondary foci for the Aedes aegypti larvae to grow then (32).

A method employed in Thailand if Dengue is present is Buffering operation. It is carried out to determine extended neighborhood of place of occurrence. Buffers are created to specify distance of the point pattern of disease from urban/ village locations and to identify the geographic environment conditions such as land cover, water bodies, surrounding village affected by DHF. The buffer distance is considered owing to two factors: flight distance covered during the life span and average distance travelled per day by the Aede*s aegypti* mosquito (36).

6.3 Virus Development in the Mosquito

Research has indicated that extrinsic incubation period and viral development rate can be shortened with higher temperature and therefore increase the proportion of mosquitoes becoming infective at a given time (45). The transmission of dengue viruses is climatic sensitive for several reasons. Temperature changes affect vector-borne disease transmission and epidemic potential by altering the vector’s reproductive rate, biting rate, the extrinsic incubation period of the pathogen, by shifting a vector’s geographical range or distribution and increasing or decreasing vector pathogen- host interaction and thereby affecting host susceptibility(46).

6.4 Temperature and Dengue

Atmospheric Temperature was the most mentioned factor to influence Dengue Infections in 13 Papers. This can be explained by the effect of warmer temperature which can increase the transmission rates of DHF in various ways. Warmer temperature may allow vectors to survive and reach maturity much faster than at a lower temperature (47). Warmer temperature can also reduce the size of mosquito larvae resulting in smaller adults that have high metabolism rates and they require more frequent blood meals and need to lay eggs more often (34).Environmental temperature has a marked effect on the length and efficiency of the extrinsic incubation periods (EIPs) of arboviruses in their vectors (47). Mosquitoes exposed to higher temperature after ingestion of virus become infectious more rapidly than mosquitoes of the same species which are exposed to lower temperatures (47). Thus, the transmission of arboviruses may increase under warmer conditions as more vector mosquitoes become infectious within their life-span. Higher temperature may reduce the length of viral extrinsic incubation periods (EIPs) in mosquitoes (48-50). At 30 °C, the duration of dengue virus EIPs is 12 days, compared with only 7 days at 32–35 °C (51).

Even a 5–day decrease in the duration of the incubation period can triple the transmission rate of Dengue (52).

The epidemic potential increases with a relatively small temperature rise, so fewer mosquitoes would be necessary to maintain or spread dengue in a vulnerable population (34).

6.5 Rainfall and Dengue

Rainfall was seen to contribute as a major factor in 6 of the papers discussed. Rainfall may increase the breeding sites of Aedes particularly outside the house. An increase in the amount of rainfall leads to an increase in available breeding sites which, in turn, leads to an increase in the number of mosquitoes. An increase in the number of adult female mosquitoes increases the odds of a mosquito obtaining a pathogen and transmitting it to a second sensitive host (34).They complete their lifecycles in water and then hatch into adult mosquitoes, increasing the density of mosquitoes. Mosquito density is positively correlated to rainfall with the relationship being more marked in the dry season (53).

The onset of the rainy season increases the Aedes population rather than the peak of the rainy season. This can be due to the fact that when the water levels rise, the eggs of Aedes laid on the inner surfaces of water containers hatch (30, 56).This can be observed in Thailand where the number of Dengue cases generally rise after one month after the rains start and Aedes populations increase during the first half rather than the latter half of the rainy season (30, 57).

6.6 Relative Humidity and Dengue

The review highlighted 4 studies that positively correlated Relative Humidity with Dengue Incidence. Relative humidity is a crucial factor affecting the life pattern of mosquitoes, such as mating and oviposition.Being Hygroscopic in nature, Aedes *Aegypt*i tend to follow an “annual pulsation” route where they move to mother foci like central parts of cities which are humid during the dry season and spread out during the wet season (60).The combined effects of heat and moisture would significantly influence the feeding patterns of mosquitoes and how they attract each other (29).Rising humidity generally increases vector survival rate, and therefore prolonging the time allowing for them to feed effectively on an infective host (54).

6.7 Vapour pressure and Dengue

Vapour pressure was found to be related in 3 papers reviewed. Vapour pressure, which unlike the relative humidity, is a measure of the actual water vapour content of the atmosphere and has a stronger relationship with the incidence of the dengue cases. The maximum incidence occurs at an average temperature of 278C and at vapour pressures of 30 – 31mb. This combination of meteorological variables would suggest that large outbreaks of dengue appear to depend on a combination of these variables (55).

6.8 Precipitation and Dengue

Precipitation occurs when the water vapour content in the atmosphere is condensed and it produces rain, sleet or drizzle. Three studies found precipitation to be a factor influencing Dengue incidence. Precipitation affects adult female mosquito density by increasing the breeding sites necessary for possible multiplication by rainfall and thereby increasing mosquito population (34).

6.9 Combination of Temperature, Rainfall and Humidity

In a tropical setting like India temperature tends to decrease towards the end of monsoon period and remains moreover constant during the later months of rainy season. India and Bangladesh fall in the deciduous, dry and wet climatic zone (32). The average temperature tends to remain high during the period before monsoon. Then it is continuous rainfall for a few days that bring the temperature down when the monsoon starts and that in turn increases the relative humidity and decreases the evaporation rate. Secondary reservoirs come up containing rain water thus increasing breeding pools (32).

6.10 Other Factors

Drought was an interesting variable observed and was postulated. Droughts happen when there is a period of prolonged dry weather in an area where a normal rainfall is expected. The amount of water can be less in the area due to a variety of factors like prolonged episodes of low or less than adequate rainfall, over usage or groundwater depletion In countries with high rainfall, drought can cause normally fast-flowing rivers to recede into a series of stagnant pools, ideal for mosquito breeding(39,58). A study in Kenya by Jean-Paul et al (2007) found that during the drought epidemics, there was emergence of Dengue 3 virus also along with elevated temperatures (40).

There were a number of positive contributions of the authors from the different articles positively correlating the relationship of climatic variables with Dengue Incidence. Also there were other interesting findings that drew light on different perspectives of other factors and their direct impacts on Dengue.

For e.g. the study done by Paul et al. (2003) in Texas border of United States with Mexico, an arid area found that it was the lifestyle adopted in this county that limited the transmission of Dengue Infection. Their opinion was that the probability of dengue transmission is likely to decrease due to Human behaviour of staying indoors and reduced efficacy of breeding of Aedes *Aegypti* Indoors when Air-conditioning provides a drier artificial atmosphere lowering their survival rate and the cool temperature extends the extrinsic incubation period, reducing the likelihood of transmission (41).

The study by Chadee et al. (2007) in Trinidad found the outbreak to fade away after a brief surge due to the presence of herd immunity in the population, effective vector control and a decline in the numbers of vectors due to natural mortality (27).This can be attributed to the small size of the country and less demanding resource management in such a small setting.

6.11 Limitations

This study evaluated 17 papers and a number of limitations did come up. During the initial search, there were numerous studies undertaken in Brazil but unfortunately most of these papers were published in Portuguese and could not be included.Due to the heterogeneity of the articles in this work in terms of study setting, geographical locations, different statistical methods, variables and indices used, a meta-analysis using statistical tests could not be carried out.

Another factor was the competent vector of Dengue Fever., Aedes a*lbopictus*.It is mainly an outdoor breeder and almost all the articles included in this study did not mention the role of Aedes *albopictus*, neither in development stages, vector surveillance, control or relationships with Dengue Incidence. In USA, it has been shown to replace Aedes

Aegypti populations due to a combination of various factors like sterility of the offspring from interspecific mating, Decreased viability of Aedes *aegypti* from parasites brought in with Aedes.*albopictus* and dominance of Aedes*.albopictus* in larval resource competition (59).

There are a number of other factors like socio cultural, ecological and vector control that have parallel relationships with an epidemic but these were not taken into account as the primary aim of this study was to look into the climatic factors only.

7. Conclusion

This study has given an insight into a variety of climatological factors that can influence a Dengue epidemic. The consistent view of most authors is the role of Temperature and Rainfall. Some studies assessed Relative humidity, Precipitation and Vapour pressure gradient and the association of these variables with Dengue incidence is noted.

Temperature can alter mosquito incubation, viral replication and biting frequency. An increased precipitation leads to increased rainfall.Rainfall accelerates and increases breeding habitats.Humdity influences mating, oviposition thus influencing feeding frequency and vector survival rate.

It can be important to foresee the emergence of Dengue epidemics in new parts of the world due to changing climatic conditions. Episodes of heat waves, cyclones, droughts are a recurring phenomena now.With warmer temperatures' setting in cooler climatic regions and higher altitudes the risk of Aedes proliferation is profound.

If a model is simulated over an area where there is enough warm temperature to accelerate a Drought phenomenon, the oncoming rainy season would bring the factors namely precipitation, vapour pressure along with relative humidity. It would be a perfect setting for Aedes to propagate and mature and if a Dengue Virus Serotype is present, an impending epidemic can set in.

The eggs of Aedes are Drought resistant and can survive even a period of one year in receptacles that previously held water. Overseas ocean vessels or transport planes from Dengue endemic areas carrying cargo can be infested with eggs deposited in tiny vesicles of containers or discarded tires. They harbour a potential risk in spreading the disease to various parts of the world, where previously it was not found. Introduction of different serotypes in a country where there are rapid transport systems and cargo liners coming from all over the world pose a disease outbreak hazard.

Even industrialized countries can have the potential impact of a Dengue epidemic like Australia where there is severe Drought phenomenon every year now. The government subsidises water tank installations in households to beat the scarcity of water. These tanks are perfect reservoirs for these eggs to be laid and hatched over a definite time when conditions are conducive for breeding of the Aedes mosquito and a Dengue virus serotype introduction on these populations can prolong and propagate a severe epidemic.

The risk of Dengue infection is increasing and an understanding of the changes in climatic variables more than normal should be taken into account when developing early warning systems and assessing epidemic potential in detail all over the world.

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