Spatial SEIR Models

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A Spatial SEIR Model for COVID-19 in South Africa

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A Spatial SEIR Model for COVID-19 in South Africa

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Spatial COVID Modeling

What should be considered?

South Africa is a large, diverse country with marked income inequality and differences in access to adequate housing, basic municipal services, transportation and medical care. Increased morbidity risks due to TB and HIV. Thus spatially diverse levels of vulnerability to the COVID-19 pandemic, which will result in limited accuracy if not taken into account when modelling.

- heterogeneity in COVID-19 prevalence
- SEIR model with a spatial spread component
- four infectious compartments
- spatial vulnerability index based on socioeconomic and health susceptibility characteristics
- post-modeling vs. status quo modeling

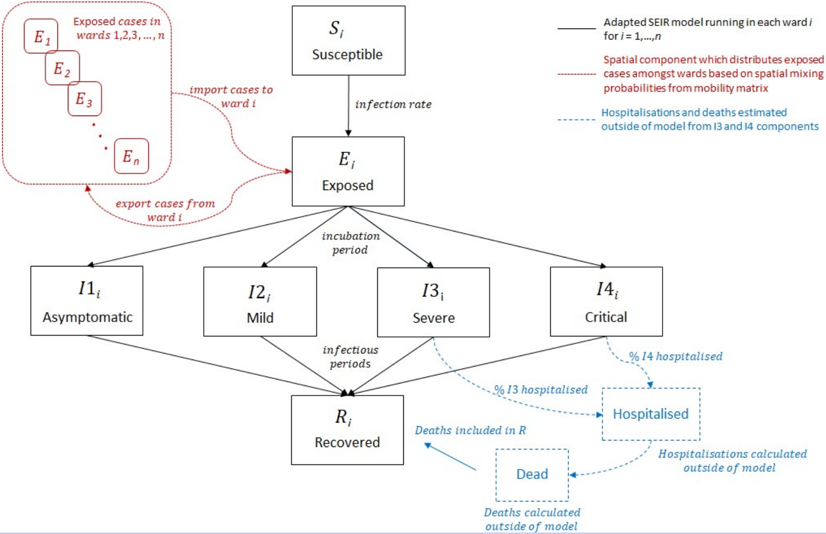
SEIR Models

- The Susceptible-Exposed-Infectious-Recovered compartmental model: well-known epidemiological model, developed by Kermack and McKendrik
- The underlying assumption: each person is equally likely to interact with any other person, i.e. ‘homogeneous mixing’
- Epidemic outbreak exhibits spatial structure

South Africa

Large differences in the capacity of different segments of society to self-isolate, and therefore in their exposure to the disease. This makes modeling the pandemic at national or provincial scale unsatisfactory, due to a number of societal characteristics.

Spatial SEIR Model



$$\frac{dS_i}{dt} = -\frac{\beta_i S_i(\rho I_{1_i} + I_{2_i} + I_{3_i} + I_{4_i})}{N_i}$$

$$\frac{dE_i}{dt} = \frac{\beta_i S_i(\rho I_{1_i} + I_{2_i} + I_{3_i} + I_{4_i})}{N_i} - \sigma E_i$$

$$\frac{dI_{1_i}}{dt} = p_1 \sigma E_i - \gamma_1 I_{1_i}$$

$$\frac{dI_{2_i}}{dt} = p_{2_i} \sigma E_i - \gamma_2 I_{2_i}$$

$$\frac{dI_{3_i}}{dt} = p_{3_i} \sigma E_i - \gamma_3 I_{3_i}$$

$$\frac{dI_{4_i}}{dt} = p_{4_i} \sigma E_i - \gamma_4 I_{4_i}$$

$$\frac{dR_i}{dt} = \gamma_1 I_{1_i} + \gamma_2 I_{2_i} + \gamma_3 I_{3_i} + \gamma_4 I_{4_i}$$

Considerations

- Model parameters
- Societal change due to interventions
- Mobility repesentability
- Case data location accuracy
- Immunity
- Vaccinations

Spatial SEIR Model with Vaccinations

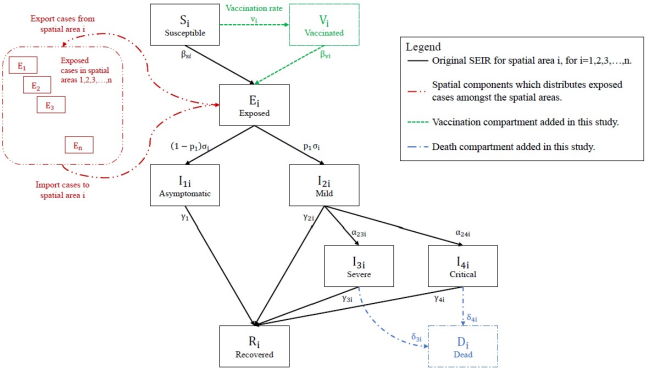


Figure 1: The extended spatial SEIRDV model indicating the movement of exposed between spatial areas, for areas $i = 1, 2, 3, ..., n$.

$$\frac{dS_i}{dt} = -\nu_i S_i - \frac{\beta_{si} S_i(\rho I_{1i} + I_{2i} + I_{3i} + I_{4i})}{N_i}$$

$$\frac{dV_i}{dt} = \nu_i S_i - \frac{\beta_{vi} S_i(\rho I_{1i} + I_{2i} + I_{3i} + I_{4i})}{N_i}$$

$$\frac{dE_i}{dt} = \frac{(\beta_{vi} + \beta_{si}) S_i(\rho I_{1i} + I_{2i} + I_{3i} + I_{4i})}{N_i} - \sigma E_i$$

$$\frac{dI_{1i}}{dt} = p_1 \sigma E_i - \gamma_1 I_{1i}$$

$$\frac{dI_{2i}}{dt} = (1 - p_1)\sigma E_i - \gamma_{2i} I_{2i} - \alpha_{23i} I_{2i} - \alpha_{24i} I_{2i}$$

$$\frac{dI_{3i}}{dt} = \alpha_{23i} I_{2i} - \gamma_{3i} I_{3i} - \delta_{3i} I_{3i}$$

$$\frac{dI_{4i}}{dt} = \alpha_{24i} I_{2i} - \gamma_{4i} I_{4i} - \delta_{4i} I_{4i}$$

$$\frac{dR_i}{dt} = \gamma_1 I_{1i} + \gamma_{2i} I_{2i} + \gamma_{3i} I_{3i} + \gamma_{4i} I_{4i}$$

$$\frac{dD_i}{dt} = \delta_{3i} I_{3i} + \delta_{4i} I_{4i}$$

Thank you!

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