EFFECT OF ADULT MOSQUITO CONTROL ON DENGUE PREVALENCE IN A MULTI-PATCH SETTING: A CASE STUDY IN KOLKATA (2014–2015)

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DENGUE

- Dengue is a fast emerging vector borne disease mainly prevalent in tropical and sub tropical countries.

- Caused by dengue virus (DENV) which is transmitted by *Aedes* mosquito.

- Four distinct but closely related serotypes of the virus: **DEN-1, DEN-2, DEN-3, DEN-4.**

Aedes aegypti
(Courtsey: Wikipedia)

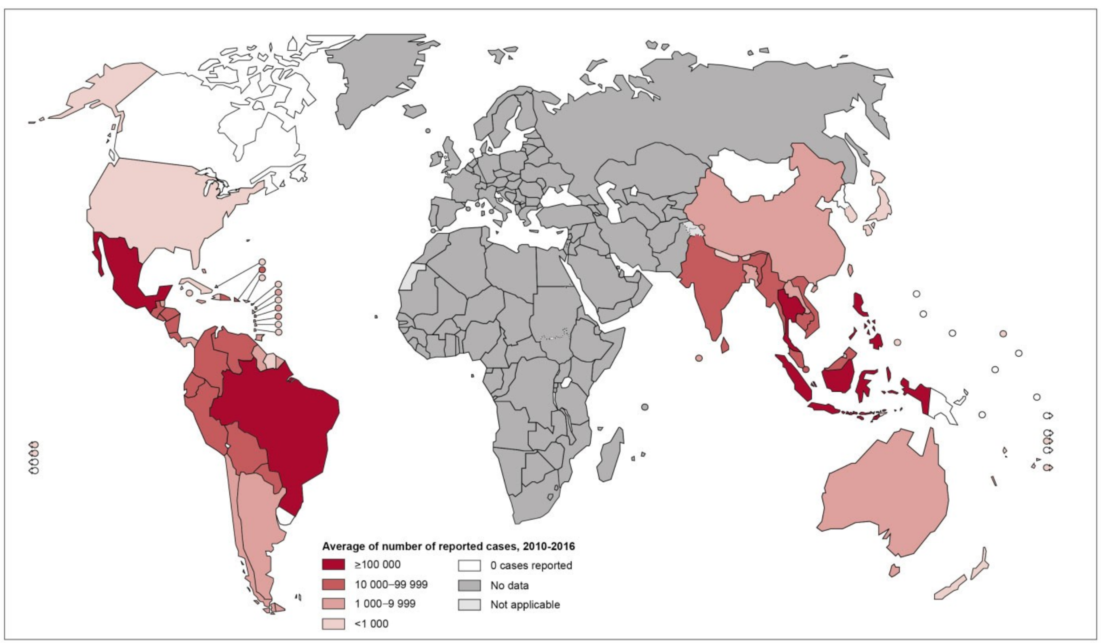
Nearly 3.9 billion people in 128 countries are at risk of infection.
PloS Negl. Trop. Dis. (2012)

In 2017, a provisional total of 1,88,401 cases has been reported all over India
(NVBDCP)

Global Burden of Dengue

- **50 – 100 million** Dengue infections occur annually.

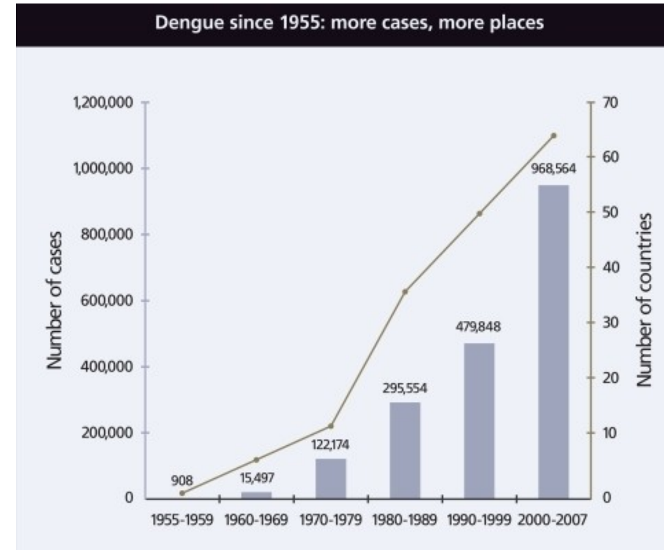
Distribution of dengue, worldwide, 2016



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Control of Neglected Tropical Diseases (NTD)
World Health Organization

Courtsey: WHO



Courtsey: WHO

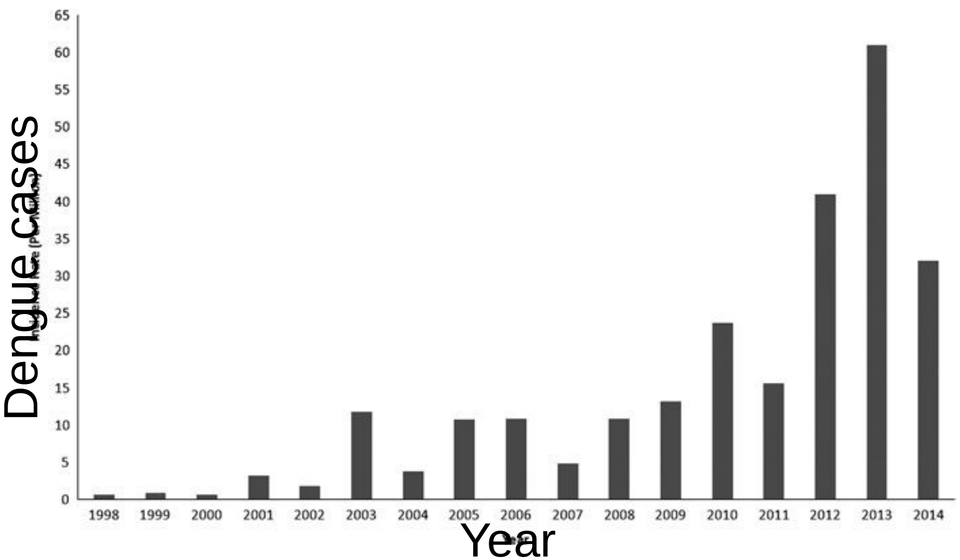
- The number of dengue outbreaks between 1990 − 2015 is 262: **India** (58), **China** (38) and **Brazil**(24).
- **112** outbreaks occurred after 2010.
- **291964** outbreak associated cases had been reported till 2016.

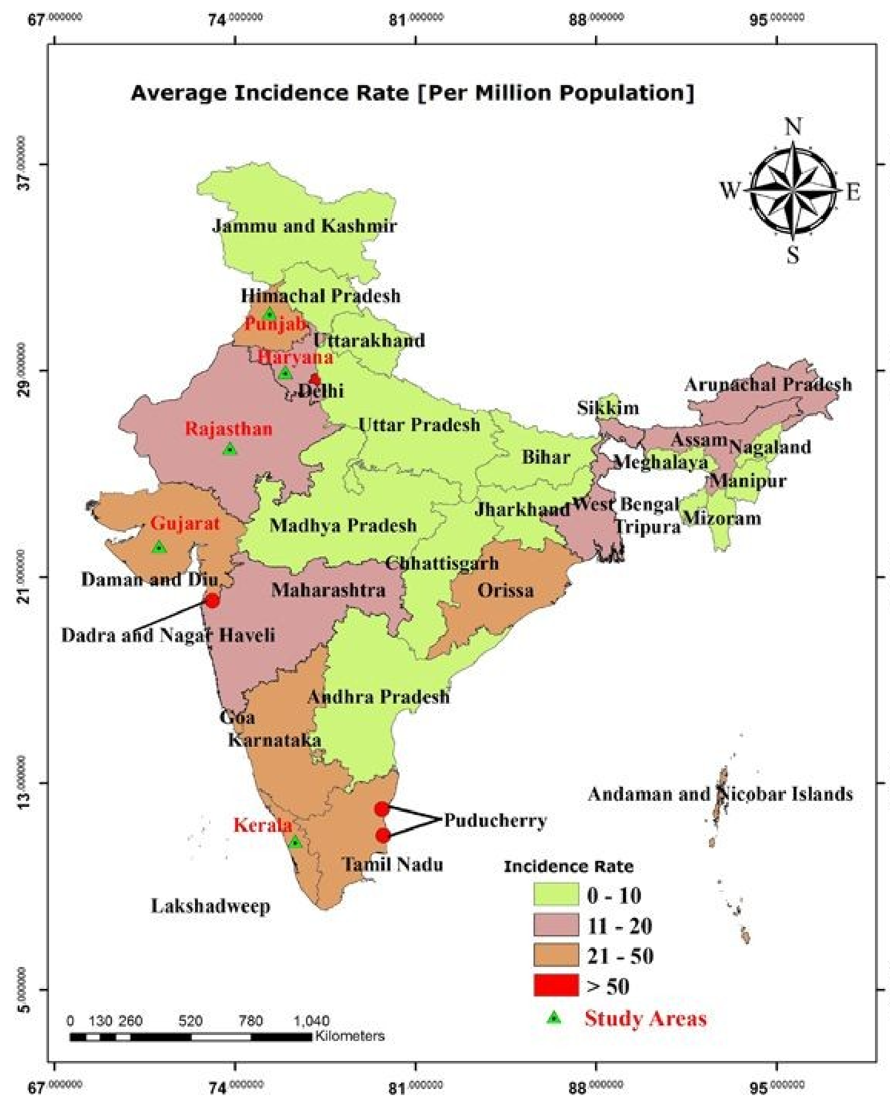
Nature (2013), Front Cell Infect Microbiol. (2017)

Situation In India

- 1998–2009 : **82,327** cases (incidence: **6.34** per million population) were reported.
- 2010–2014: **213,607** cases (incidence: **34.81** per million population) of dengue fever were observed.

The highest incidence reported : **Pondicherry (372.92)**, followed by **Dadra Nagar Haveli (176.31)** and **Delhi (102.15).**





Emerg Microbes Infect. (2017)

Modeling In Spatial Setting

- Variability in different **epidemiological** and **entomological** factors of dengue across geographical locations.
- Dengue transmission mechanism **:** human and mosquito both infect each other.
- Human mobility **accelerates** the disease propagation.
- This can be captured by so called **Metapopulation models.**

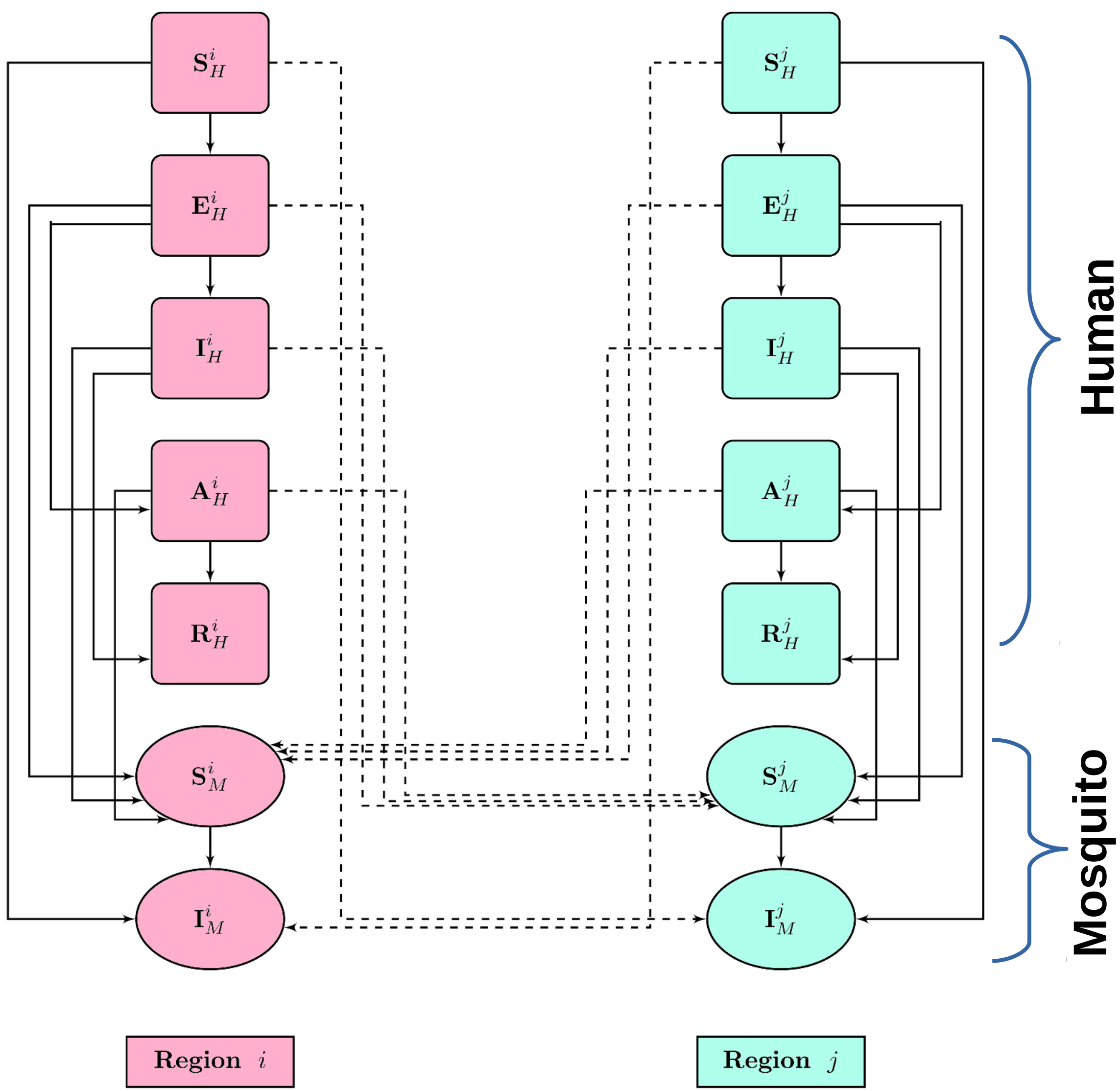
- *Stoddard et. al.*

Space is divided into discrete regions (**patch**) connected through **human migration.**

- *Levin et al. (1993) (Patch Dynamics)*
- *Arino (2009) (Diseases in metapopulations)*

- Consider the **control specific characteristics** of available vector controls.
- **Efficiency** of different mosquito control strategies in spatial setup.
- **Role of spatial coupling** in the effectiveness of the controls.

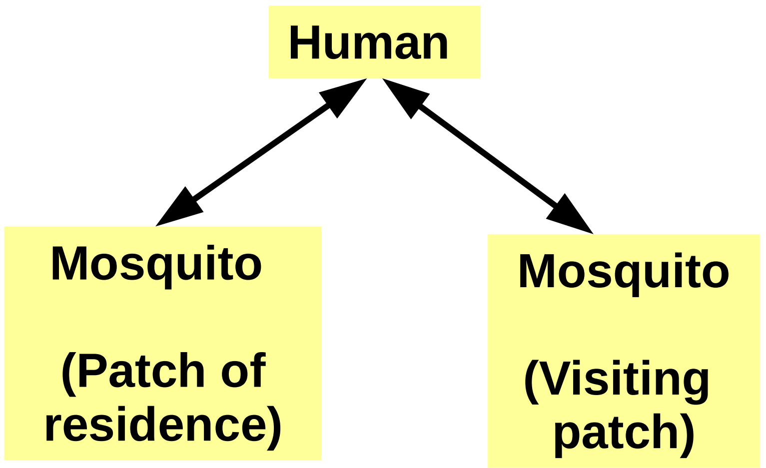
Schematic Of The Model



Human: Susceptible (S^i_H)
Exposed (E^i_H)
Infected (I^i_H)
Asymptomatic (A^i_H)
Recovered (R^i_H)

Mosquito: Susceptible (S^i_M)
Infected (I^i_M)

Patches are connected through human migration



MODEL

$$
\begin{aligned}
\frac{dS_H^i}{dt} &= \mu_H H^i - \beta_H S_H^i \left(\frac{b_i(t)}{H^i} I_M^i + \sum_{\substack{j=1\\ j\neq i}}^{n} \theta \frac{\hat{H}^i \hat{H}^j}{d_{ij}^{\alpha}} \frac{b_j(t)}{H^j} I_M^j \right) - \mu_H S_H^i, \\
\frac{dE_H^i}{dt} &= \beta_H S_H^i \left(\frac{b_i(t)}{H^i} I_M^i + \sum_{\substack{j=1\\ j\neq i}}^{n} \theta \frac{\hat{H}^i \hat{H}^j}{d_{ij}^{\alpha}} \frac{b_j(t)}{H^j} I_M^j \right) - (\sigma_H + \mu_H) E_H^i, \\
\frac{dI_H^i}{dt} &= p\sigma_H E_H^i - (\mu_H + \gamma_H) I_H^i, \\
\frac{dA_H^i}{dt} &= (1-p)\sigma_H E_H^i - (\mu_H + \gamma_H) A_H^i, \\
\frac{dR_H^i}{dt} &= \gamma_H (I_H^i + A_H^i) - \mu_H R_H^i, \\
\frac{dS_M^i}{dt} &= \Pi_M^i - b_i(t)\beta_M S_M^i \left(\boxed{\frac{(I_H^i + \eta_1 E_H^i + \eta_2 A_H^i)}{H^i} + \sum_{\substack{j=1\\ j\neq i}}^{n} \theta \frac{\hat{H}^i \hat{H}^j}{d_{ij}^{\alpha}} \frac{(I_H^j + \eta_1 E_H^j + \eta_2 A_H^j)}{H^i}} \right) - \mu_M S_M^i, \\
\frac{dI_M^i}{dt} &= b_i(t)\beta_M S_M^i \left(\frac{(I_H^i + \eta_1 E_H^i + \eta_2 A_H^i)}{H^i} + \sum_{\substack{j=1\\ j\neq i}}^{n} \theta \frac{\hat{H}^i \hat{H}^j}{d_{ij}^{\alpha}} \frac{(I_H^j + \eta_1 E_H^j + \eta_2 A_H^j)}{H^i} \right) - \mu_M I_M^i,
\end{aligned}
$$

Gravity-like function

$$\epsilon_{ij} = \theta \frac{\hat{H}^i \hat{H}^j}{d_{ij}^{\alpha}}.$$

Periodic biting rate

$$b_i(t) = b_{0i}\left(1 - \delta_i cos\left(\frac{2\pi t}{12}\right)\right).$$

Force of infection

Within Patch

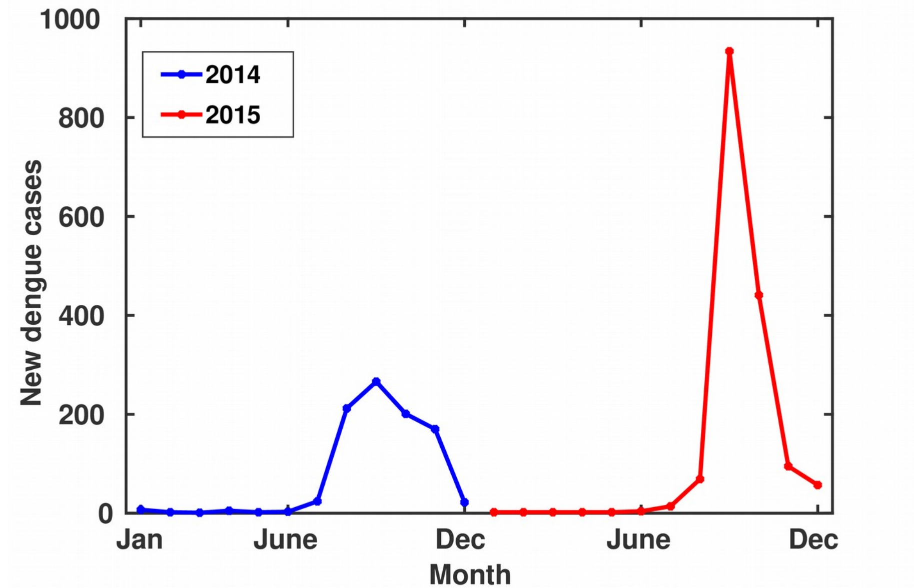
Remaining Patches

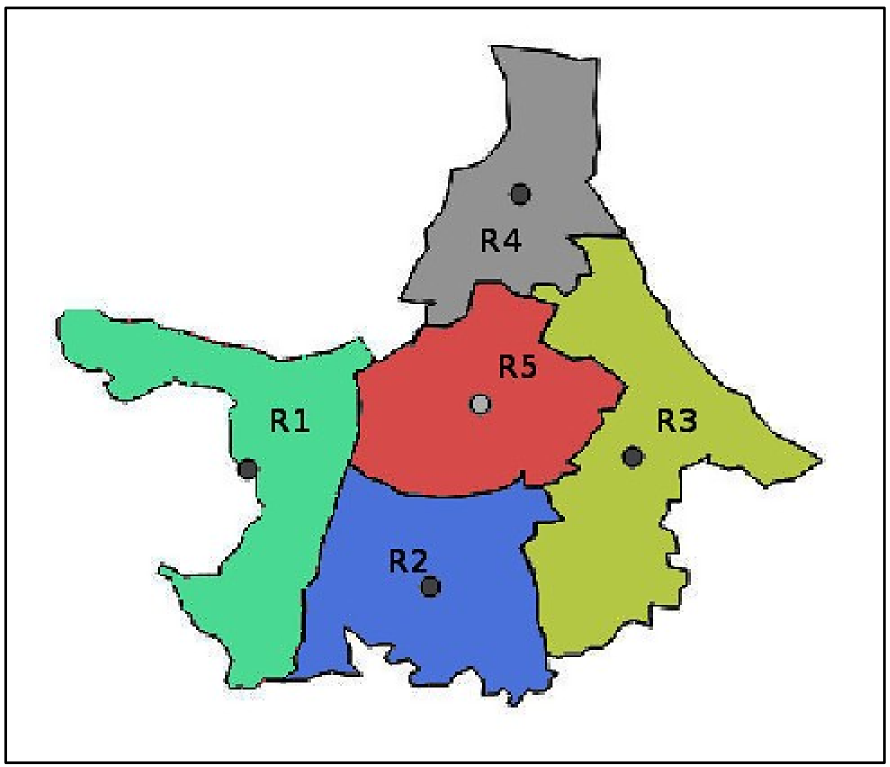
List Of Parameters

Parameters	Description	Value	Reference
μ_H	Birth/death rate of human population	$0.0143 - 0.0167 \quad year^{-1}$	Pinho et al.
Π_M^i	Recruitment rate of mosquito	$\mu_M(S_M^i(0) + E_M^i(0) + I_M^i(0))$	Sardar et al.
μ_M	Mortality rate of female mosquitoes	$0.6 - 7.5 \quad month^{-1}$	Sardar et al.
b_{0i}	Average bite per mosquito per month in patch i	Estimated	-
β_H	Transmission probability from mosquito to human	$0.1 - 1$	Sardar et al.
β_M	Transmission probability from human to mosquito	$0.5 - 1$	Sardar et al.
p	Fraction of exposed human move to dengue infected class	Estimated	-
η_1	Modification parameter	Estimated	-
η_2	Modification parameter	Estimated	-
γ_H	Recovery rate from dengue infection	$2.14 - 10 \quad month^{-1}$	Sardar et al.
σ_H	Intrinsic incubation rate	$2.1410 \quad month^{-1}$	Pinho et al.
d_{ij}	Distance between the centroids of patch i and patch j	-	
θ	Scaling parameter	Estimated	-
α	Power that determines the strength of the dependence of migration rate on distance	Estimated	-
$\hat{H}_i$	Human population density in patch i	-	-

CASE STUDY : KOLKATA

- **Kolkata** faced many dengue outbreaks in recent times.
- The dengue situation of Kolkata during the period ***2014 – 2015*** is considered.



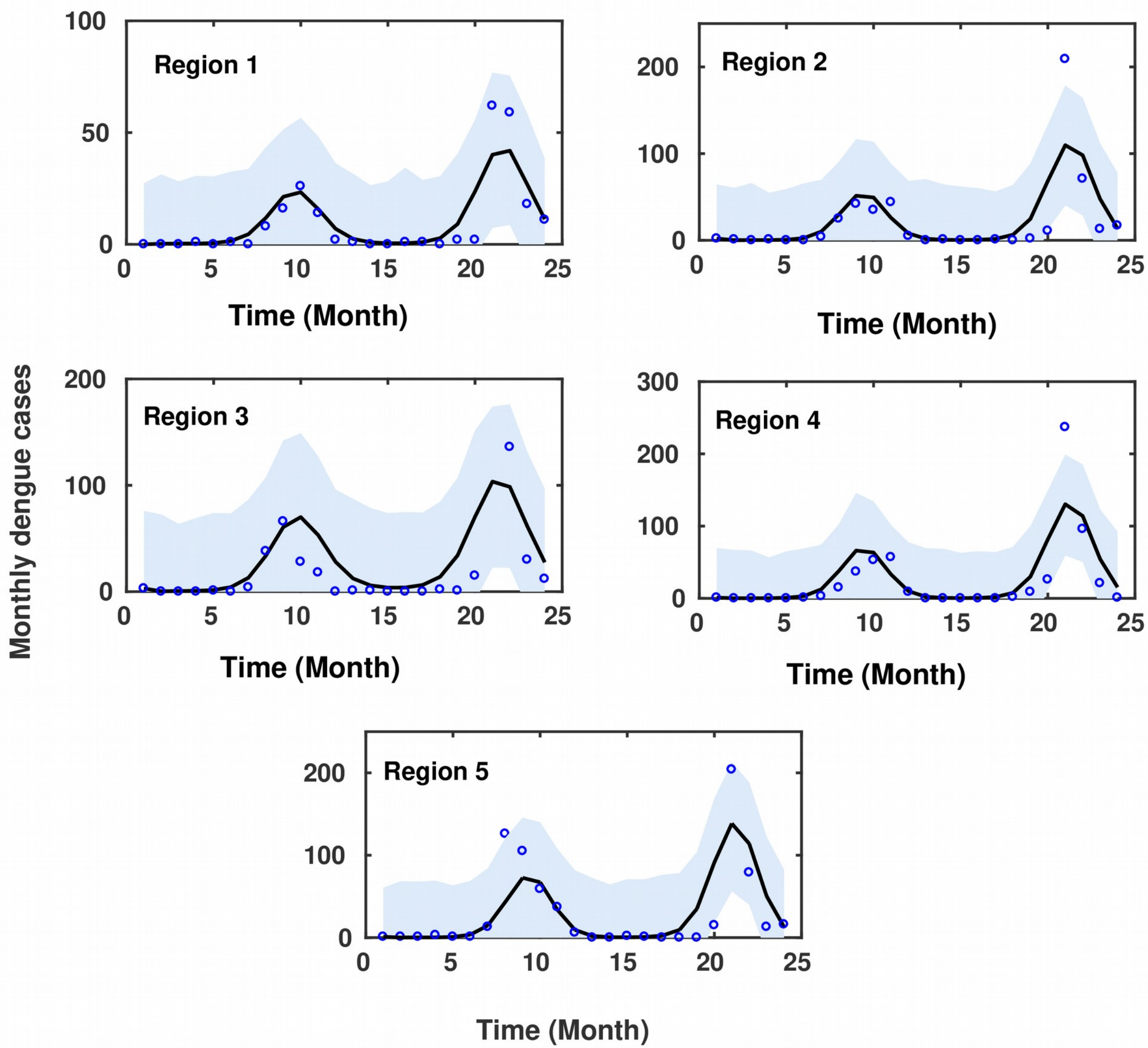


- Monthly dengue cases data are collected from Kolkata Municipal Corporation (KMC) for 141 wards.
- Depending on the geographical location 141 wards grouped into **5** regions :

R1(West) R2(South) R3(East)

R4(North) R5(Cental)

Model Fitting



New dengue cases for j^{th} region

$$N^j(t,\hat{\theta}) = \int_{t-1}^{t} p\sigma_H E_H^j(\tau)d\tau, \quad j = 1,2,...,5.$$

The sum of square function

$$SS_j(\hat{\theta}) = \sum_{k=1}^{T}[N^j(t_k) - N^j(t_k,\hat{\theta})]^2, \quad j = 1,2,...,5.$$

Solid line: Model solution
Blue circle: Data point

ADULT MOSQUITO CONTROL

The adult mosquito control strategy performs better than larval control especially in the situation where a faster depletion in disease prevalence is required.
Epidemiol. Infect. (2009)

Interventions	Efficacy	Env. Persistence.
ULV spray (C1)	90%	1 day
Treated surface (C2)	25%	180 days
Lethal ovitrap (C3)	25%	120 days

ULTRA LOW VOLUME (ULV) SPRAY

A small amount of insecticides are used to create cold fog droplets using ULV cold fogging machine.

TREATMENT WITH INSECTICIDE

Windows and door curtains, water container etc. in households are treated with insecticides to avoid the contact of adult mosquito.

LETHAL OVITRAPS

Black in colour and are filled with water and very small amount of lethal substances which kill the mosquito.

Application Of Vector Control

Controls are applied for **one year (beginning of 2nd year) only** to the regions only where :

Case fraction > Population fraction

Region	Case fraction	Population fraction
Region 1	0.074	0.140
Region 2	0.173	0.323
Region 3	**0.172**	**0.112**
Region 4	0.192	0.231
Region 5	**0.386**	**0.192**

Efficiency of **seven** intervention settings (by **combining** the above said controls) are studied in **reducing disease prevalence.**

Additional death rate due to the application

$$
\begin{aligned}
d_i(t) &= \kappa_i\left(1 - \frac{t^2}{T_i^2}\right), \; for\ 0 \le t \le T_i \\
&= 0, \quad for\ t > T_i, \quad i = 1, 2, 3.
\end{aligned}
$$

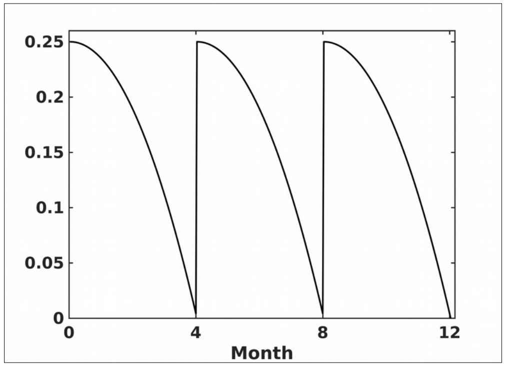
$$\kappa_i \equiv \text{efficacy},$$

$$T_i \equiv \text{environment persistence}.$$

Luz et al., (2009)

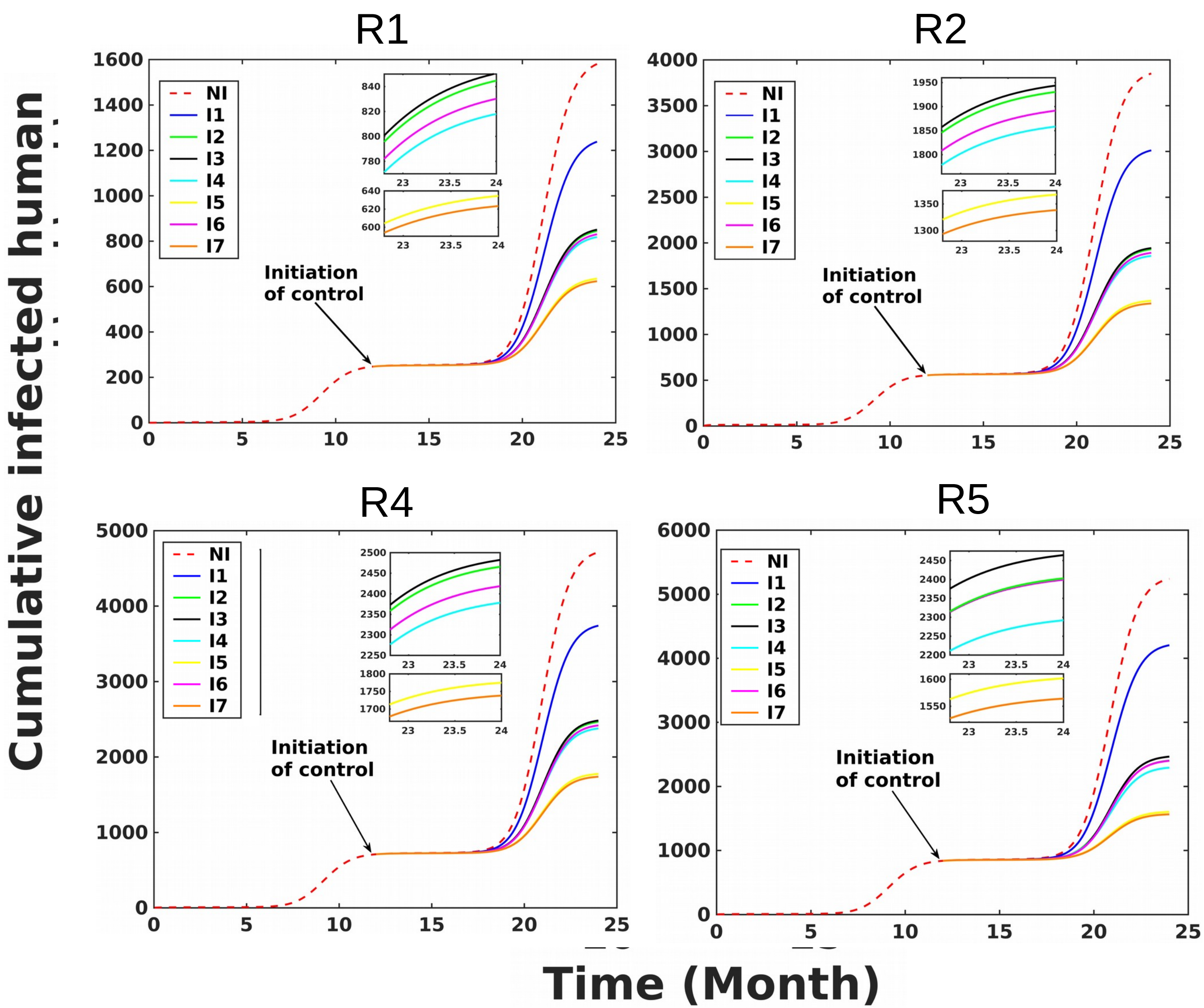
Maximum at the beginning and equals to **efficacy.**

Zero at the end of its **environment persistence.**



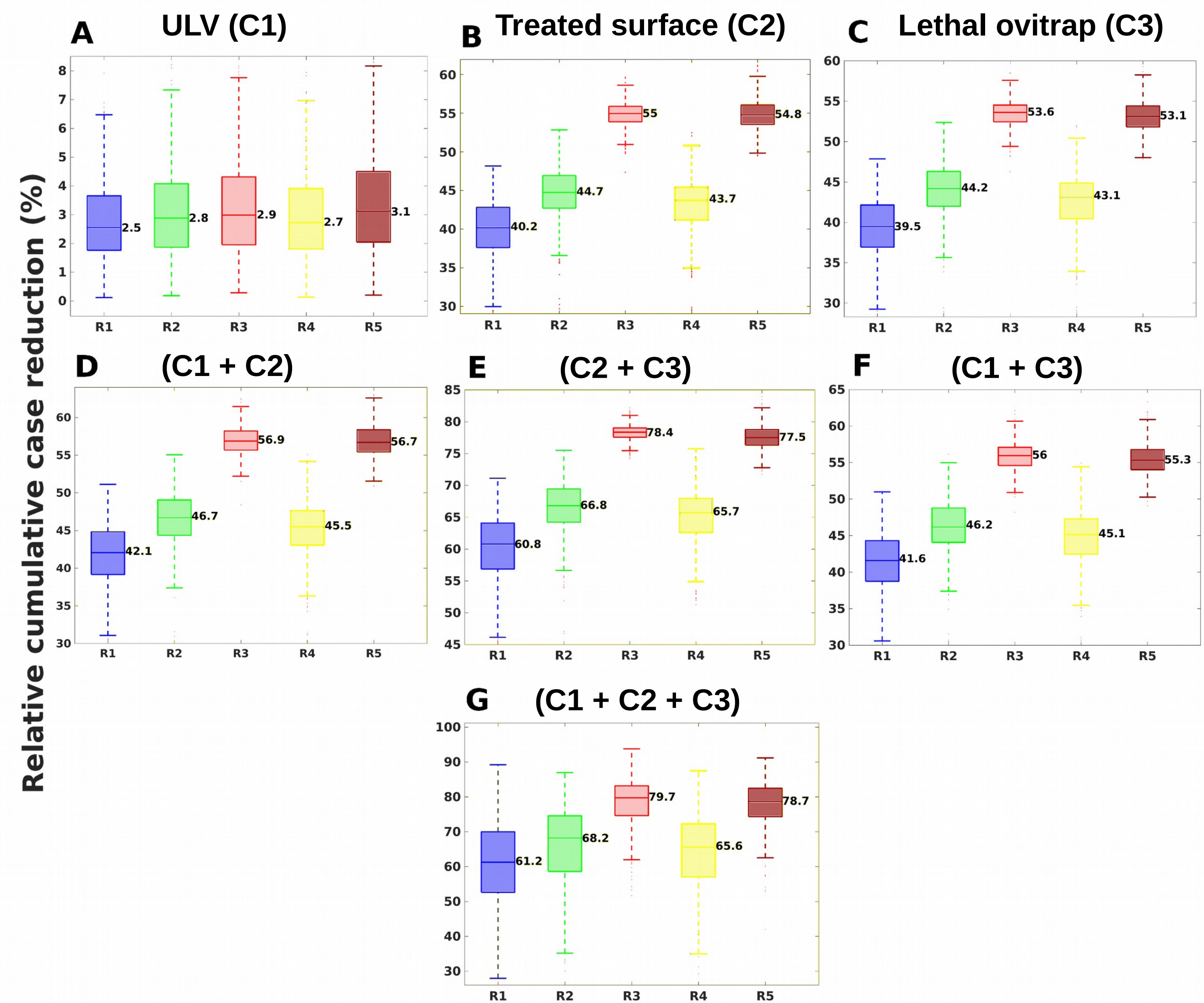
Control Profile

Time Evolution Of Cumulative Infected



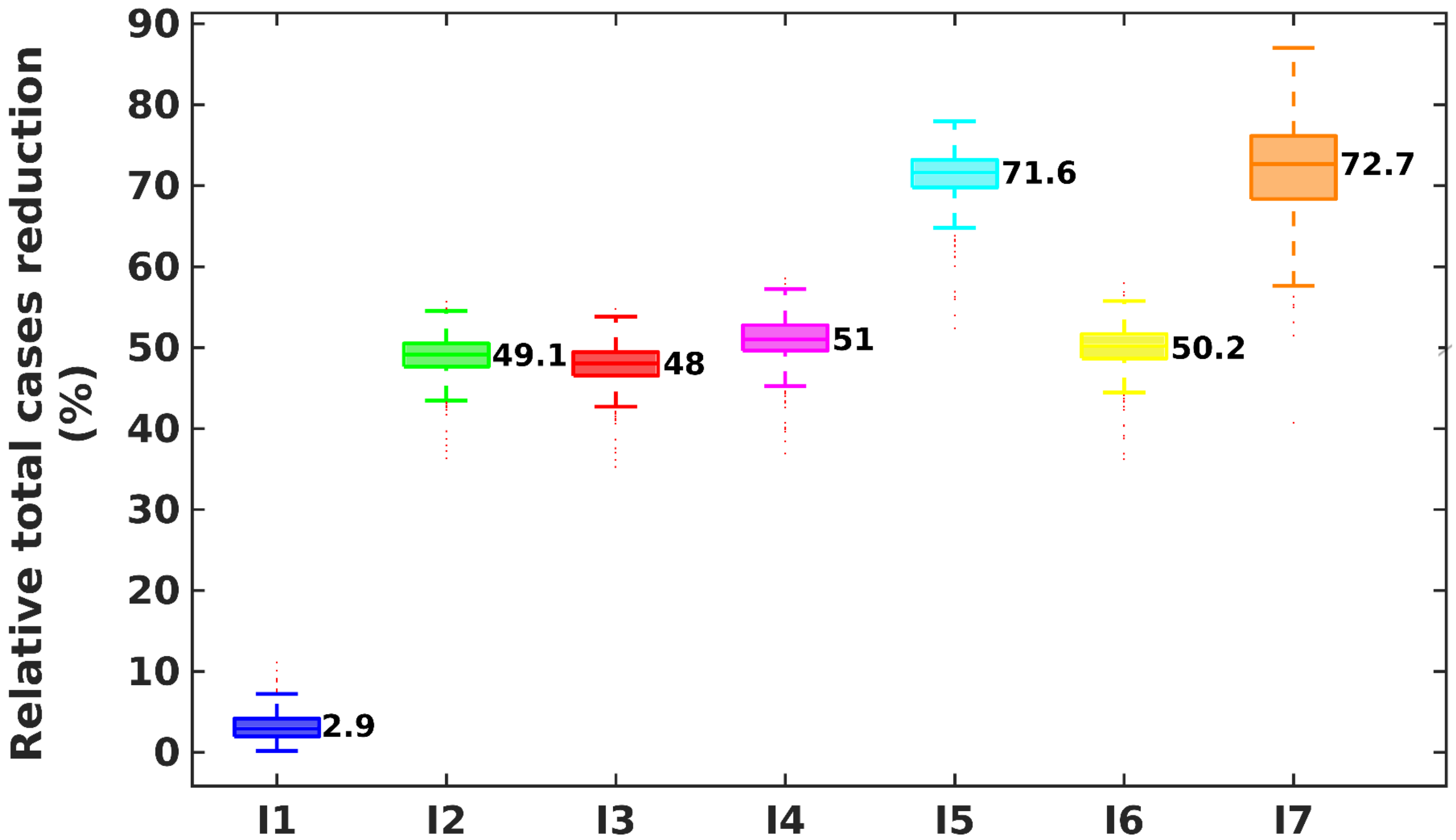
Time evolution of the cumulative infected human after application of **seven** control strategies in the **five** regions

Role Of Spatial Coupling



Spatial connectedness make it possible to reduce the cases significantly in **R1 , R2 & R4.**

EFFICIENCY OF CONTROLS



ULV spray has **least** impact

The treatment of surface and materials is the **most efficient**

Performance of Lethal ovitraps is also significant

Higher environment persistence gives better performance in reducing cases

Conclusion

- Use of ULV spray has the least impact in reducing cases.
- Treatment of surface and materials alone reduces maximum cases.
- Role of spatial coupling in the effectiveness of interventions is well reflected from our study.
- Higher environment persistence of a control strategy gives better performance in reducing cases.

Some Selected References

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Thank You