# Modelling Climate Migration in Southeast Asia due to Sea-Level Rise


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SEA² Program

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## MAIN MESSAGES

- Displacement risk and radiation models address the two key questions of sea-level rise induced migration, "who will be affected?" and "where will they go?" respectively
- The risk-informed quantification of displacement improves the reliability of subsequent migration flow projections
- Both the displacement risk and radiation models require minimal data inputs and can be readily applied in data-scare contexts, such as Southeast Asia
- Preliminary results for Indonesia suggest that sea-level rise can increase migration outflows by at least 18%
- The displacement risk model can be improved by incorporating multiple hazards and indirect impacts associated with sea-level rise, and the radiation model could be enhanced by testing variables other than population as a proxy for the attractiveness of destinations

## INTRODUCTION

**Sea-level rise (SLR) induced migration* is a real risk for Southeast Asia (SEA), but has been insufficiently studied**

**SLR Hazard**
- Globally, 1 billion people to be exposed to coastal hazards by 2050 (Dodman et al., 2022)
- Sea level has risen at a rate of 2.3mm/yr since 1960, and is projected to rise up to 77 cm in the 21st Century (Trisos et al., 2021)

**Exposure to SLR in SEA**
- Growing populations, rapid urbanisation & pre-existing social vulnerabilities
- GDP losses from SLR expected to be double that of global average (ADB, 2009)

**SLR-linked Migration**

Pathways:
- Uninhabitable conditions
- Property & infrastructure damage
- Threats to livelihoods

**Gaps in Research**
- Few studies on climate change-linked migration in SEA
- Coverage of SEA has generally been on global/near-global scales

**There are 2 key questions to be answered with regards to SLR-induced migration**

**1 Who will be affected?**

This pertains to the volume of expected migration, differentiated by the vulnerability of populations.

**2 Where will they go?**

This pertains to the migration flows in the face of SLR hazards, and the level of agency and choice in deciding the destination.

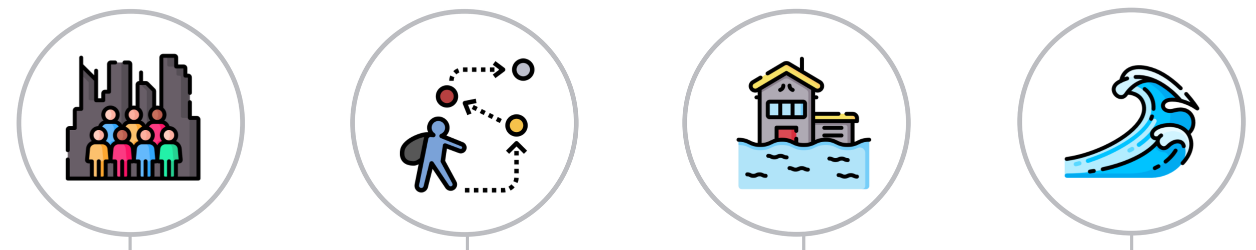
* Note that migration is used in this study as an umbrella terms to describe a range of mobility processes, including voluntary migration and forced displacement.

## METHODOLOGY

### 1 Displacement Risk Model

In order to address the 'who' dimension of climate change-induced displacement, a displacement risk model is developed to assess the risk of displacement of populations in the face of sea-level rise and storm surges.

**Risk = Hazard x Exposure x Vulnerability**



| Variable | POP | DIS | HD | FD |
|---|---|---|---|---|
| | No. of people displaced | Proportion of people displaced | Proportion of housing damage | Flood depth |
| **Rate of exceedance function** | - | $G_{DIS\,|\,HD}$ | $G_{HD\,|\,FD}$ | $\lambda(FD)$ |

**Equation to calculate Average Annual Displacement (AAD)**

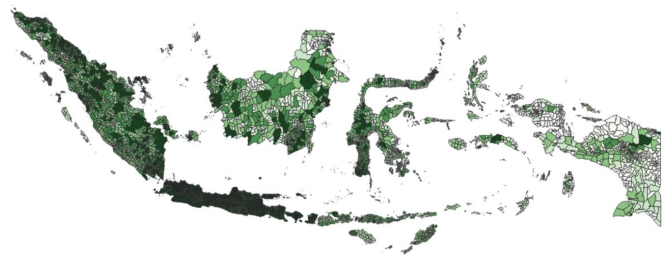
$$AAD = \sum_i POP_i \times \int_{FD} \int_{HD} GDIS_{|\,HD}\,(DIS|HD)\;|\;dG_{HD\,|\,FD}\,(HD|FD)\;d\lambda(FD)$$

### 2 Radiation Model

To address the next dimension of 'where', a radiation model is applied to project internal migration flows. In the climate change scenarios, the displacement risk produced above is used as one of the inputs.

**Baseline Scenario (2010, 2050)**

**Input: Population Distribution**



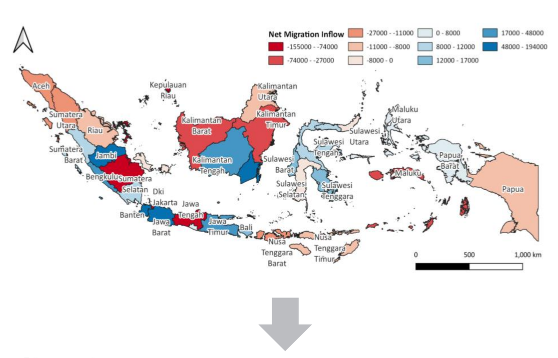
WorldPop 2020 population counts (Bondarenko et al., 2020)

**Model: Baseline Radiation** (Simini et al., 2012)

$$p_{i,j} = \frac{m_i n_j}{(m_i + s_{ij})(m_i + n_j + s_{ij})}$$

where,
$p_{ij}$ = probability of an individual migrating from location $i$ to location $j$
$m_i$ = population at location $i$
$n_j$ = population at location $j$
$s_{ij}$ = (total population within a circle of radius $r_{ij}$) – $(m_i + n_j)$
$r_{ij}$ = Euclidean distance between locations $i$ and $j$

**Output: Migration Flows**



**Validation**

5-year flows (BPS, 2010)

Lifetime flows (BPS, 2010)

**Climate Change Scenario (2050 – RCP4.5)**

**Input: Population Distribution**

WorldPop 2020 population counts (Bondarenko et al., 2020)

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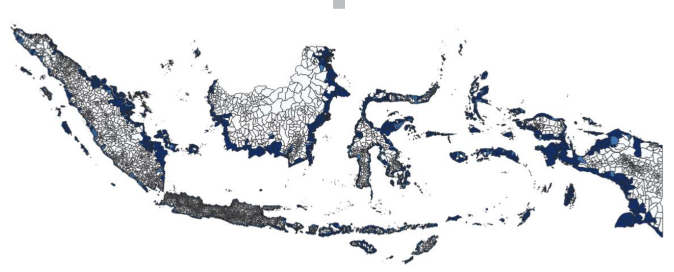


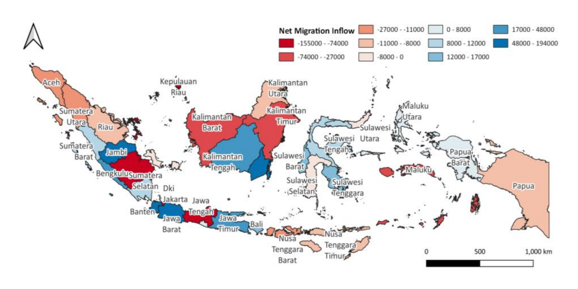
Average Annual Displacement (AAD) from the displacement risk model

**Model: Sea-level Rise Radiation** (Davis et al., 2018)

$$p_{i,j} = \frac{m_i (n_j - T_j)}{(m_i + \tilde{s}_{ij})(m_i + n_j + \tilde{s}_{ij})}$$

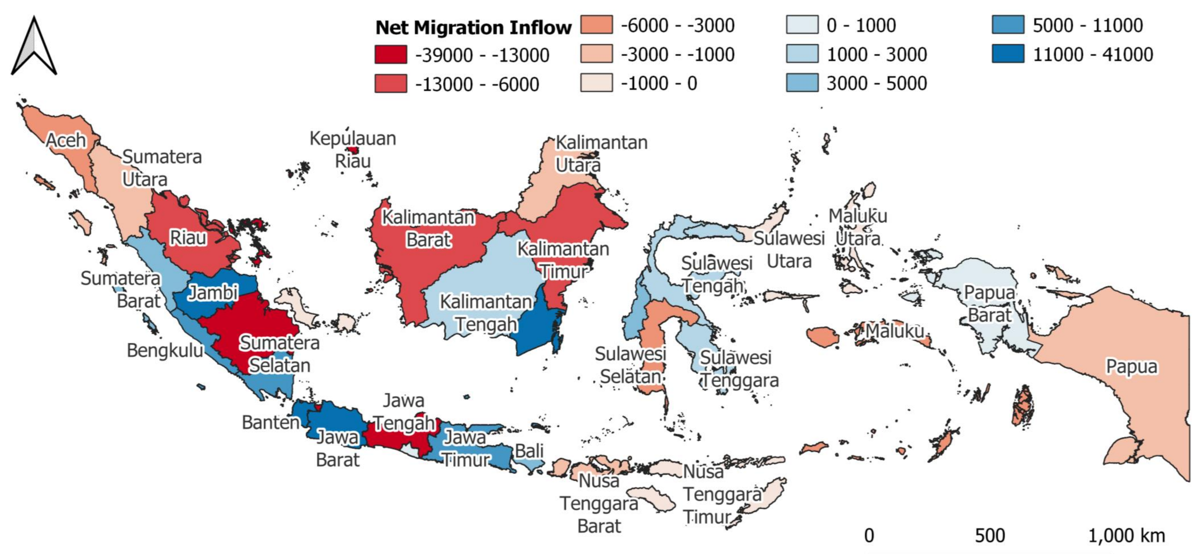
where,
$T_j$ = total population expected to migrate from location $j$ due to inundation
$\tilde{s}_{ij} = s_{ij} - \sum_{k \in r_{ij}}^{j} T_k$, the population who remain in a circle of radius $r_{ij}$ following inundation

**Output: Migration Flows**



## RESULTS

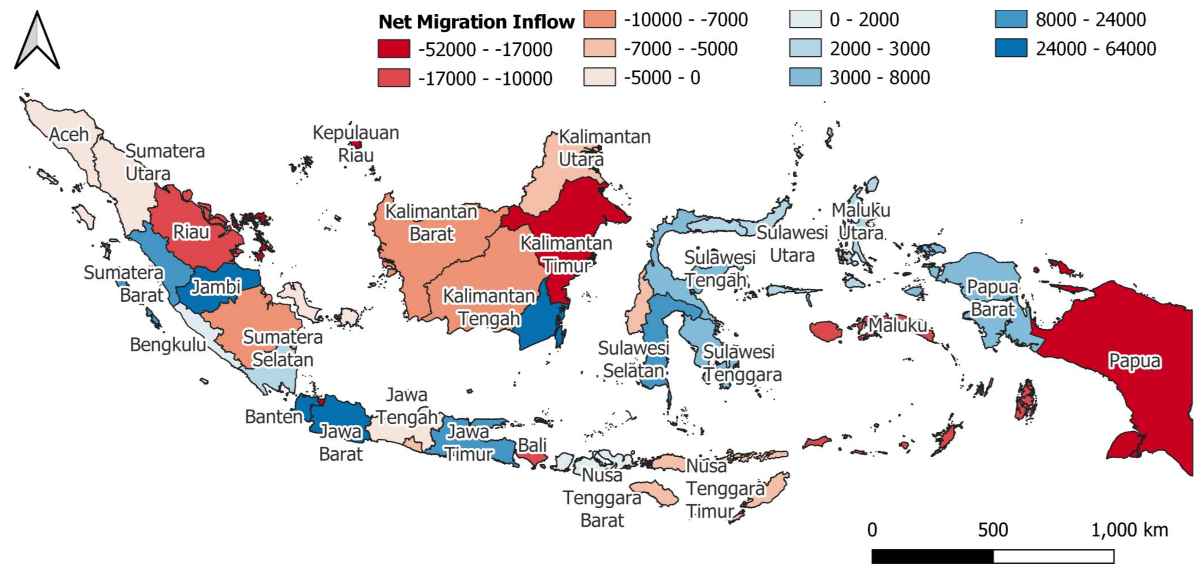
**Baseline Scenario (2010)**




Net migration inflows by province in Indonesia for 2010, as predicted by the baseline radiation model.

- 1.38 million people migrated internally, inter-province out-migration rate of 0.77%
- $R^2$ = 0.512 (recent flows), validated against 2010 migration statistics
- 90% of the predictions have negative residuals relative to recent flows, but recent flows are cumulative over 5 years

**Climate Change Scenario (2050 – RCP4.5)**




Net migration inflows by province in Indonesia for 2050, under RCP4.5, as predicted by the sea-level rise radiation model.

- 1.9 million people predicted to migrate internally with sea-level rise and population growth in 2050, with an inter-province out-migration rate of 0.71%
- Under the baseline scenario in 2050, 1.68 million people were predicted to migrate internally, with an out-migration rate of 0.61%
- With sea-level rise, out-migration increased by an average of 18.29%

## NEXT STEPS

**1 Displacement Risk Model**
- Consideration of other SLR hazards and indirect impacts
- Calibrate displacement threshold using historical data
- Improve projections of future population distribution
- Include projections of future protections levels
- Computation for remaining countries in SEA

**2 Radiation Model**
- Test other proxy variables on attractiveness of destinations
- Validate against additional years of observed migration flows
- Pinpoint hotspots of climate out- and in-migration
- Run on smaller spatial scales
- Run for additional RCPs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