# Sub-national Level Analysis of Measles Prevalence in India

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# Motivation

- India is committed to eliminate measles by December 2023

- Measles outbreak in India (November, December 2022)
  - Mumbai and other parts of India
  - Highly concentrated

- Analysis of measles prevalence at subnational level

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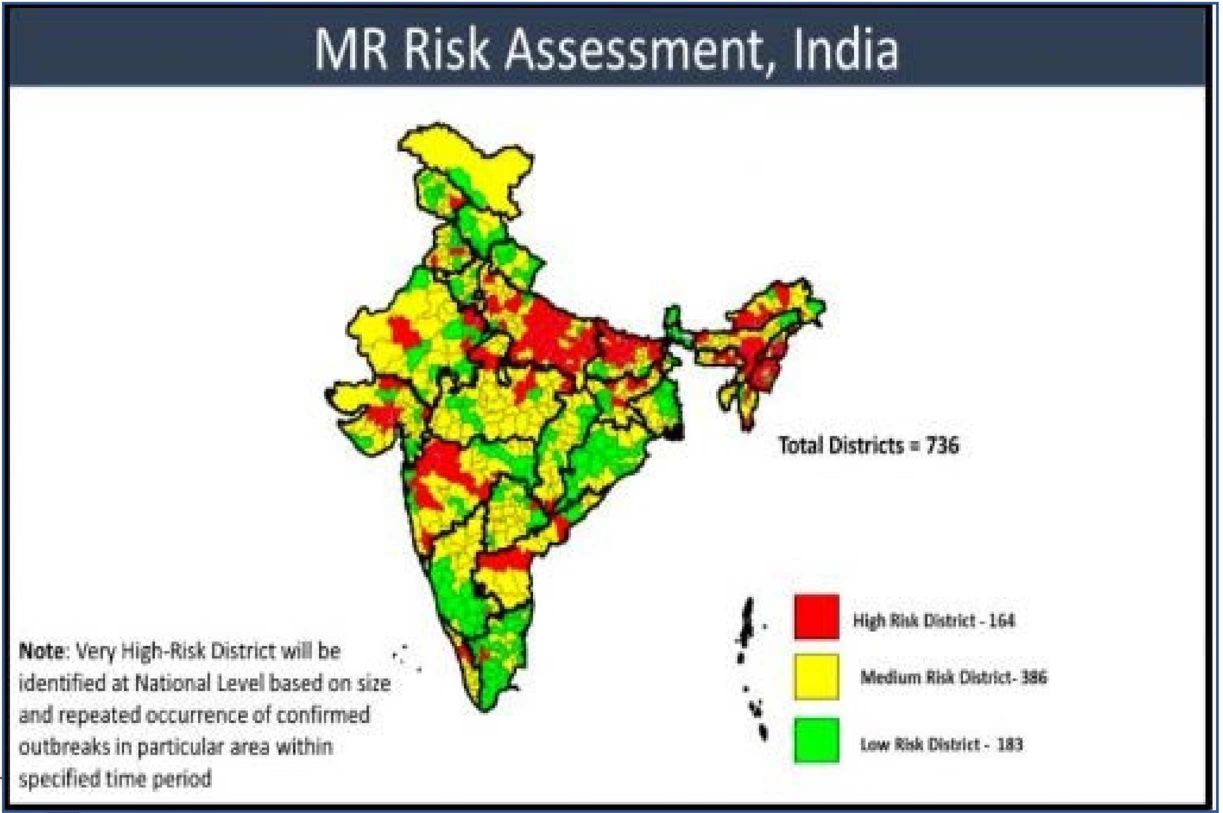
# Objectives

- Modelling the measles burden at subnational level.

- Analysis of supplemental immunization activities (SIA)



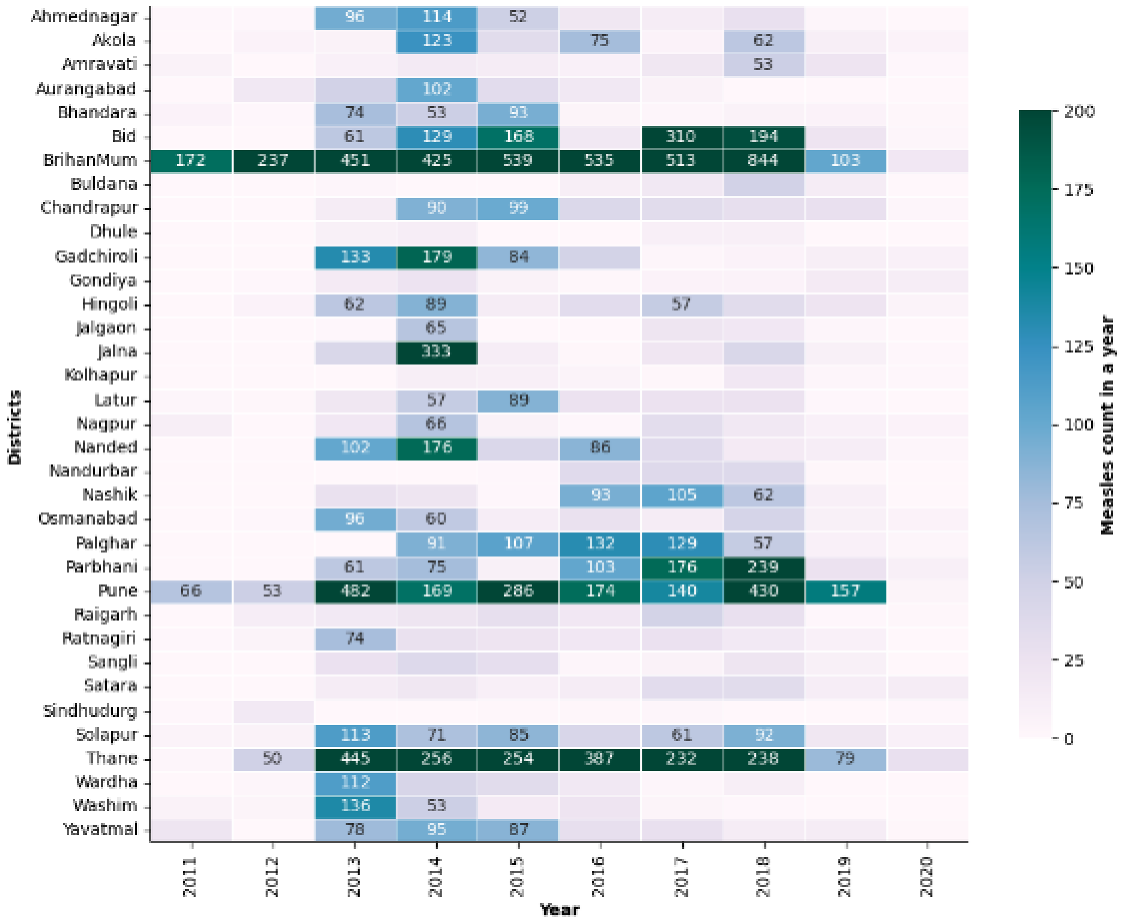

Source: Roadmap to Measles and Rubella Elimination in India by 2023

From the figure we observe that the most **high-risk districts** were located in **Uttar Pradesh (41)**, followed by **Bihar (19)**, **Arunachal Pradesh (14)**, **Maharashtra (12)** & **Manipur (12)**

# Data Sources

- **HMIS - Monthly data (April 2013 - March 2020)**
  - Data on child immunization 1st and 2nd dose
  - Live births
  - Measles disease count in children below 5
  - Child deaths with probable cause being measles (1-11 months and 1-5yrs)
- **NFHS-5 - Districts Fact Sheets**
  - Data on MCV-1 for the years 2019-20, 2015-16
  - Data on MCV-2 for the year 2019-20
- **Census of India, 2011**
  - District level population age-wise

# Identifying the High Risk Districts of Maharashtra




According to the heat map our districts of focus should be Mumbai, Pune and Thane

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# Methods

- Time series SIR model: Grenfell *et al*. (2002) and Thakkar *et al*. (2019)
  - Fit the model for three high risk districts of Maharashtra: Mumbai, Pune and Thane
  - Based on the fitted models predict the effect of future SIAs on estimated susceptible population and measles infections

- State space model: Chen, Fricks and Ferrari (2012)
  - Fit the model for Mumbai

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# TSIR Model

- Following **<u>Grenfell *et al.* (2002)</u>** and **<u>Thakkar *et al.* (2019)</u>**, we model $S_t$ and $I_t$ as a discrete stochastic dynamical system
- $S_t = (1 - \mu_{t-1})(B_t + S_{t-1} + I_t)$
- $I_t = \beta_t I_{t-1}^{\alpha} S_{t-1} \varepsilon_t$
- $C_t \sim Binom\{I_t, p\}$

- $\beta_t$ - unknown transmission rate

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# TSIR Modelling

- $B_t = \overline{B_t}\left[1 - 0.9V_{1,t}\left(1 - V_{2,t}\right) - 0.99V_{1,t}V_{2,t}\right]$

- NFHS data - MCV1 & MCV2 coverages
- Monthly fluctuations in $V_{1,t}$ and $V_{2,t}$ from HMIS

- TSIR Model has been fitted using monthly data from April’13-March’20 (84 time points for each district).

- SIA at 2018 December with 60% efficacy is incorporated.

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# TSIR Model Calibration

- In this method we have utilized the live birth counts for the next 20 years (Apr’20 to Mar’40) to calculate the adjusted birth counts from the National Population Projection Report published by the Government of India

- We used Crude Birth Rate (CBR), Population growth rate and total Population of respective districts reported in the Government report to calculate the live births.

- To Calculate the adjusted live births we have used MCV1 coverage as 75% and MCV2 coverage as 20% (constant throughout the time period) and the above obtained live birth counts.

# State Space Model

- **Chen, Fricks and Ferrari (2012)**
- Observation equation: $C_t = \theta_2\{1 - exp(-\theta_1 S_{t-1}/N_{t-1})\}S_{t-1} + \varepsilon_t$
- System equation: $S_t = S_{t-1} - \left[\left\{1 - exp\left(-\frac{\theta_1 S_{t-1}}{N_{t-1}}\right)\right\} S_{t-1} + X_t\right](1 - Y_{t-1}) + \eta_t$
- Where $\varepsilon_t \sim iid\ N(0, \theta_3^2)$ $and$ $\eta_t \sim iid\ N(0, \theta_4^2)$
- $X_t$: adjusted birth rate accounting for MCV1 and MCV2 coverge
- $Y_t$: Coverage of SIA at time t
- $N_t$: Total population at time t
- $\theta_1$-$\theta_4$: unknown parameters

# State Space Model Calibration

- The number of susceptible individuals (St) is treated as unobservable Markovian process while the case counts (Ct) are treated as observed time series.

- Both Ct and St are modelled simultaneously via non-linear time series regression models with covariates as population, at risk birth cohort and outreach of vaccination campaigns.

- We use extended Kalman filter to estimate Ct and St.

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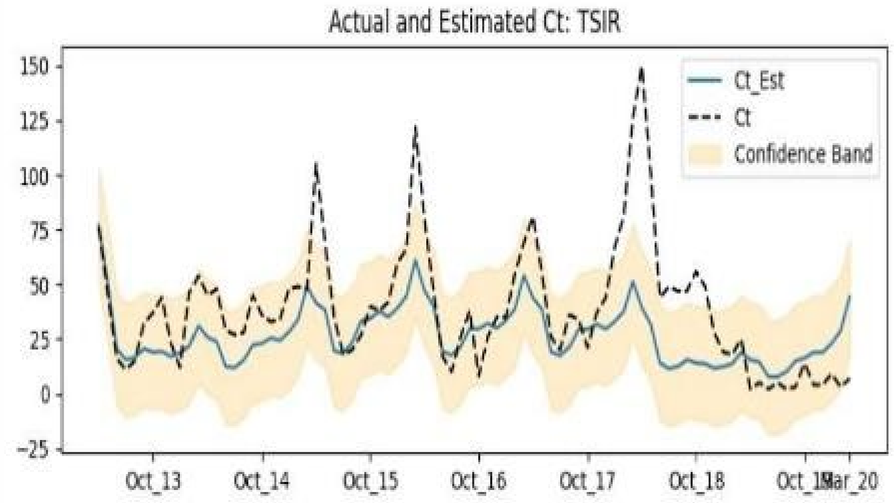
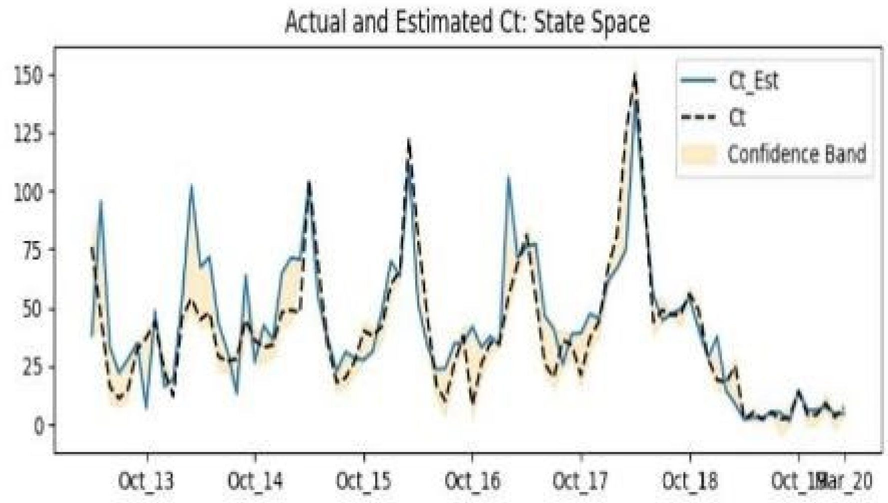
# Findings for Mumbai: RMSE and MAPE

The root-mean-squared error (RMSE)and mean absolute prediction error (MAPE) in the estimation of $C_t$ are given below.

| Method | RMSE | MAPE |
|---|---|---|
| TSIR | 25.9300 | 0.8583 |
| State Space | 21.1627 | 0.8318 |

# Findings for Mumbai : Estimated Case Counts

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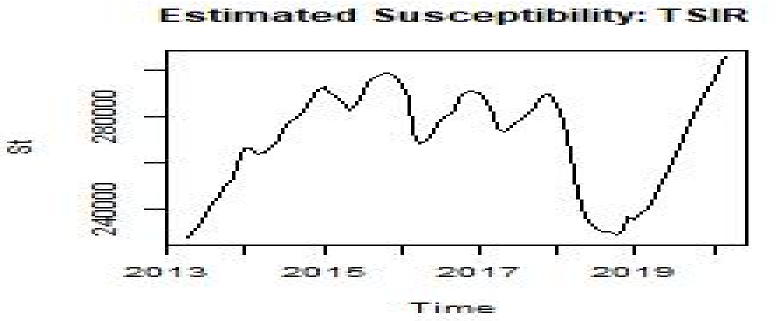
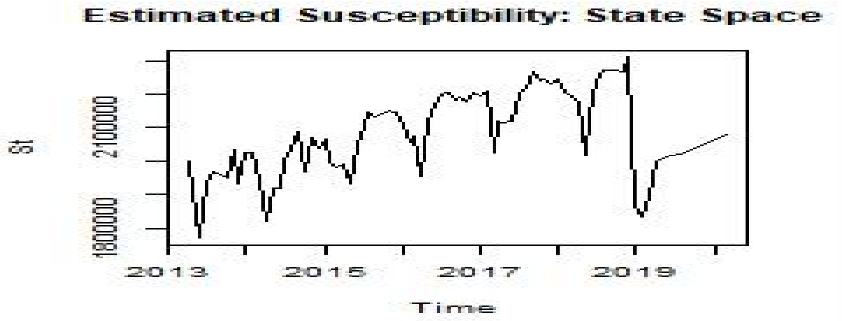
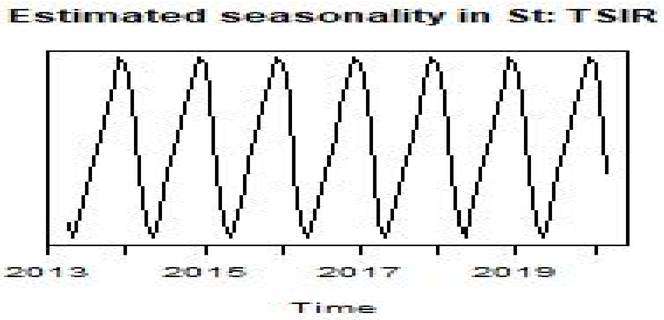
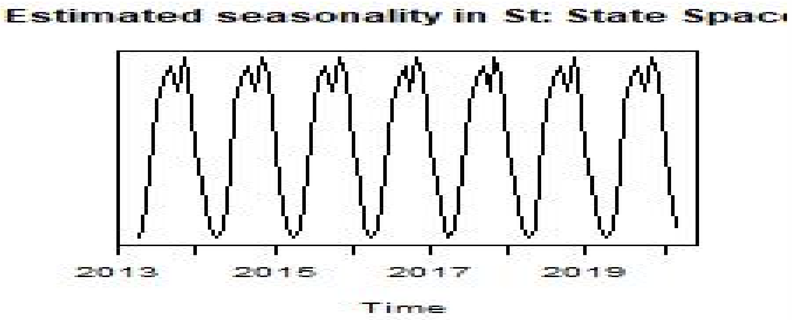
# Findings for Mumbai : Estimated Susceptibility

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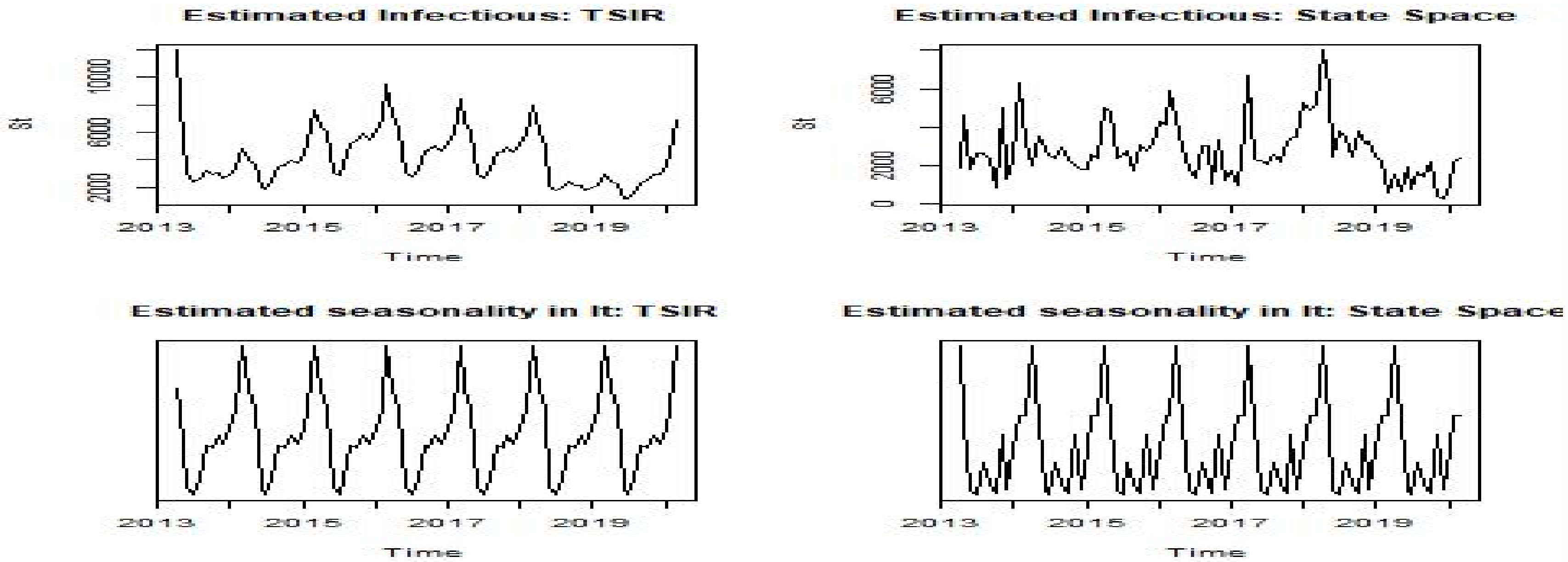
# Findings for Mumbai : Estimated Infectious Population

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# Findings for Mumbai

- Both the approaches show similar trend and annual seasonality in $S_t$ and $I_t$.

- Effect of 2018 SIA is visible – temporary reduction in estimated susptability and infectious population

- This calls for the periodic SIA analysis (TSIR).

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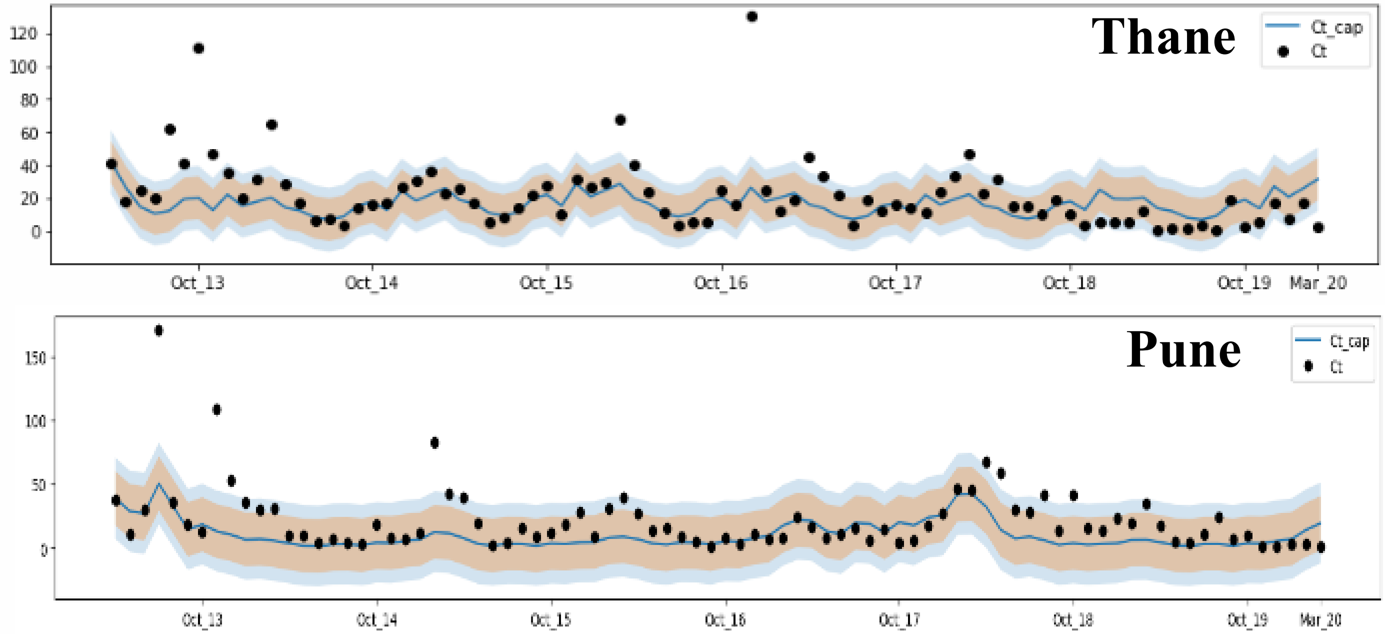
# Findings for Thane and Pune based on TSIR




*Actual case counts Vs. predicted case counts using TSIR model with SIA at Dec'18*

(Blue shaded region indicates 3σ confidence interval, red shaded region indicates 2σ confidence interval)

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# SIA Scenarios

- Coverage scenarios considered
  - Covering children upto 5 years
  - Covering children upto 14 years
  - Covering population upto 40 years

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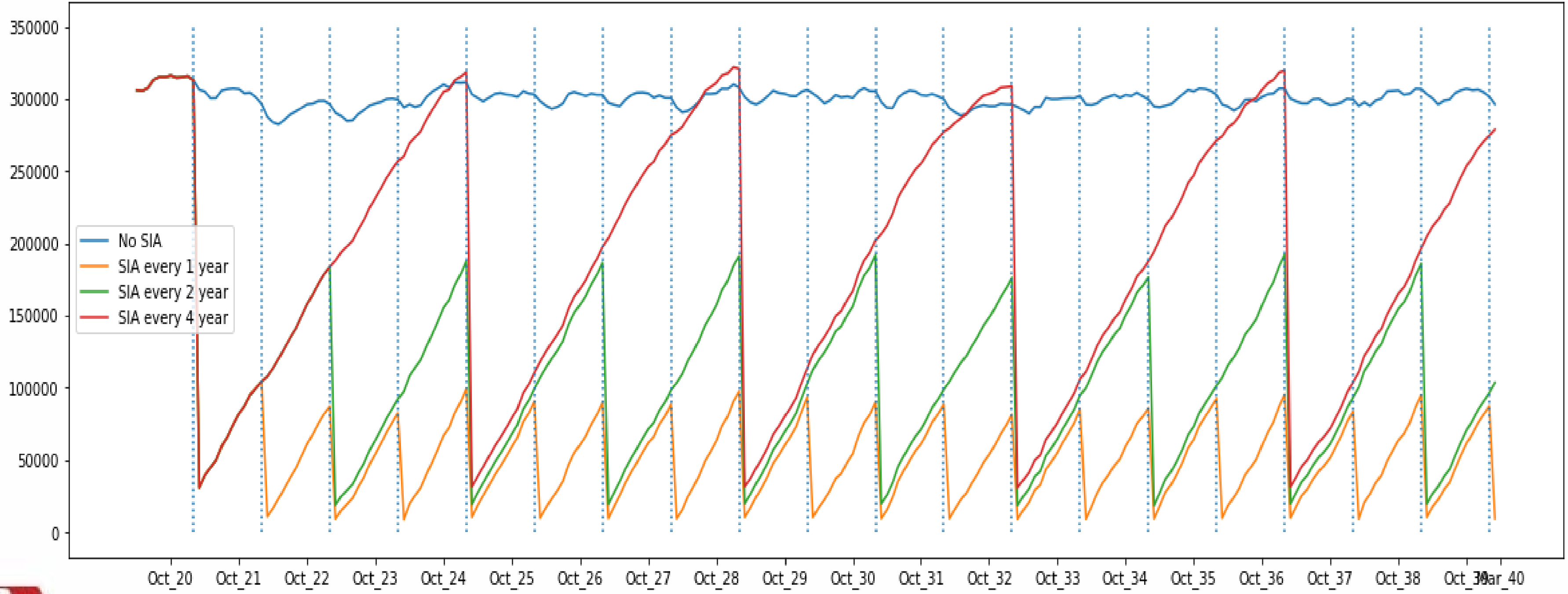
# SIA plot for Mumbai: Susceptibility




Estimation based on HMIS, NFHS data for India

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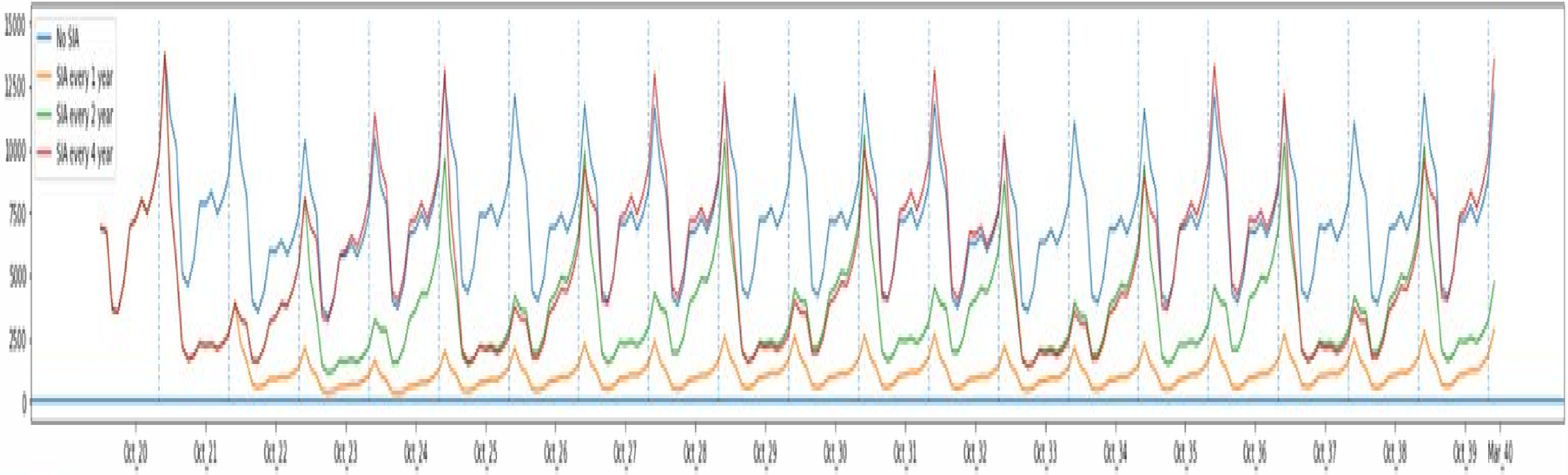
# SIA plot for Mumbai: Infectious population

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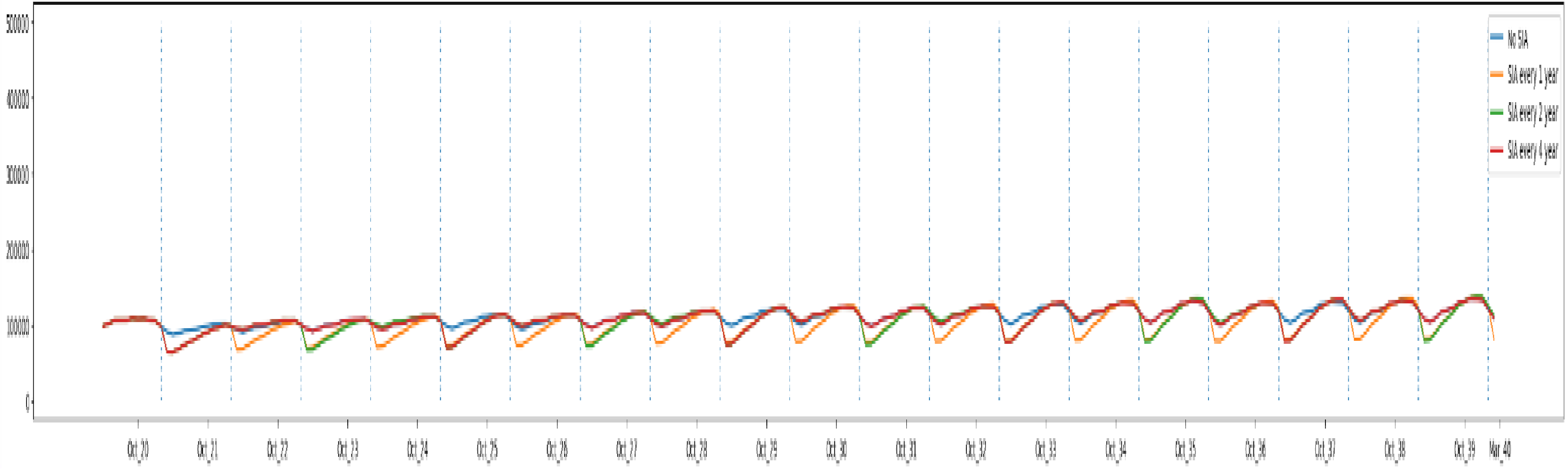
# SIA Covering Children upto 14 years in Pune: Susceptibility

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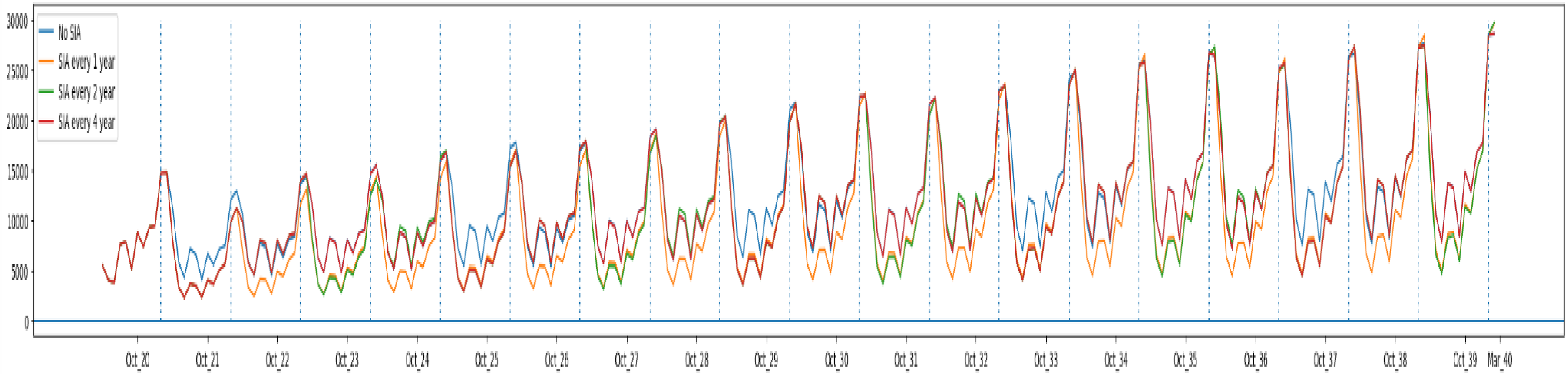


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# SIA Covering Children upto 14 years in Thane: Susceptibility


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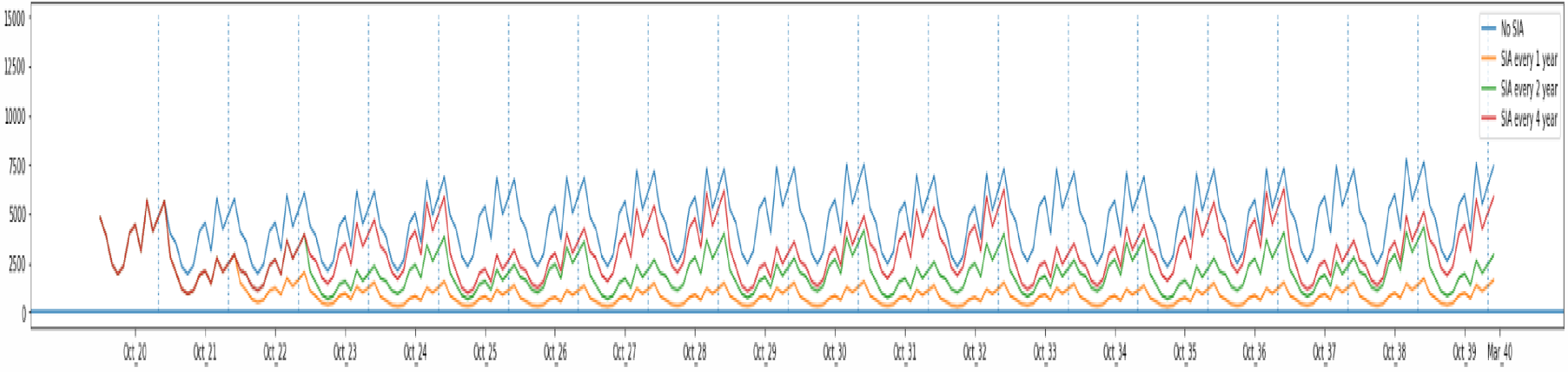
# SIA Covering Children upto 14 years in Thane: Infectious population




Estimation based on HMIS, NFHS data for India

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# Concluding Remarks

- The trend in the estimates of $C_t$ and $S_t$ are similar for both the approaches.
- State space modeling provides smaller RMSE, MAPE and confidence intervals.
- SIA analysis shows the reduction in measles incidences if regular SIAs are implemented.
- The susceptibility is seen to be increasing which calls for more aggressive vaccination campaigns and SIAs.

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# Future Work

- Incorporate spatio-temporal dependence amongst the measles burden across various districts.
- Analyze the effect of migrations.
- Include the age-wise stratification in the models.
- Include additional covariates which may act as potential predictors of measles burden.

# Thank You