**Impact of continued closure of red-light areas on COVID-19 transmission in India**

**Introduction**

**Methods**We developed an age-structured SEIR-type dynamic model for COVID-19 transmission to understand the impact of continued closure of red light areas in five cities of India as well as nationally after the initial countrywide lockdown of 40 days from 24 March 2020 to 3 May 2020 (**Figure 1**). The population of each location considered was compartmentalized into red-light area residents and the general population. Red-light area residents included sex workers as well as non-sex workers such as pimps, brothel managers, security, servants, and others performing miscellaneous roles in the area. Both populations were stratified into four age groups: 0–19 y, 20–49 y, 50–64 y, and ≥65 y. Age-distribution of each location was based on the most recent census [1], adjusted to current population estimates for each location and for the red-light areas within it **(Table 1)**. The general population and red light areas were further compartmentalized (**Table 2**) based on natural history of disease as well as interventions.

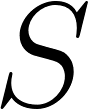
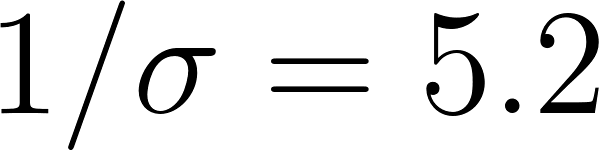
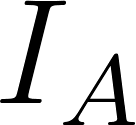
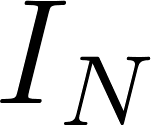
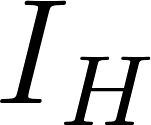
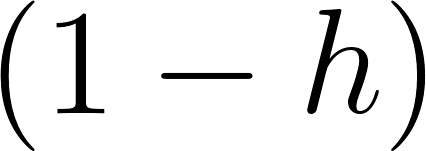
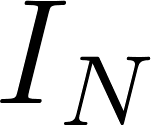
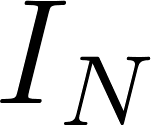
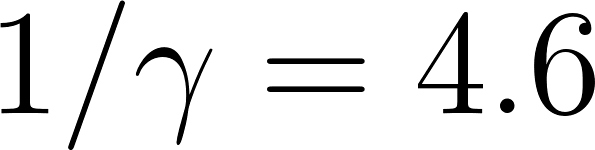
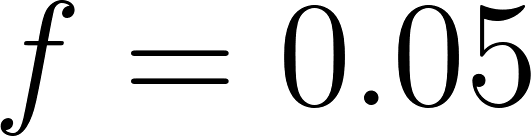
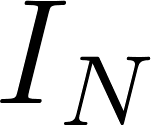
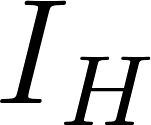
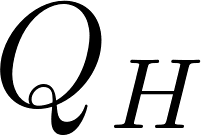
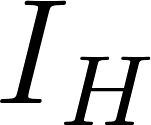
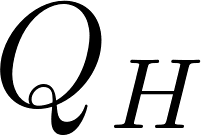
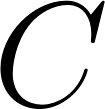
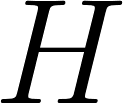
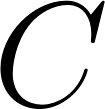
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| **Table 1**. Demography and red-light area data. | | | | | | |
| Location | Mumbai | Nagpur | Delhi | Kolkata | Pune | India |
| General population | 20,411,00 | 2,893,000 | 19,500,00 | 14,850,000 | 6,629,000 | 1,380,004,385 |
| Red-light area population | 5,471 | 2,310 | 4,048 | 16,000 | 6,345 | 637,500 |
| Total daily interaction between general population and red-light area | 441,000 | 252,000 | 777,000 | 2,112,000 | 820,000 | 20,475,000 |
| Contact rate between general population and red-light area () | 0.0216 | 0.0871 | 0.0398 | 0.1422 | 0.1237 | 0.01484 |

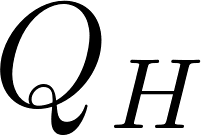
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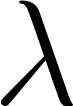
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| **Table 2**. Model compartments | |
| Compartment | Definition |
|  | Susceptible |
|  | Incubation |
|  | Asymptomatic infections |
|  | Symptomatic severe infections (not isolated) |
|  | Symptomatic mild infections (not isolated) |
|  | Symptomatic severe infections (isolated) |
|  | Symptomatic mild infections (not isolated) |
|  | Hospitalization |
|  | Need ICU |
|  | Deaths |

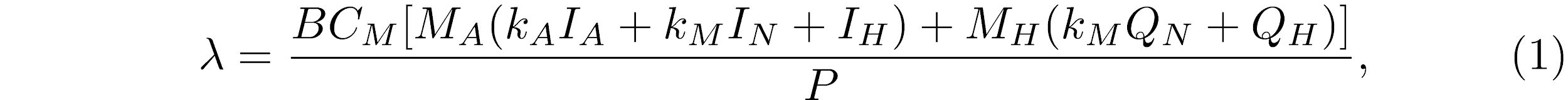
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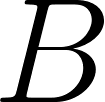
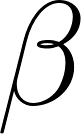
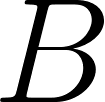
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| **Figure 1**. Model schematic. |

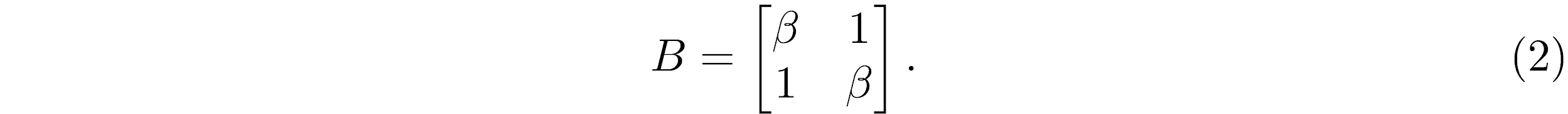
In our model, a susceptible individual ([](https://www.codecogs.com/eqnedit.php?latex=S#0)) after acquiring infection remained in an non-infectious incubation period ([](https://www.codecogs.com/eqnedit.php?latex=E#0)) for an average of [](https://www.codecogs.com/eqnedit.php?latex=1%2F%5Csigma%20%3D%205.2#0) days (**Table 3**). Following the incubation period, an infected individual either remained asymptomatic ([](https://www.codecogs.com/eqnedit.php?latex=I_A#0)) or developed symptoms ([](https://www.codecogs.com/eqnedit.php?latex=I_N#0),[](https://www.codecogs.com/eqnedit.php?latex=I_H#0)). A proportion of symptomatic individuals ([](https://www.codecogs.com/eqnedit.php?latex=(1-h)#0)) developed only mild symptoms ([](https://www.codecogs.com/eqnedit.php?latex=I_N#0)). Symptomatic individuals with mild symptoms ([](https://www.codecogs.com/eqnedit.php?latex=I_N#0),[](https://www.codecogs.com/eqnedit.php?latex=Q_N#0)) did not need hospitalization, and recovered in an average of [](https://www.codecogs.com/eqnedit.php?latex=1%2F%5Cgamma%20%3D%204.6#0) days **(Table 3)**. A proportion of individuals ([](https://www.codecogs.com/eqnedit.php?latex=f%20%3D%200.05#0)) with mild or severe symptoms were isolated within a day ([](https://www.codecogs.com/eqnedit.php?latex=I_N#0) → [](https://www.codecogs.com/eqnedit.php?latex=Q_N#0), [](https://www.codecogs.com/eqnedit.php?latex=I_H#0) → [](https://www.codecogs.com/eqnedit.php?latex=Q_H#0)). Symptomatic individuals with severe symptoms ([](https://www.codecogs.com/eqnedit.php?latex=I_H#0),[](https://www.codecogs.com/eqnedit.php?latex=Q_H#0)) were either hospitalized ([](https://www.codecogs.com/eqnedit.php?latex=H#0)), or required an ICU admission within a hospital ([](https://www.codecogs.com/eqnedit.php?latex=C#0)). Those hospitalized patients ([](https://www.codecogs.com/eqnedit.php?latex=H#0),[](https://www.codecogs.com/eqnedit.php?latex=C#0)) either recovered or died.

The spread of infection within each population depended on the prevalence of infections at the given time, age-specific contact patterns and per contact transmission rate of the virus. Prem et. al [[2]](https://paperpile.com/c/dN8otS/Kwwz) estimated contact patterns between different age-groups in India overall and within specific locations such as households. We use estimates of overall contact patterns to parameterize contact rate between different age groups in our model. Contact rate of individuals who are isolated ([](https://www.codecogs.com/eqnedit.php?latex=Q_N#0),[](https://www.codecogs.com/eqnedit.php?latex=Q_H#0)) is parameterized by the data on household contact patterns .

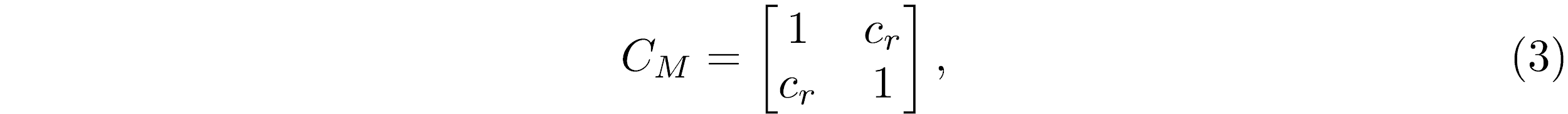
The force of infection [](https://www.codecogs.com/eqnedit.php?latex=%5Clambda#0) is given by

[](#D2L_code_render_ \begin{equation}
\lambda = \frac{B C_{M} [ M_{A}(k_{A} I_{A}+k_{M} I_{N}+I_{H})+M_{H}(k_{M}Q_{N}+Q_{H})]}{P},
\end{equation})

where [](https://www.codecogs.com/eqnedit.php?latex=B#0) is a matrix representing the probability of infection given contact within the general population and the red-light area as well as the probability of infection given contact between the two subpopulations. Interaction between the general population and the red-light area occurred through customers from the general population. The probability of infection given a contact between a customer from the general population and a resident of the red-light area was assumed to be 1. Probability of infection within the red-light area or within in the general population [](https://www.codecogs.com/eqnedit.php?latex=%5Cbeta#0), was calibrated to the basic reproduction number [](https://www.codecogs.com/eqnedit.php?latex=R_0#0) (**Table 3**). Thus [](https://www.codecogs.com/eqnedit.php?latex=B#0) is given by

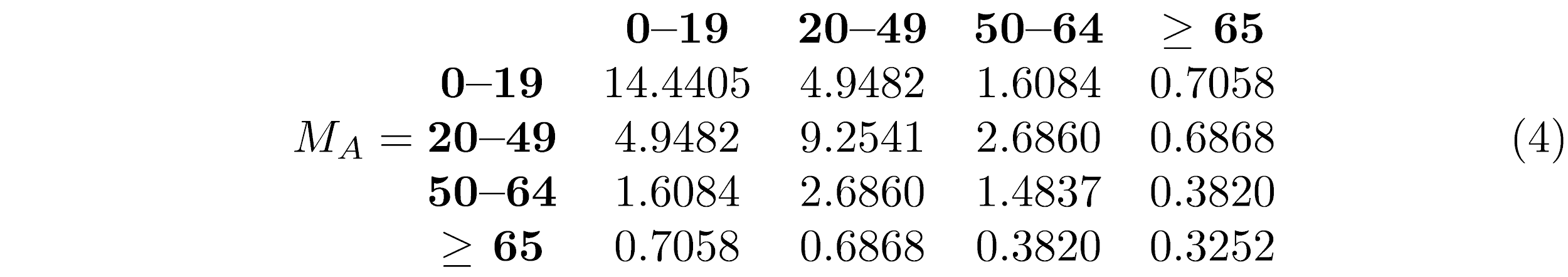
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\begin{equation} 
B = \begin{bmatrix} \beta & 1 \\ 1 & \beta \end{bmatrix}. \end{equation})

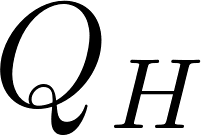
The interactions between the general population and the red-light area are defined by a connectivity matrix

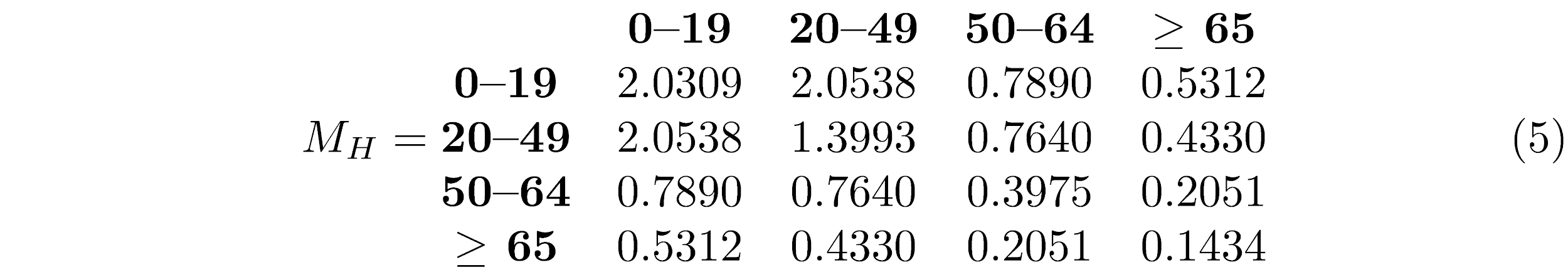
[](#D2L_code_render_\begin{equation} \tag{3}
C_M = \begin{bmatrix} 1 & c_r \\  c_r & 1 \end{bmatrix},
\end{equation})

where contact rate [](https://www.codecogs.com/eqnedit.php?latex=c_r#0) is calculated as the per-capita daily interactions between the customers from the general population and residents of the red-light area (**Table 1**).

The contact patterns between different age-groups are informed by two matrices:

[](#D2L_code_render_\setcounter{equation}{3}
\begin{equation}
M_A = \begin{matrix}
& \textbf{0--19} & \textbf{20--49} & \textbf{50--64} & \textbf{$\ge$ 65} \\
\textbf{0--19} & 14.4405 &   4.9482  &  1.6084  &  0.7058 \\
\textbf{20--49} & 4.9482  &  9.2541   &  2.6860  &  0.6868 \\
\textbf{50--64} & 1.6084  &  2.6860   &  1.4837  &  0.3820 \\
\textbf{$\ge$ 65} & 0.7058  &  0.6868   &  0.3820  &  0.3252
\end{matrix}
\end{equation})

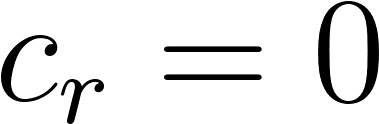
when individuals are not isolated / quarantined in their home ([](https://www.codecogs.com/eqnedit.php?latex=Q_N#0),[](https://www.codecogs.com/eqnedit.php?latex=Q_H#0)), and

[](#D2L_code_render_\setcounter{equation}{4}
\begin{equation}
M_H = \begin{matrix}
& \textbf{0--19} & \textbf{20--49} & \textbf{50--64} & \textbf{$\ge$ 65} \\
\textbf{0--19} & 2.0309 &   2.0538 &  0.7890 &   0.5312 \\
\textbf{20--49} & 2.0538 &   1.3993 &  0.7640 &   0.4330 \\
\textbf{50--64} & 0.7890 &   0.7640 &  0.3975 &   0.2051 \\
\textbf{$\ge$ 65} & 0.5312 &   0.4330 &  0.2051 &   0.1434
\end{matrix}
\end{equation})

when they are (matching contact patterns at the household level) [[2]](https://paperpile.com/c/dN8otS/Kwwz).

We assumed that individuals with asymptomatic and mild infections are only 50% infectious compared to severe infections (**Table 3**).

*Implementation of initial lockdown*To implement the 40 day national lockdown in our model, we specified that everyone remained at home, and their contact patterns were informed by the household matrix [](https://www.codecogs.com/eqnedit.php?latex=M_H#0) for the duration of lockdown. Moreover, set the interaction rate $$c\_r$$ between the general population and the red-light area at zero during this period.

*Post-lockdown*After the initial lockdown period, contact patterns were informed by the overall contact matrix [](https://www.codecogs.com/eqnedit.php?latex=M_A#0), and it was assumed that as a result of improved contact-tracing capacity achieved during lockdown, 50% of symptomatic cases were isolated after the lockdown period [[3]](https://paperpile.com/c/dN8otS/6qtn). For the scenario of continued closure of the red-light area after lockdown, we maintained the contact rate [](https://www.codecogs.com/eqnedit.php?latex=c_r%20%3D%200#0); with no lockdown it was reset at its original value (**Table 1**).

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| **Table 3.** Model parameters | | | |
| Parameter | Definition | Value | Reference |
|  | Reproduction number | 1.75–2.25 | [[4,5]](https://paperpile.com/c/dN8otS/38yW+k1rM) |
|  | Probability of infection | Calibrated to | |
|  | Relative infectivity of asymptomatic infections | 0.5 | [[6]](https://paperpile.com/c/dN8otS/lLL3) |
|  | Relative infectivity of mild cases | 0.5 | [[6]](https://paperpile.com/c/dN8otS/lLL3) |
|  | Duration of incubation period | 5.2 | [[7]](https://paperpile.com/c/dN8otS/OWam) |
|  | Proportion of asymptomatic cases | 0.28 | [[8]](https://paperpile.com/c/dN8otS/tohb) |
|  | Proportion of severe symptomatic cases, age group 0–19 | 0.025 | [[9]](https://paperpile.com/c/dN8otS/ORd7) |
| age group 20–49 | 0.32 |
| age group 50–64 | 0.32 |
| age group ≥65 | 0.64 |
|  | Number of days before isolation of symptomatic case | 1 | [[9]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Proportion of symptomatic cases being isolated | 0.05 | [[9]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Recovery period of mild and asymptomatic cases | 4.6 | [[9]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Hospitalization rate | 1/3.5 | [[10]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Proportion of symptomatic cases needing ICU in hospitals, age group 0–19 | 0.014 | [[9]](https://paperpile.com/c/dN8otS/ORd7) |
| age group 20–49 | 0.042 |
| age group 50–64 | 0.075 |
| age group ≥65 | 0.15 |
|  | Proportion of hospitalized cases that are fatal | 0.2296 | [[9]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Proportion of hospitalized cases needing ICU that are fatal | 0.1396 | [[9]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Recovery rate of hospitalized cases | 1/10 | [[11]](https://paperpile.com/c/dN8otS/PFuL) |
|  | Recovery rate of hospitalized cases needing ICU | 1/13.25 | [[10]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Mortality rate of hospitalized cases | 1/9.7 | [[10]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Mortality rate of hospitalized cases needing ICU | 1/7 | [[12]](https://paperpile.com/c/dN8otS/SpsH) |

*Data collection*

To collect city-level population data, statistical analysis was conducted to estimate the year-on-year population growth rate based on the information reported by the the Department of Economic and Social Affairs, United Nations (Gerland, 2014) & , Govt. of India (Census, 2011) for population size of City/District and Population Density.

To analyze data about RLAs, extensive review and evaluation of research articles (including published reports, books, journals, research papers, program agendas/assessments/summaries), press releases, and credible media reports was conducted for ascertaining accurate estimates for number of sex workers, number of brothels, and the number of sex workers per brothel.

For confirming the above data and getting the information on the number of non-sex workers per brothel, number of customers per sex worker per day, number of sex workers crossed on the way to brothel in the RL per visit, number of brothel workers met inside brothels on an average red light visit by a customer per visit, total interaction with sex workers and staff by a customer per visit and sex worker interaction with other sex workers per day, primary data collection techniques were used as an additional measure to validate the data estimates suggested in preexisting literature [(Ghosh 2009; Shahriar 2020; Nair and Sen 2005)](https://paperpile.com/c/dN8otS/H7Zg+2sse+omwI)(NACO, 2016; NRCB, 2016; 2017).

The respondents were identified and selected based on their work experience in RLAs and continued access/exposure to the primary sampling units that comprised of active/former sex workers, brothel keepers, pimps and communities inhabiting in and around RLAs. The work experience/access/exposure to RLAs for the respondents ranged from minimum 1 year to up to 15 years. The respondents were identified based on their close engagement with RLA residents, police, the city’s municipal corporation, NGOs specifically working in the particular RLA, NGOs addressing broad issues relating to RLA, counsellors, health service providers, workers association active in RLA, local business, and shop owners.

Cumulatively, for 5 RLAs, 147 sex workers, 87 Pimps/Brothel Managers, 143 customers, 33 social workers/researchers, 103 community members, and 39 local business owners i.e. 552 individuals were approached. Among these, 180 completed follow-up in-depth face to face interviews at 5 RLAs conducted in local languages resulting in a 32.6% overall response rate. The primary sample units includes 48 sex workers, 31 Pimps/Brothel Managers, 43 customers, 14 social workers/researchers, 24 community members, 20 local business owners. The trained field data collectors conducted confidential in-depth interviews with the sex workers after obtaining consent to share information. To get an estimation of the population working in RLAs, non-sex-workers in RLAs were oriented to work as survey enumerators. The survey included demographic details, indicators of mobility, socio-economic vulnerability, engagement with customers, and routine activity patterns. The respondent’s identities are kept confidential for safety reasons.

For all-India data, the number of sex workers, brothels, and customer visits was evaluated from secondary sources (Global March, 2014; DESA, UN). Exhaustive face validation with subject experts was conducted for the dynamic data sets pertaining to the movement of sex / non-sex workers, customers, and their interaction within the brothels due to the high volatility of movement patterns of primary respondents at any given time-space in RLAs. Where more general secondary sources exhibited discrepancies with the specific RLA surveys, the more specific estimates from the five RLA surveys were used to compose final data at the national level.

**Results**

**Discussion**

**References**

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