Analyzing Malaria in Indian States and Modeling Future Trends

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Malaria: A Global Challenge

CDC / James Gathany

- Malaria is a mosquito borne disease caused by *plasmodium* parasite transmitted through the bite of blood-feeding *Anopheles* mosquitoes.
- Symptoms of Malaria include:
  - Fever, Headache, Body-ache, Chills, Vomiting
  - Severe: Organ Failure, Kidney Failure, Metabolic acidosis, Hypoglycemia
- WHO stated that nearly half of the world population was at risk of malaria in 2021
- According to World Malaria Report 2022, there were an estimated 247 million cases of malaria worldwide in 2021.
- The death count during the same year was estimated by WHO at 619000.
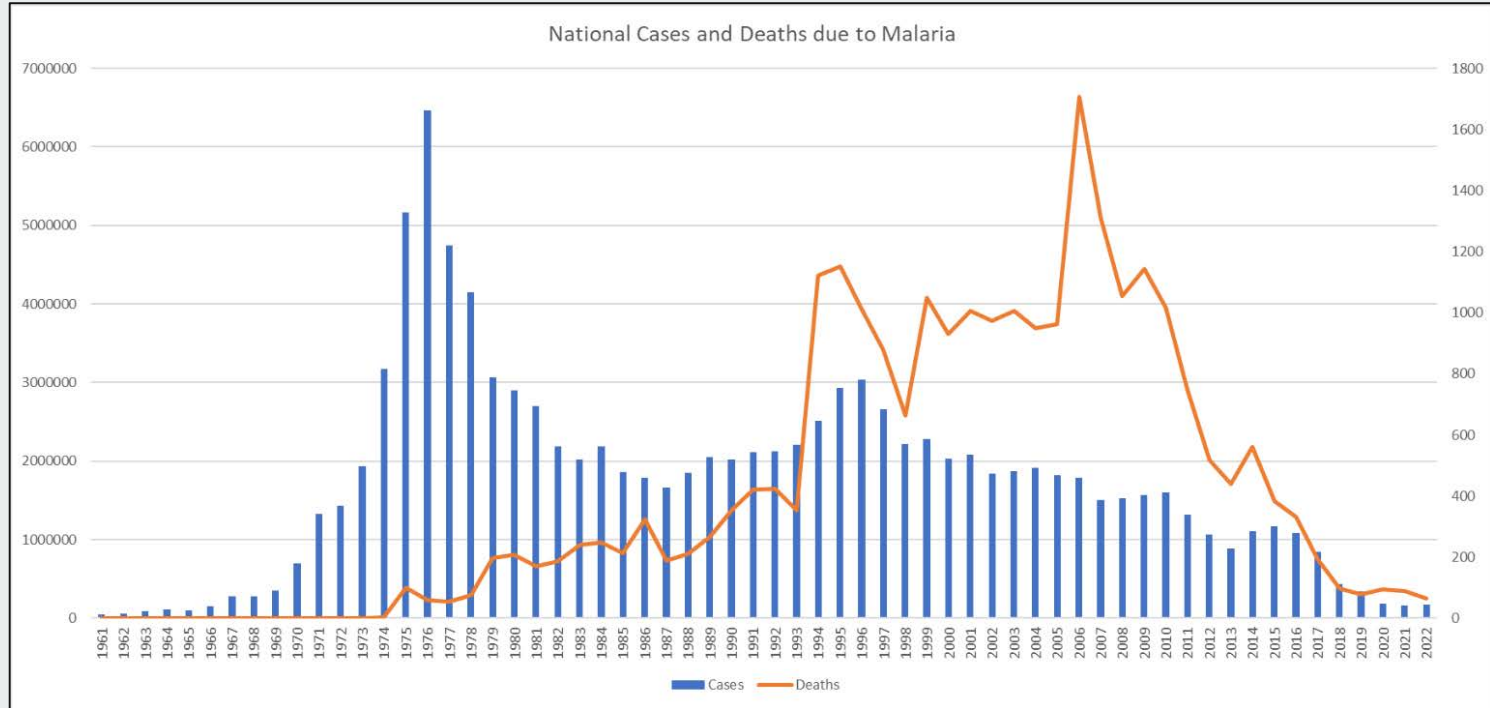

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Malaria in India

- According to the WMR 2022, India represents 1.7% of the global malaria burden
- In 2021, India accounted for 79% of all malaria cases and 83% of all malaria deaths in Southeast Asia as per WMR 2022.
- While *Plasmodium falciparum* accounts for nearly all the cases in Sub-Saharan Africa. *Plasmodium vivax* accounts for 34% of all cases in India
- The aforementioned points emphasize upon the need for region-specific research and analysis especially in India.

India has a vision of a malaria free country by 2027 and elimination by 2030

Malaria in India

National Cases and Deaths due to Malaria

Malaria in India

Number of States: 28

Number of Union Territories: 8

Spatio-Temporal Analysis of Cases (2002-22)

- To get a better understanding of the spatial distribution of malaria in India, a 100% stacked area chart is used, where higher area equals higher percentage of cases
- This helps to get a visual idea of how much each state contributes to the total malaria cases in India
- At first glance, we can see that Odisha is the highest contributor followed by Chhattisgarh and Jharkhand

Statewise Number of Cases

Statewise Number of Cases

Legend (top to bottom):
- West Bengal
- Uttarakhand
- Uttar Pradesh
- Tripura
- Tamil Nadu
- Sikkim
- Rajasthan
- Punjab
- Orissa
- Nagaland
- Mizoram
- Meghalaya
- Manipur
- Maharashtra
- Madhya Pradesh
- Kerala
- Karnataka
- Jharkhand
- Jammu & Kashmir
- Himachal Pradesh
- Haryana
- Gujarat
- Goa
- Chhatisgarh
- Bihar
- Assam
- Arunachal Pradesh
- Andhra Pradesh

Y-axis: Cumulative % of Cases

X-axis: Year (2002–2022)

Top contributing states (cases)

States	Avg
Odisha	24.86
Chhattisgarh	13.09
Jharkhand	10.77
West Bengal	8.037
Uttar Pradesh	7.099
Madhya Pradesh	6.067
Maharashtra	5.09
Gujarat	5.009
Others	19.97

- The adjacent table shows the states that account for the highest percentage of cases in India per year on average
- As seen in the 100% stacked area plot Odisha, Chhattisgarh and Jharkhand are the prominent states with 24.86%, 13.09% and 10.77% respectively.
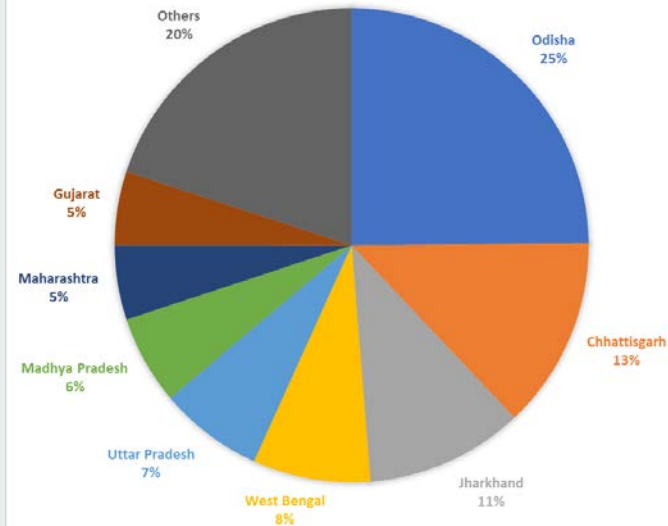
Spatio-Temporal Analysis of Deaths (2002-22)

- Similar state-wise analysis was conducted for deaths as well
- From the 100% stacked area chart, the top contributors come out to be Chhattisgarh, Maharashtra, Meghalaya, Odisha and West Bengal


Statewise Number of Deaths
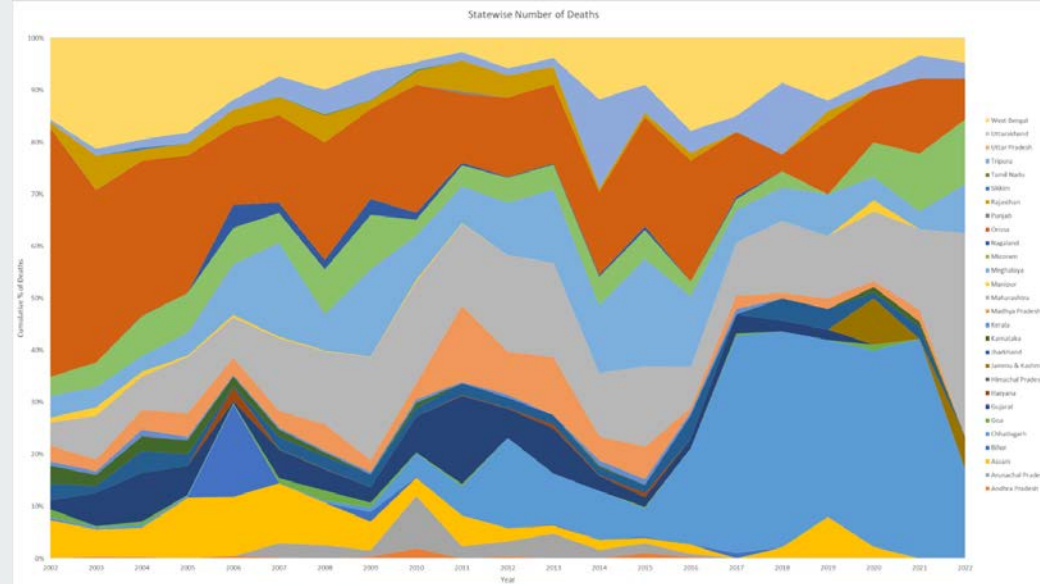
Statewise Number of Deaths
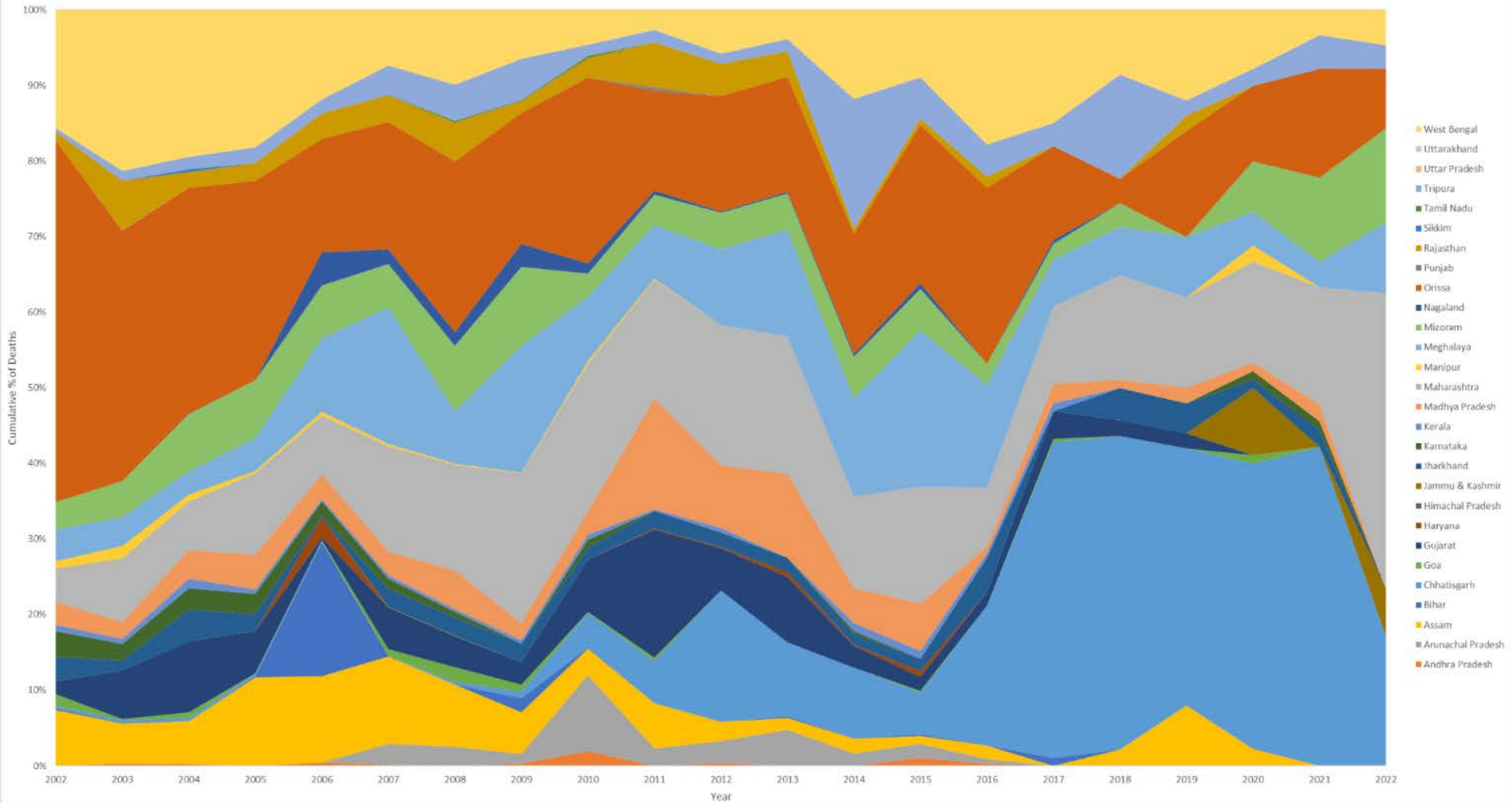
Top contributing states (deaths)

States	Avg
Odisha	19.02
Maharashtra	14.15
Chhattisgarh	13.71
West Bengal	10.31
Meghalaya	9.122
Mizoram	5.777
Assam	4.648
Gujarat	4.22
Madhya Pradesh	4.056
Tripura	3.957
Uttar Pradesh	0
Others	11.03

- The adjacent table shows the states that account for the highest percentage of deaths in India per year on average
- Surprisingly, Maharashtra, Meghalaya, Mizoram and Assam are high up in this table even though they are not top contributors in terms of the number of cases
- On the other hand, Uttar Pradesh shows 0 deaths despite averaging the fifth highest percentage of cases
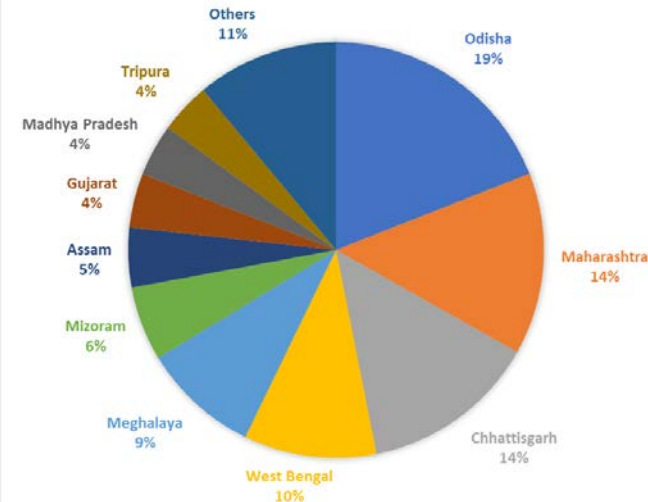
Population adjusted Cases per million (2002-22)

- As the absolute numbers do not show the full picture of how the state is affected by malaria, we have adjusted the cases and deaths for the population of each state
- The adjacent table shows the worst performing states wrt population adjusted cases per million
- Owing to their lower population, the states from the northeastern region of India figure at the very top of this table. But their population adjusted number of cases are comparable to that of states with highest absolute number of cases

| States	Avg
Arunachal Pradesh	13812.34
Mizoram	10323.88
Meghalaya	9544.9
Odisha	7677.924
Chhattisgarh	5909.181
Tripura	5061.937
Jharkhand	4202.311
Goa	2531.919
Assam	1584.81
Nagaland	1258.915
Madhya Pradesh	1187.682
Gujarat	1186.377
West Bengal	1044.712

Population adjusted Deaths per million (2002-22)

- The adjacent table shows the worst performing states wrt population adjusted deaths per million
- The numbers pertaining to Mizoram, Meghalaya and Arunachal Pradesh are abnormally high and is a cause for concern. However, these states could be much easier to deal with appropriate measures for controlling the number of deaths on account of their low population

States	Avg
Mizoram	42.93
Meghalaya	24.99
Arunachal Pradesh	10.29
Tripura	6.327
Nagaland	4.357
Odisha	3.865
Goa	2.669
Assam	1.617
Manipur	1.218
Chhattisgarh	1.164
West Bengal	0.888
Maharashtra	0.809
Gujarat	0.609

Trends in population adjusted figures
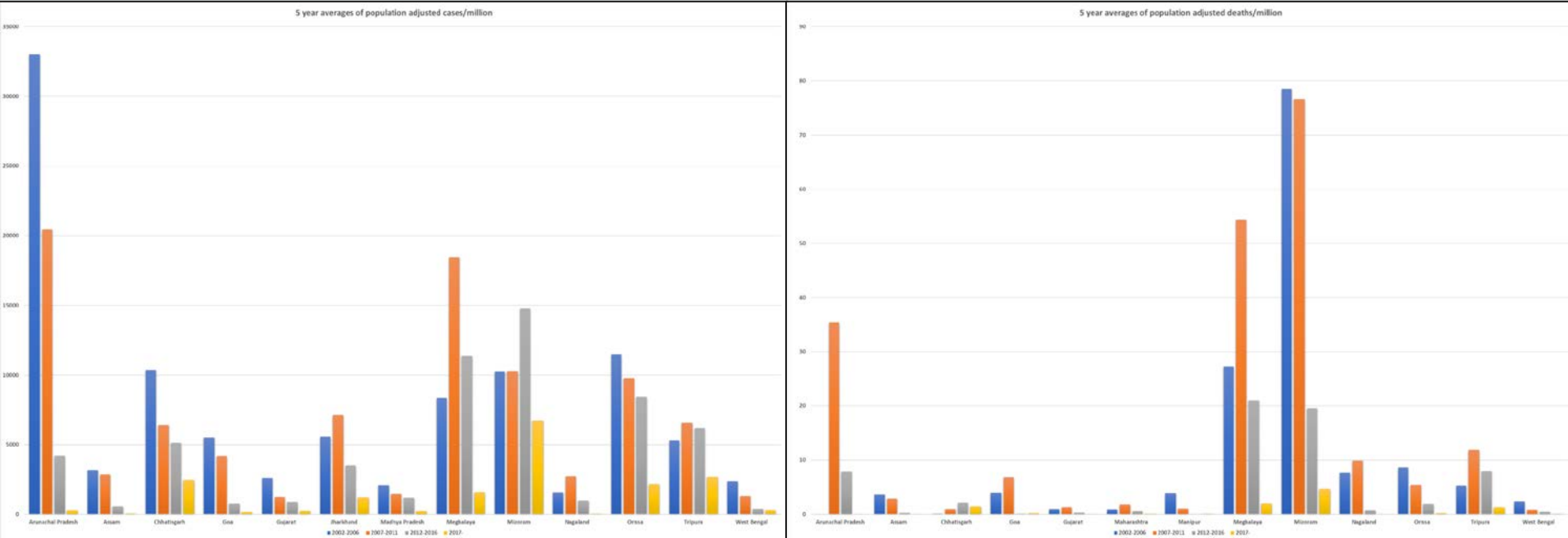
Countermeasures

- Increase investment in malaria control programs

- Improve access to prevention and treatment services

- Strengthening surveillance to identify areas where malaria is present and monitor them

- Usage of disease modeling for better understanding and control of malaria

Disease Modeling

What is Disease Modeling?
- Mathematical Disease Models enable linking of the biological process of transmission and the emergent dynamics of infection at the population level.
- Disease models are used to simulate various complex scenarios to gain insight into the effect of different parameters.
- Such models can also help policymakers understand the potential impact of interventions.

Need for Modeling in India
- India has the highest burden of malaria in southeast Asian region.
- Since India has a vision to be malaria free by 2027 and eradication by 2030, intervention strategies need to be well timed and effective. Disease modeling can aid in identifying problem regions and planning intervention strategies needed to eradicate malaria.

EMOD is one such example of a disease modeling tool

What is EMOD?

- EMOD (Epidemiological MODeling) is an agent based modeling software developed by IDM.
- EMOD is a discrete and stochastic model which simulates the simultaneous interactions of agents in an effort to recreate complex phenomena.
- Agent Based Model: Each agent in an agent based model is assigned a variety of properties and their interaction with other agents is determined by a set of rules
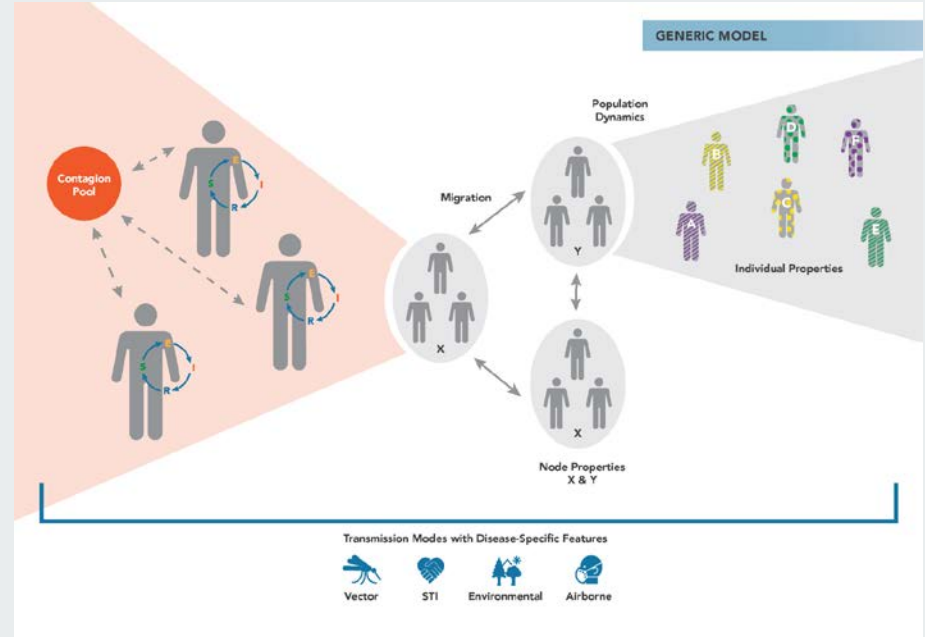

Illustration of a generic ABM model

Input parameters for EMOD

- EMOD requires different files to configure the simulation environment. Some of these are Demographics file, Configuration file, Campaign file, Migration and Climate files, etc.
- Binned population, fertility rate, Mortality rate and other demographic parameters are included in the Demographic files.
- We have seen that Chhattisgarh is one of the deeply affected Indian states. The parameters as shown by the figures on the right are some of the inputs required to run EMOD.
- Currently, we are gathering the required data, estimating and configuring parameters to run EMOD for Indian states successfully.

Mortality pyramid of Chhattisgarh

Population pyramid of Chhattisgarh
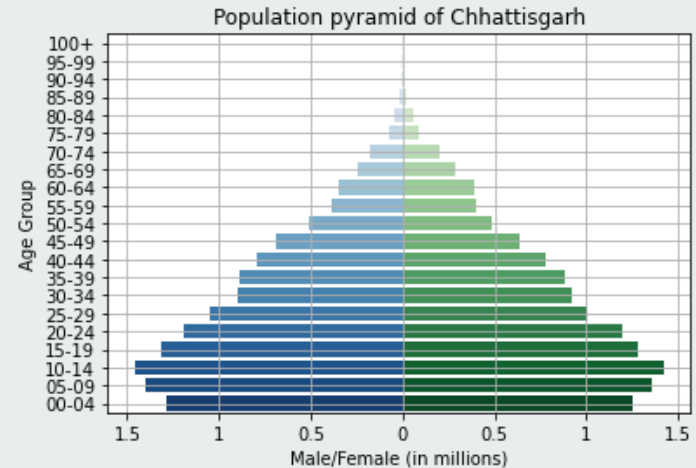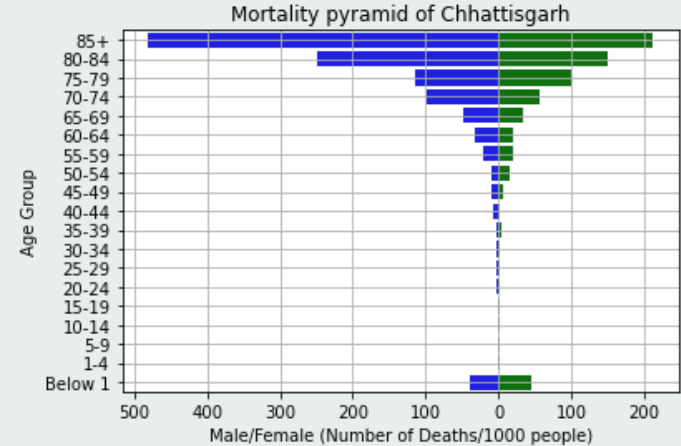
Conclusion

- The study presents the spatio-temporal analysis of Malaria in India for the period 2002 - 2022.
- High risk states have been identified and the results clearly indicate the need for immediate attention in some of the states.
- Modeling can be and should be used as a countermeasure to reduce the burden of Malaria.
- EMOD, a disease modeling software is being explored. We plan to apply this modeling tool on Indian states which are currently showing the highest burden of cases. This would result in
  - Benchmarking the EMOD model with burden of Malaria Cases in states from the past few years.
  - Predicting burden of Malaria for the near future with and without any interventions and comparing state-wise statistics.
- The study should help states and national Malaria control efforts in developing appropriate strategies and disease control policies.