Stochastic SIR Metapopulation Model of COVID-19 Spread in USA, Mexico, and Canada

Berlinda Nyantakyi, *Department of Mathematical Sciences, University of Texas at El Paso*
Michael Obuobi, *Department of Mathematics and Statistics, Auburn University*
Osei K. Tweneboah, *School of Theoretical and Applied Science, Ramapo College of New Jersey*
Maria C. Mariani, *Department of Mathematical Sciences, University of Texas at El Paso*

We develop a stochastic SIR-based compartmental model to study the spread of COVID-19 across an interconnected metapopulation consisting of the USA, Mexico, and Canada. The model incorporates disease transmission within each country, cross-border migration of susceptible and infected individuals, recovery, and disease-induced mortality.

To capture random fluctuations that deterministic models often miss, we extend the framework to a stochastic differential equation (SDE) system with multiplicative noise. Using Itō calculus and Python simulations, we analyze how stochasticity reshapes epidemic dynamics relative to deterministic predictions.

Our results show that random effects can sustain oscillations near endemic equilibria (Mexico), decline infection levels (Canada), or amplify rapid growth (USA). These findings underscore the crucial role of stochasticity in pandemic forecasting and demonstrate the value of SDE-based models for understanding epidemic outcomes in interconnected populations.

Keywords: Stochastic SIR model, COVID-19, Metapopulation dynamics, Brownian motion, Migration, Epidemic forecasting