

FUTURE RISK PATHWAYS FOR A  
SOUTHEAST ASIAN MEGACITY  
COUPLING SOCIOECONOMIC SCENARIOS  
AND AGENT-BASED MODELLING TO  
INTEGRATE EXPOSURE, VULNERABILITY, AND  
HAZARDS IN JAKARTA (INDONESIA)

EGU GENERAL ASSEMBLY 2026

NH9.4, URBAN RISK IN A CHANGING WORLD: DYNAMICS, DISRUPTION & RESILIENCE  
IN CITIES

Dr Alexandre Pereira Santos ([asantos@uni-bonn.de](mailto:asantos@uni-bonn.de)), Charlotta Mirbach, Gusti Ayu Ketut  
Surtiari, Prof. Matthias Garschagen



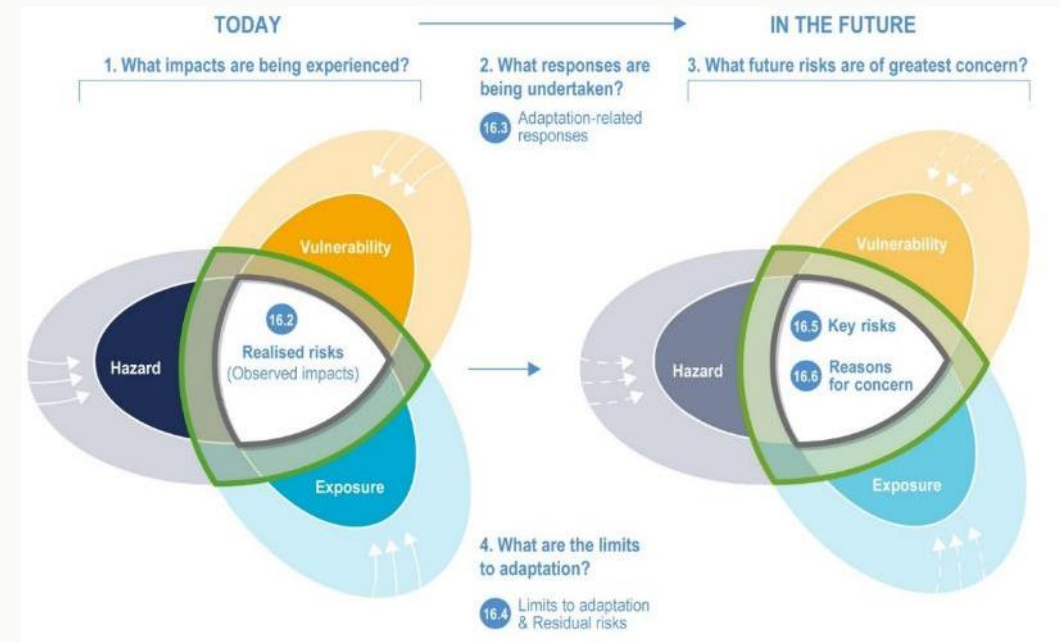
SUPPORT

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# PROBLEM STATEMENT

- The long-term development of coastal megacities in Southeast Asia faces **deep uncertainty** from:
  - increasing risks
  - dynamic socioeconomic conditions
  - rapid urbanisation
- Scenarios are helpful in outlining future adaptation conditions by engaging with future uncertainty and establishing plausible development narratives.
- Local scenarios reduce uncertainty with context-rich future socioeconomic narratives.
- Urban development leads to path dependent conditions of future adaptation.

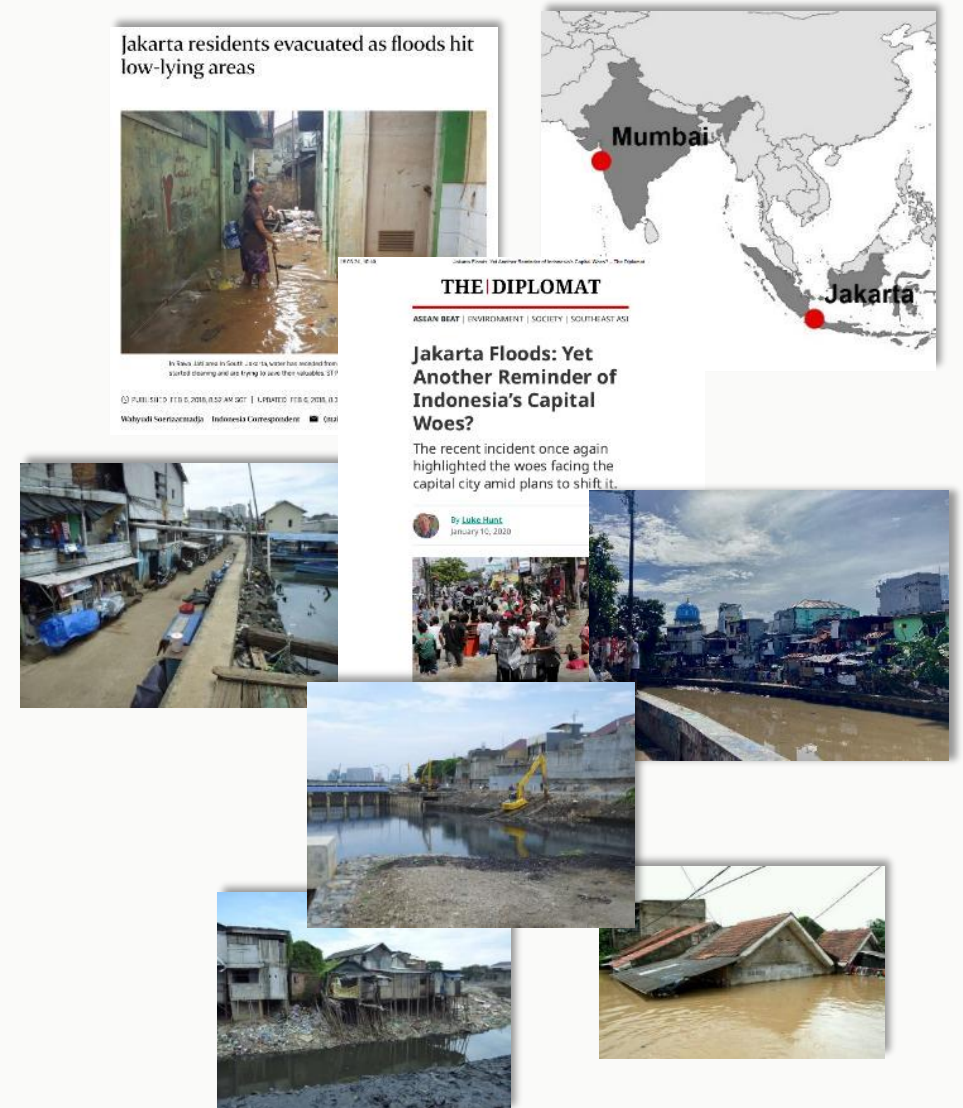


*How will the future socioeconomic and urban development pathways impact the adaptation conditions in the Jakarta Metropolitan region in 2050?*

# CASE STUDY CITIES

- Jakarta and Mumbai, Southeast Asian megacities
- High exposure to current and future hazards.
- Strong growth, economic change, and social fragmentation.
- Climate change adaptation is a strong political goal.
- First adaptation measures conceived, but more is needed in the future (especially at metropolitan scale).
- Regional knowledge hubs.

> *Uncertain risk trajectories and high adaptation pressure*

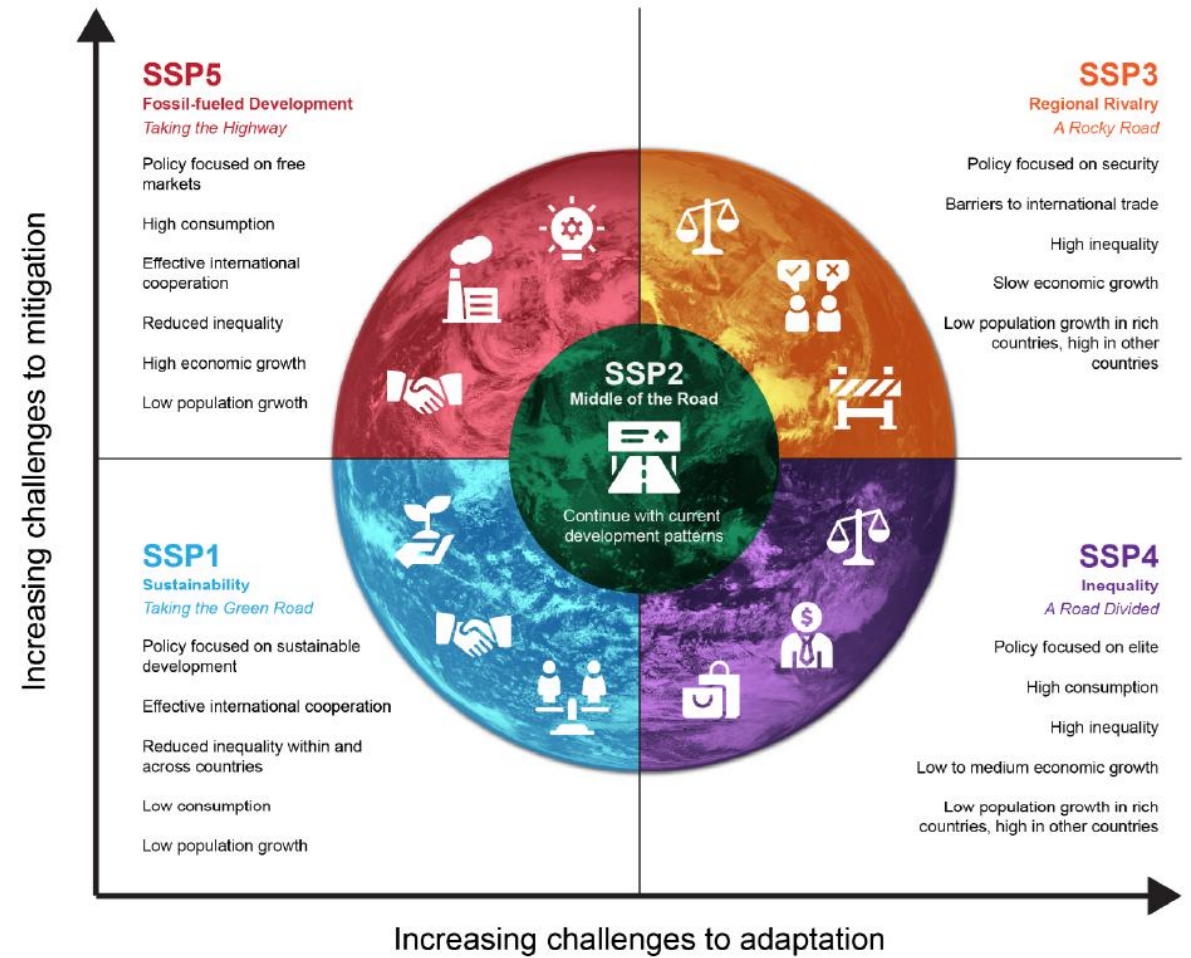
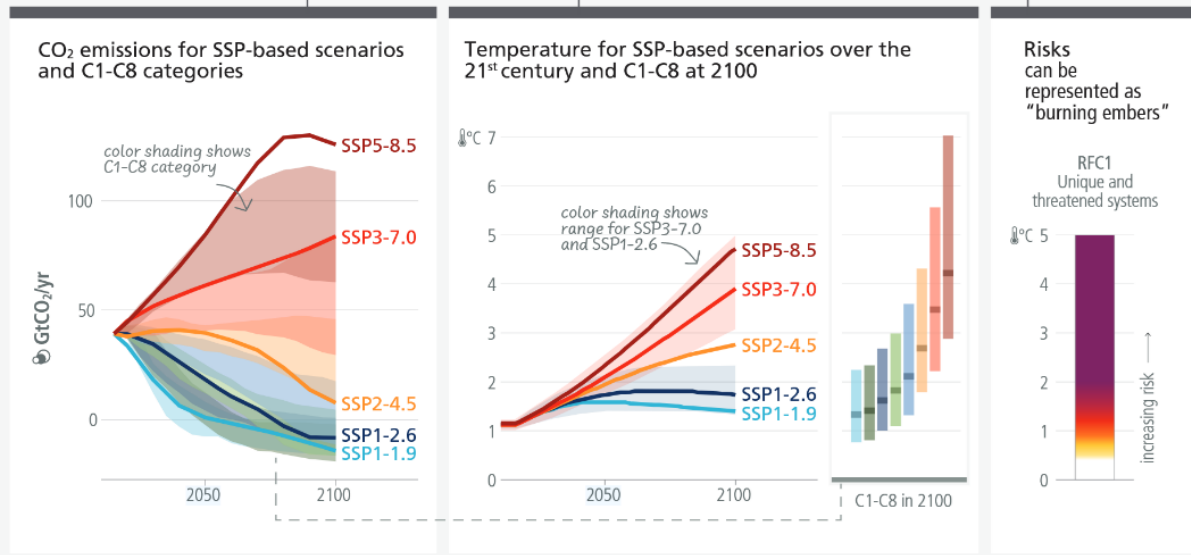
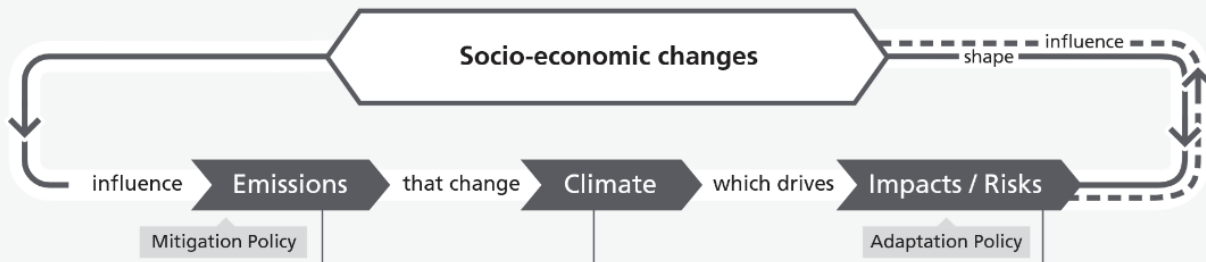


# METHODS

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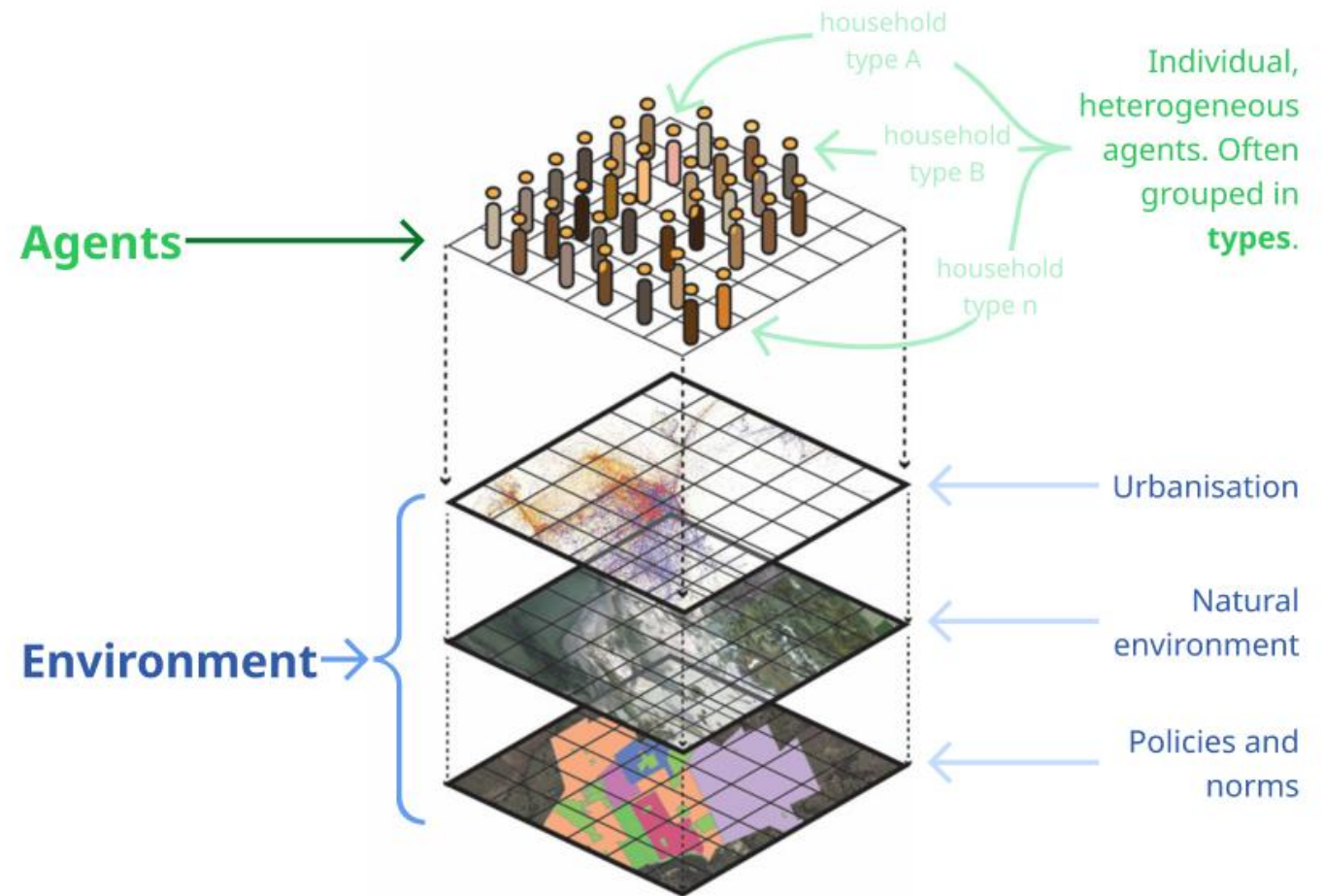
# THE SSP FRAMEWORK

a) AR6 integrated assessment framework on future climate, impacts and mitigation

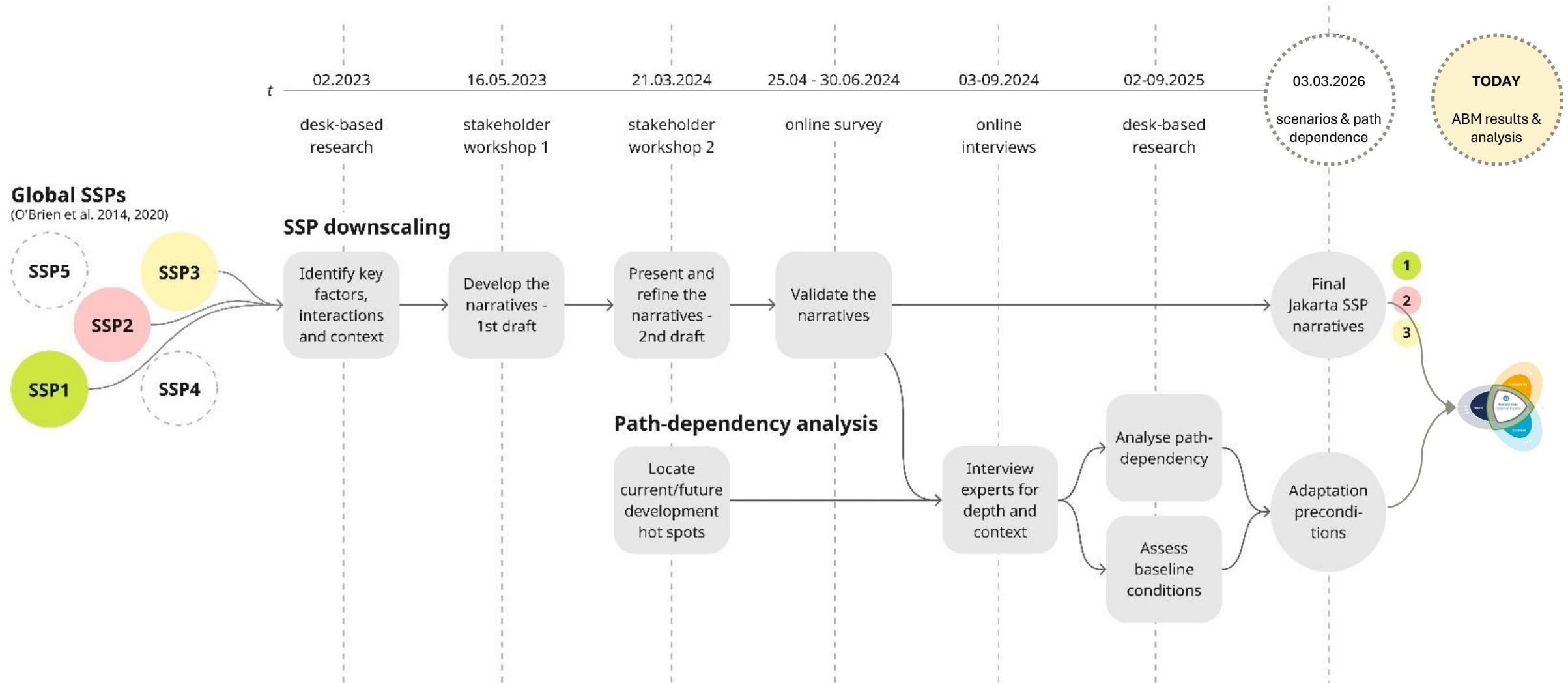


# AGENT BASED SIMULATION

- Agents: autonomous & heterogeneous
- Environment: A representation of space and time. May be discrete (usually a grid with time steps) or non-explicit
- Interactions
  - Agent-agent
  - Agent-environment
  - Environment-environment



# METHODS



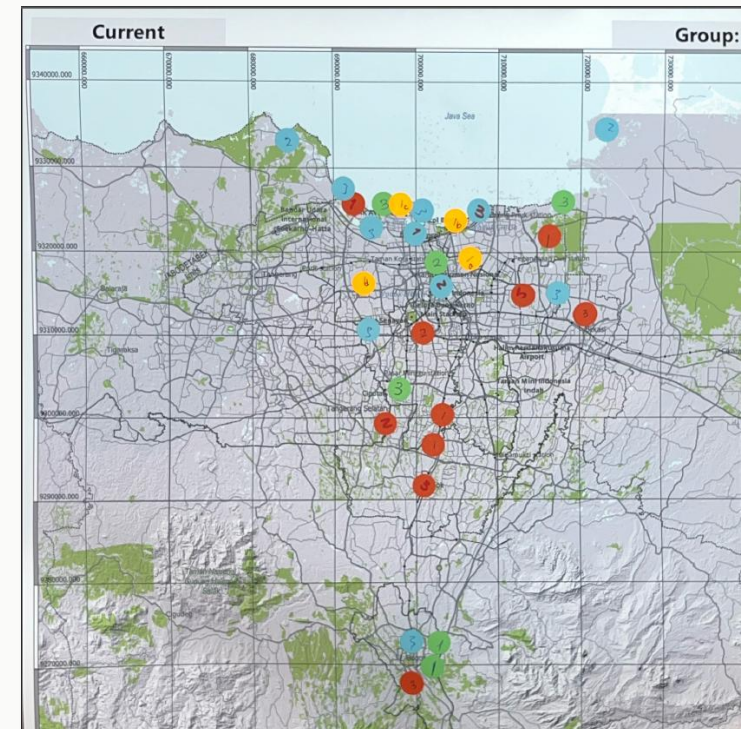
# STAKEHOLDER & EXPERT PARTICIPATION

- We held a participatory mapping exercise during the 21.03.2024 workshop, assessing ongoing and future development hot spots.
- Expert interviews (n=7) provided in-depth discussion on urban and economic development, demographics (incl. regional migration), environmental protection, and policymaking.
- We cross-analysed the evidence from the interviews and mapping with descriptive statistics of high-resolution global data on population, urbanisation, and land use.

Group discussion



Map of current state



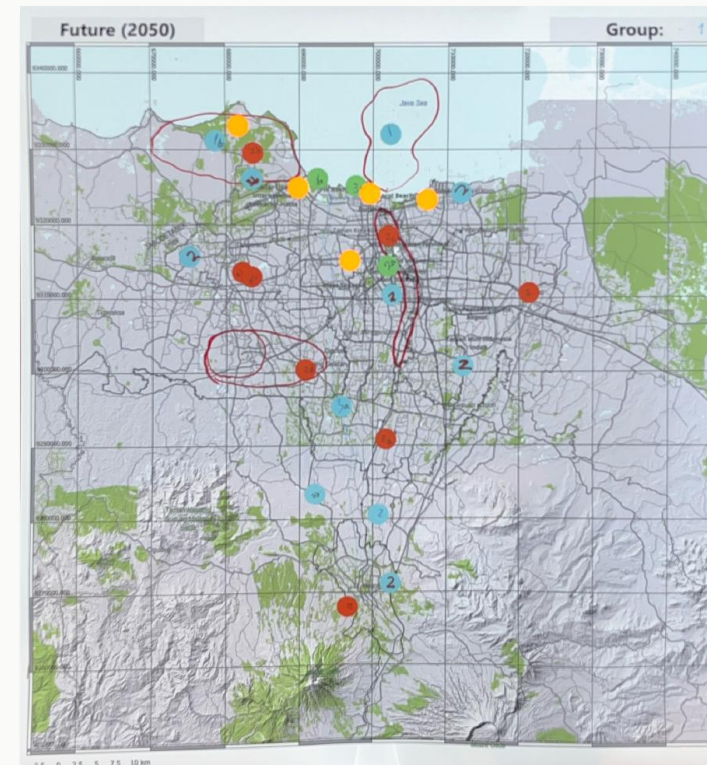
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Group discussion



Map of future trends (2050)



# RESULTS

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MUMBAI METRO: PARTICIPATORY SSP NARRATIVE DOWNSCALING

npj | climate action

Article



<https://doi.org/10.1038/s44168-024-00197-z>

# Identifying future challenges for climate change adaptation through insights from participatory scenario-downscaling in Mumbai

Jan Petzold<sup>1</sup>✉, Matthias Garschagen<sup>1</sup>, Shankar Deshpande<sup>2</sup>, Ravinder Dhiman<sup>3</sup>, Deepal Doshi<sup>1</sup>, Antje Katzschner<sup>1</sup>, Alexandre Pereira Santos<sup>1</sup> & D. Parthasarathy<sup>5</sup>



JAKARTA METRO: SCENARIO DEVELOPMENT & PATH DEPENDENCY






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ENVIRONMENTAL RESEARCH LETTERS

LETTER

# Incorporating path dependency into downscaled SSP narratives: lessons from Jakarta

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**Keywords:** climate adaptation, shared socioeconomic pathways, path dependency, scenario development, urban development








# DOWNSCALED SSP NARRATIVES FOR THE JAKARTA METRO REGION








































































































	Demographics	Land Use Transitions	Infrastructure	Housing	Poverty and inclusion
SSP1 Wider sustainability transitions	The population growth and positive net migration fuel urban expansion and densification, especially in BODETABEK. Social services keep up with the ageing population. Economic development overcomes the "middle-income trap," benefiting from investments in planning, infrastructure, and the natural and built environments.	The urban development pattern is generally compact, with controlled expansion in the periphery and increased compactness in the core regions supported by a hybrid work model and broad digitalisation. The former offices freed by the relocation of the capital support redevelopment. The layered phase-in and out between IKN and Jakarta is successful.	There are sufficient public infrastructure investments that target environmental and social equity. Innovative and participatory urban development policies integrate the expansion of blue and green infrastructure (e.g., the "Green Zone" project), leading to a significant increase in urban green and blue space on public and privately owned land.	Densification and resettlement into vertical and multi-purpose buildings prevent most land-use conflicts. Strong housing policies in high-rise provide affordable living space. Informal areas receive legal status and access to social protection. Poverty alleviation supports housing and settlement self-help initiatives complemented by public and private investment in improved conditions.	The poverty rate drops, and income inequality decreases. The right to the city is recognised for all inhabitants. Awareness raising, capacity building, and institutional change facilitate the unprejudiced inclusion of formerly neglected or marginalised groups. Political participation increases following tenure security policies.
SSP2 Following current trends and partial exploitation of existing potential	The population growth rate plateaus due to reduced birth rates and a drop in migration, most notably in Jakarta. Dependency rates increase with the ageing population, pressuring family income. Moderate economic growth, centred on trade and industry, attains little international integration.	The general urban development is partially fragmented, with interspersed compact and sprawling development supported by unequal digitalisation. Jakarta's carrying capacity peaks, leading to a surge in real estate prices that pressures middle- and low-income households into seeking alternatives at BODETABEK or informal settlements. The IKN competes with Jakarta for investments, especially green ones.	Continued investments in public infrastructure are insufficient to address all needs across sectors, including soil sealing and degradation of environmentally sensitive sites. Due to extensive urban development and land conversion in Jakarta, JABODETABEK experiences decreased green and blue spaces, including urban lakes.	Spatial inequality and land use conflicts intensify, and low-income groups struggle to access affordable housing. There is a surge in slum formation in BODETABEK. Affordable housing investment is limited to renovating existing stock, pressuring middle- and low-income households to relocate to BODETABEK. Informal settlements receive sporadic tenure rights; a few resettlements are participatory. Many deprived neighbourhood pockets remain.	Poverty rates stagnate, and income inequality remains high. The right to the city exists in legislation only. Strong biases characterise the integration of vulnerable groups, and migrants are still not included in public services, despite efforts like awareness-raising and capacity-building. Political participation still depends on formalisation, but there is growing awareness of the migrants' situation.
SSP3 Increasing barriers through inequality and fragmentation	The population growth rate decreases sharply in Jakarta and slows in BODETABEK, as migration and fertility rates drop. The ageing population overcomes the working-age one, increasing dependency and pressuring social support systems. An economic recession restricts resources and funding.	Fragmentation increases in all regions, especially in BODETABEK, where sprawl becomes the norm. Housing supply drops, and the gap increases with demand. Prices surge, built quality decreases, and households are pressured into accepting substandard and flood-prone housing options. The move to IKN is a missed opportunity to relieve the pressure and leaves large vacant and unused areas.	Investments in public infrastructure decrease. Green and blue spaces decrease, degrade, or lose their qualities in biodiversity and buffering climate impacts. Informal settlements grow, including encroachments on protected areas and other forms of land use that are neither sustainable nor equitable.	There are low investments in maintaining and expanding the affordable housing supply—existing stock decays, especially in flood-prone areas. Jakarta is more exclusive, leading to a sharp increase in peripheral informal settlements that threaten natural reserves. Informal settlements do not advance their tenure rights and are preyed upon by eviction campaigns from governmental or private actors. Progress in expanding social protection programs stagnates.	Poverty rates, income inequality and segregation increase. Marginalised groups have less access to social protection, hence the socio-economic and living conditions in vulnerable neighbourhoods deteriorate. There are no advances in providing land titles and legal citizenship status to informal settlers or migrants, restricting political participation.

Additional dimensions include “Economic growth and transitions”, “Migration, labour, and education”, “Social wellbeing, security, and protection”, and “Health”.

# SEMI-QUANTIFICATION OF SSP NARRATIVES

\* share of inhabitants not in employment, education, and training (NEET)

-  Strong increase
-  Increase
-  No significant change
-  Decrease
-  Strong decrease










































































































Socioeconomic dimensions	Dimension components	SSP narratives		
		1	2	3
Demographics	Pop. growth & migration			
	Dependency rate			
Economic growth and transitions	Economic growth			
	Jakarta's economic integration			
	Digital transition			
Migration, labour, and education	Negative impacts of capital move			
	Share of informal work			
	Share of NEET*			
	Digitalisation (work/educ.)			
	Social inclusion			
Land Use Transitions	Negative impacts of capital move			
	Urban expansion			
	Densification			
	Environmental losses			
Infrastructure	Land use conflicts			
	Water, sanitation, and hygiene			
	Drainage			
	Green investments			
Housing	Public transp. & sust. mobility			
	Sustainable and fair housing			
	Informal settlement upgrade			
	Flood-prone settlement protection			
Social wellbeing, security, and protection	Flood preventive zoning			
	Per capita expenditure vs. income			
	Social protection systems			
	Accessibility to welfare			
Poverty and inclusion	Social cohesion & mutual support			
	Poverty rate			
	Inclusion measures			
Health	GINI coefficient			
	Tenure & settlement upgrade			
	Health insurance coverage			
	Health services quality			
	Impacts from urbanisation			
	Precautionary measures			

# SEMI-QUANTIFICATION OF SSP NARRATIVES

SSP1 – Wider sustainability transitions	SSP 2 – Following current trends and partial exploitation of existing potential	SSP 3 – Increasing barriers through inequality and fragmentation
<p>1. The JABODETABEK population growth rate increases, fostering further urbanization. Jakarta's growth rate stagnates due to negative net migration, low fertility, and population loss as the capital is transferred. BODETABEK has a high growth rate, as it attracts scores of Indonesian migrants.</p> <p>2. Indonesia is at the peak of the second demographic transition; the share of the working-age population is at its highest level (low dependency ratio), and the potential for increased output per capita is at its peak.</p> <p>3. The aging trend, higher life expectancies, and lower birth rates result in an urban population of almost equal shares in each age group.</p>	<p>1. JABODETABEK population growth rate decreases due to reduced birth rates and decreased in-migration. Jakarta growth rate is stagnant, and the absolute population reduces as the capital is transferred. BODETABEK still attracts many migrants, keeping growth rate moderate.</p> <p>2. Indonesia surpasses the height of its demographic dividend between 2020 and 2030 when the share of the working-age population was at its highest level; the share of the dependent population increases (higher dependency ratio).</p> <p>3. The share of the elderly increases and outweighs the working-age inhabitants.</p>	<p>1. JABODETABEK's population growth rate decreases moderately. Jakarta's growth rate significantly decreases due to lower birth rates, reduced migration (fuelled by regional rivalry), and the population loss after the capital move. The population growth rate still increases slightly in BODETABEK.</p> <p>2. Increasing life expectancy and the city's aging population result in a high dependency ratio.</p> <p>3. The comparably large share of the elderly outweighs the working-age inhabitants.</p>

\* share of inhabitants not in employment, education, and training (NEET)

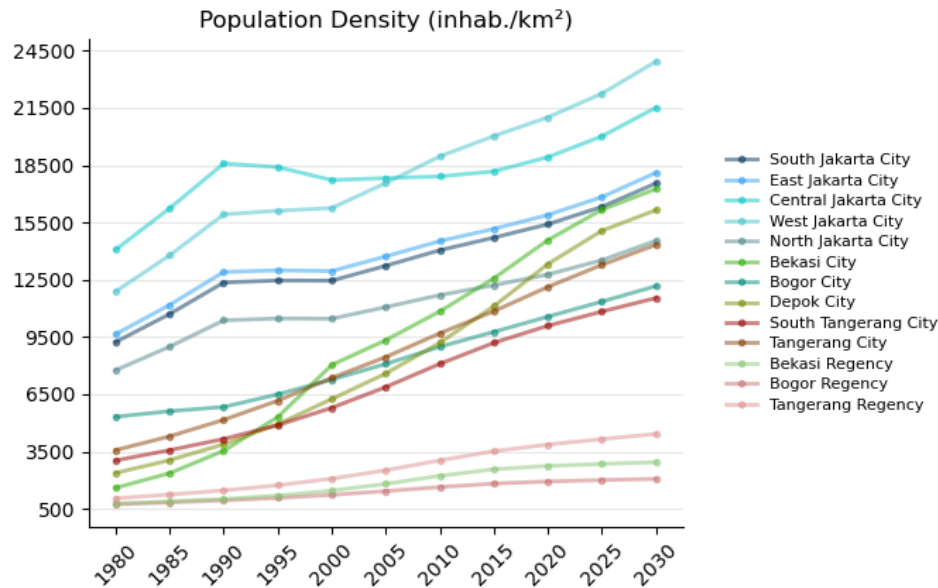
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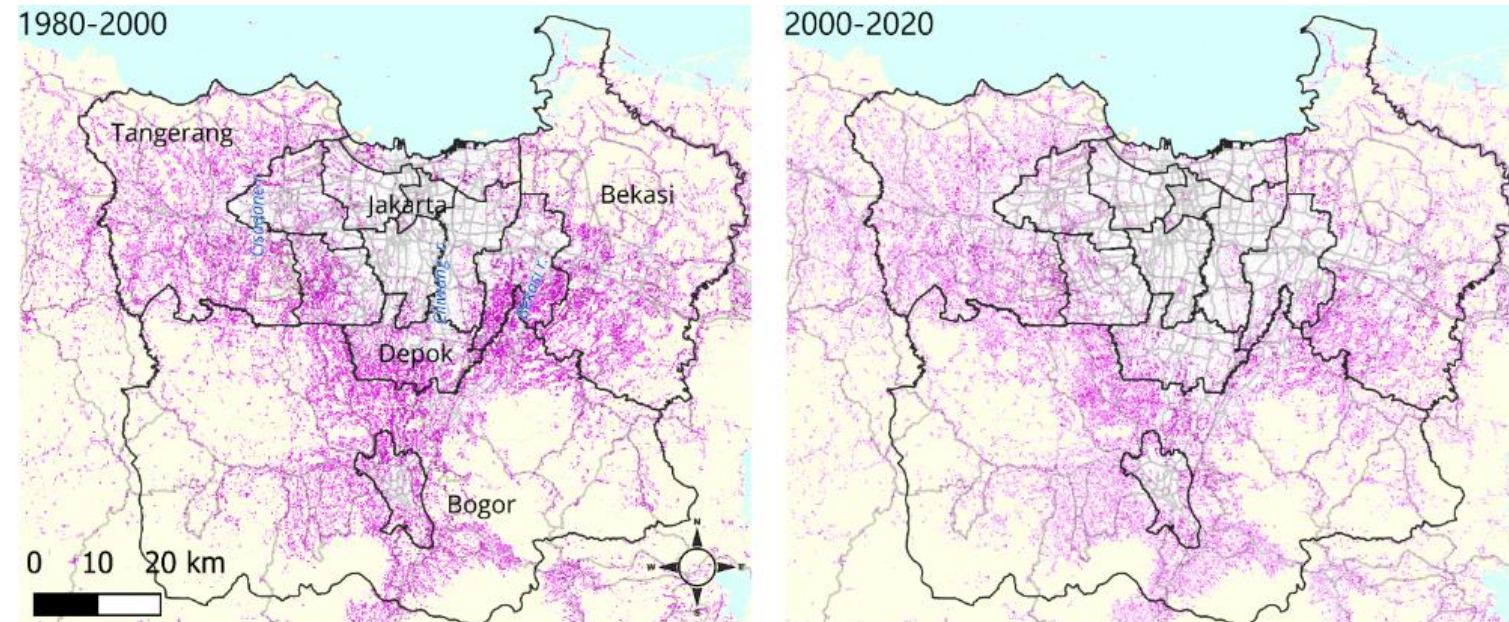
# PATH DEPENDENCE: PAST URBANISATION TRENDS

Urbanisation expanded intensely from 1980 to the 1990s, and expansion and densification are still ongoing.

Inner suburbs present the highest increases since the 2000s, but even the core still grows.



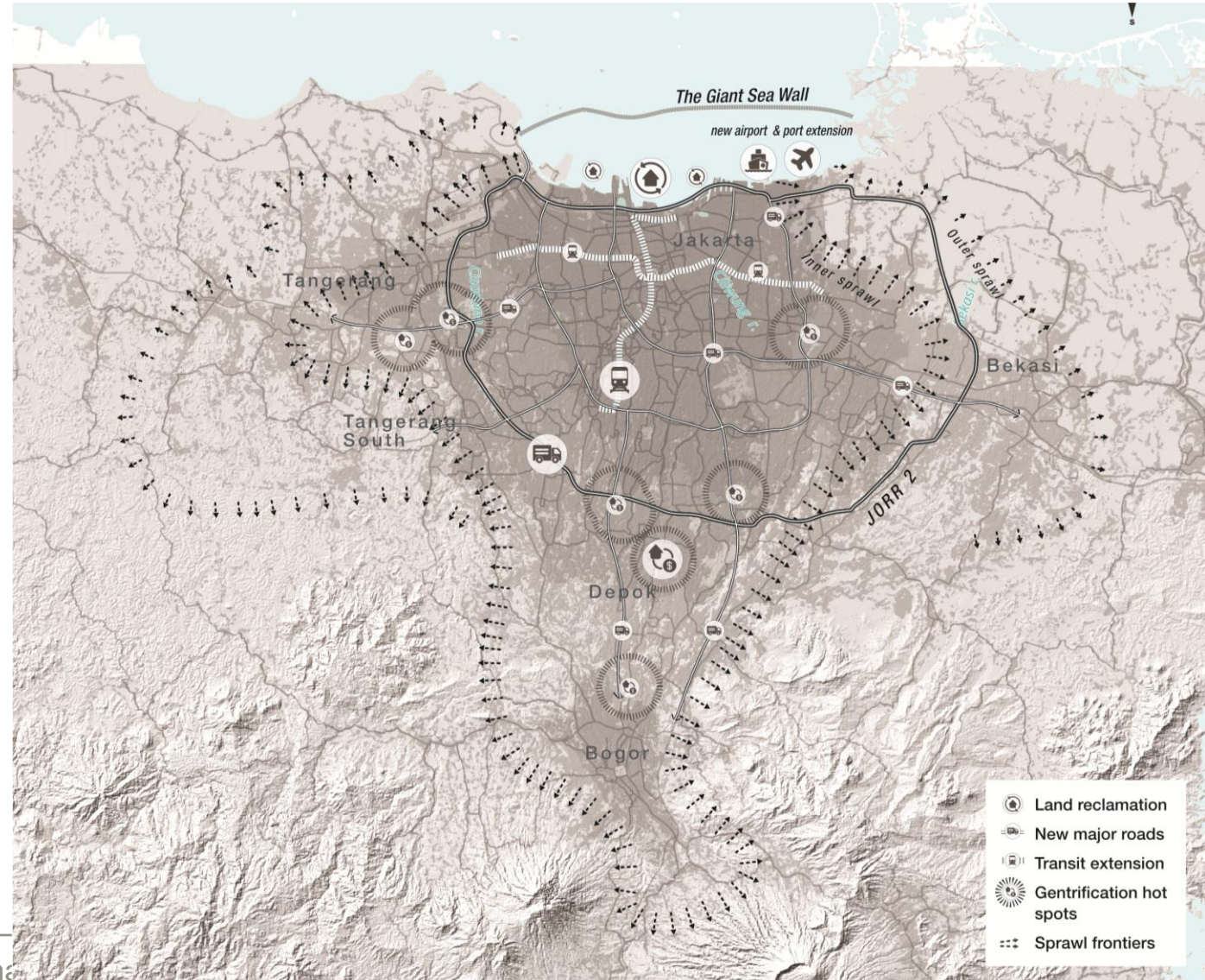
Population density for each city in Jabodetabek between 1980 and 2030. Source: the authors with data from Kemper et al. 2024.



New urban areas added between 1980-2000 and 2000-2020. Source: the authors with data from Kemper et al. 2024.

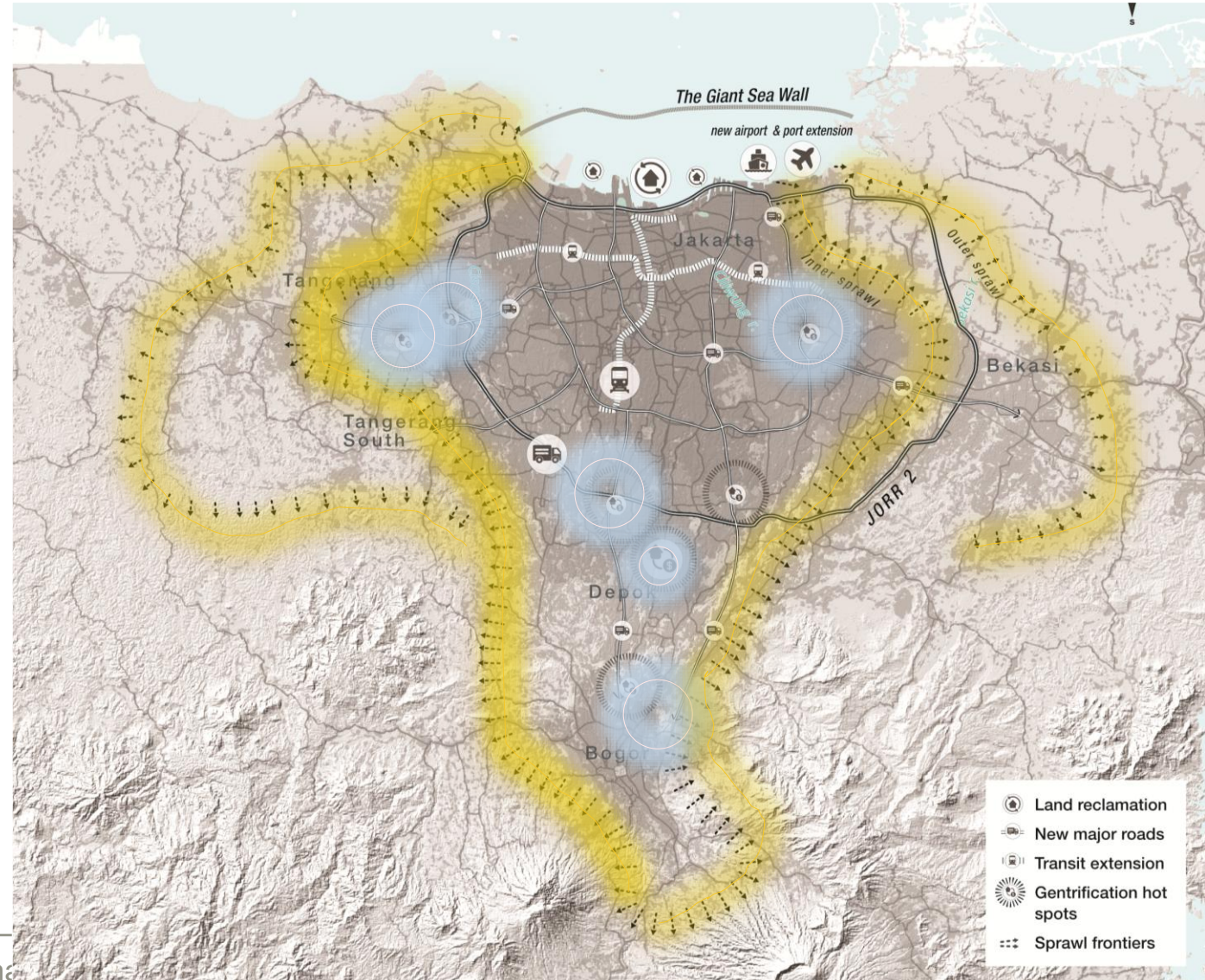
# PATH DEPENDENCE FROM URBANISATION

- Contingent events:
  - giant sea wall
  - transit-oriented development
  - national capital transfer to IKN
- Lock-in effects:
  - sprawl
  - gentrification.
- Driver of sub-optimality:
  - gentrification coupled with unequal development

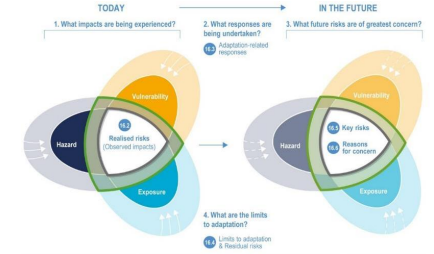


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# FUTURE RISK: SCENARIO COMPARISON



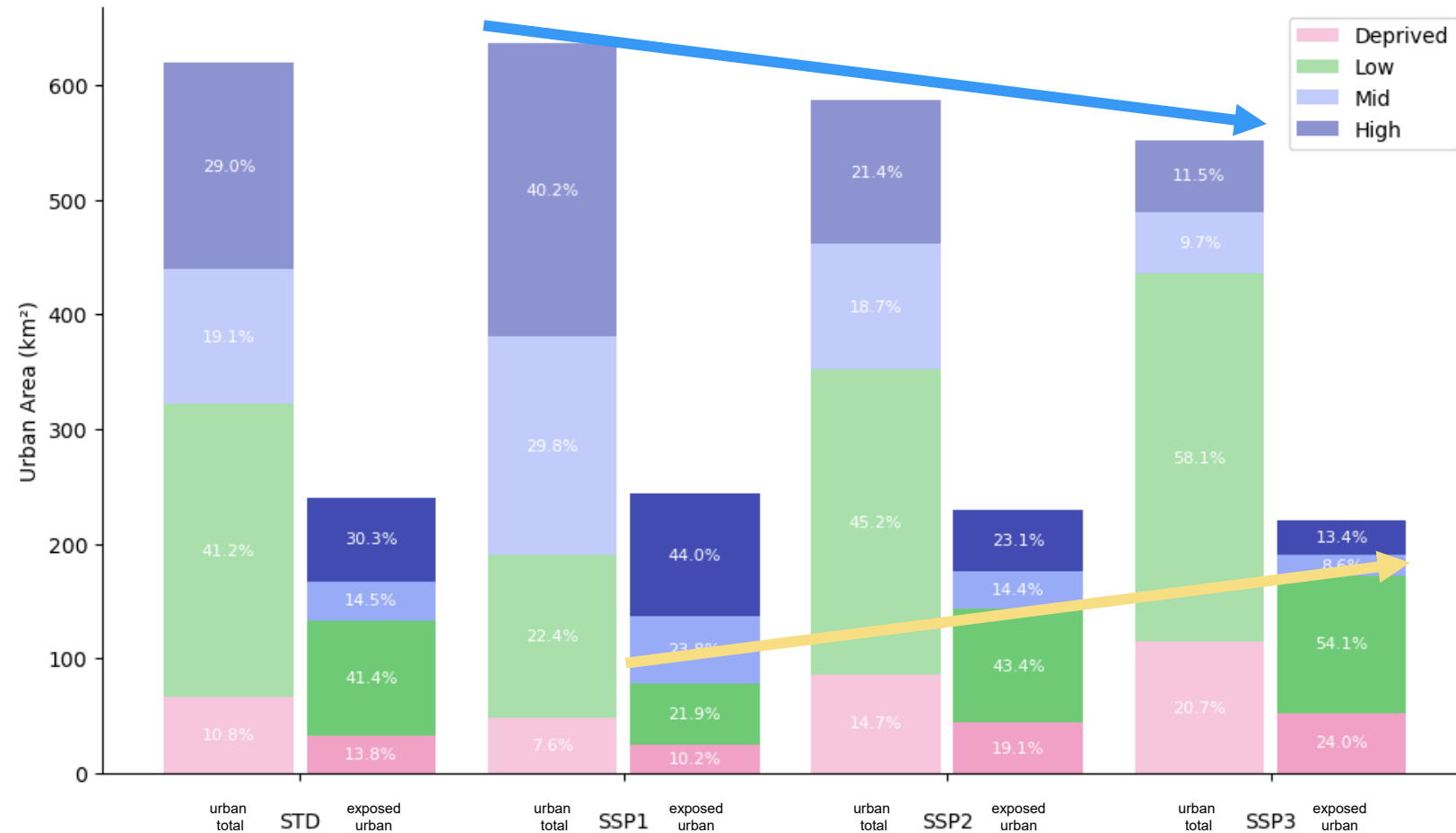
– SSP1: increased exposure among high SEP

Potential for individual capacity & insurance

– SSP3: despite smaller urban footprint, exposure is concentrated among deprived and low SEP

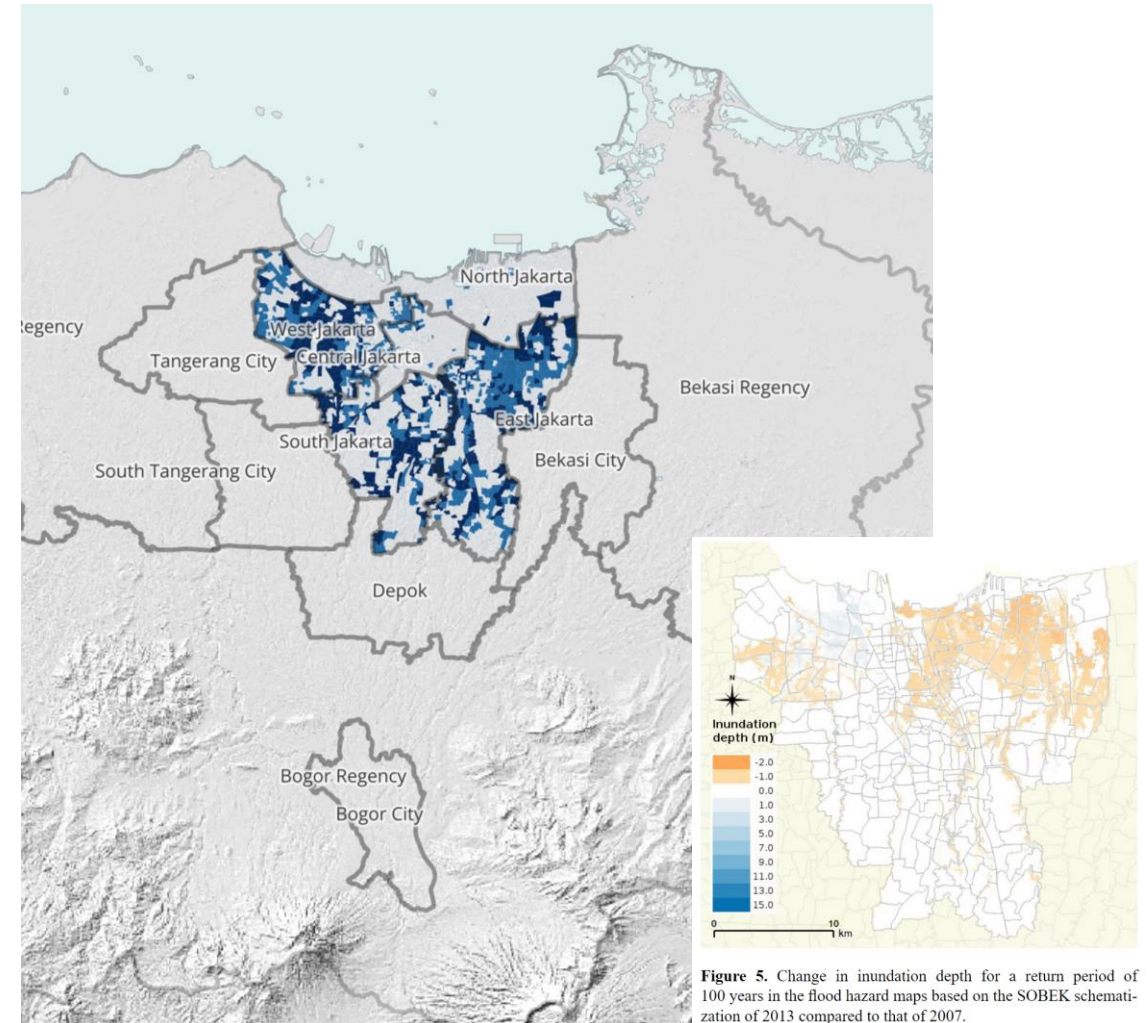
“Wicked” problem of exposure & vulnerability overlap

Urban and Exposed Areas per Class by Scenario (2050 simulation)



## DISCUSSION

- Integrated models ask hard questions
  - We need granular socioeconomic data
  - We need to confront the metropolitan cities beyond Jakarta
- Developing robust assumptions is crucial for scenario development
- Matching past trends with plausible future exposure and vulnerability modelling under scenarios is promising

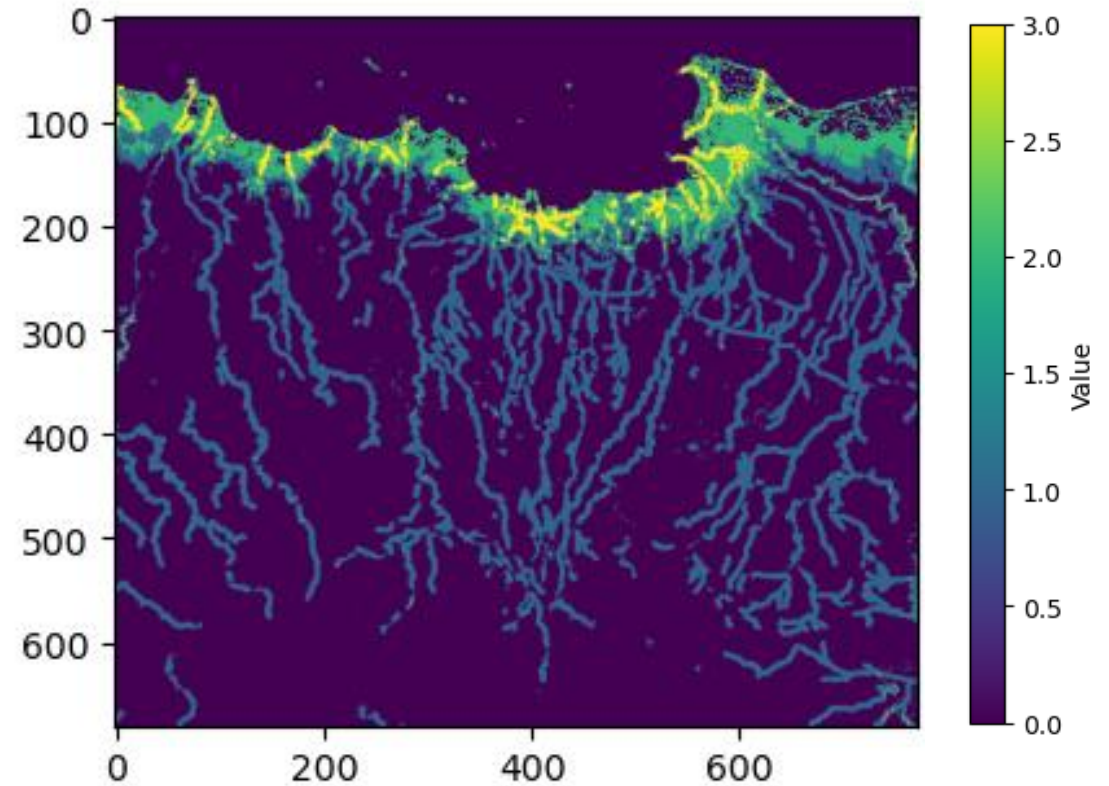


Jakarta DKI Open Data

Budyono et al. 2015

Exposure is kept constant and we face a **scale paradox**:

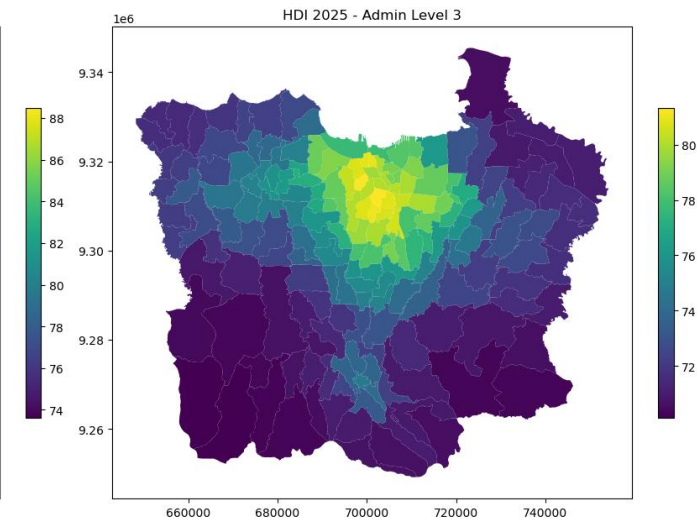
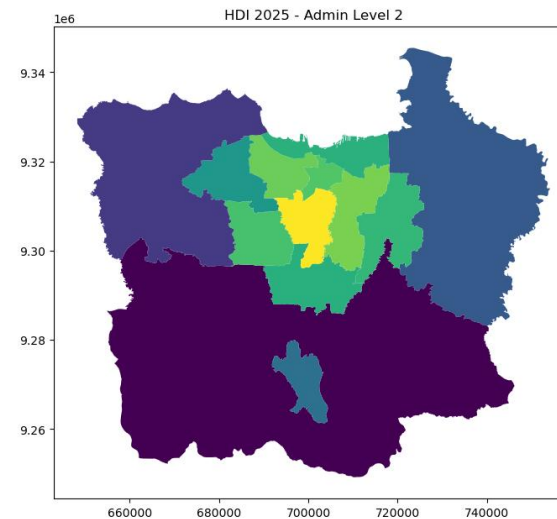
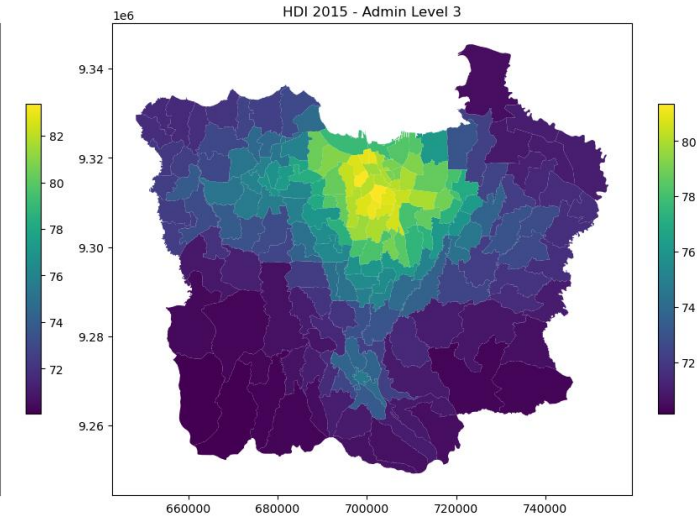
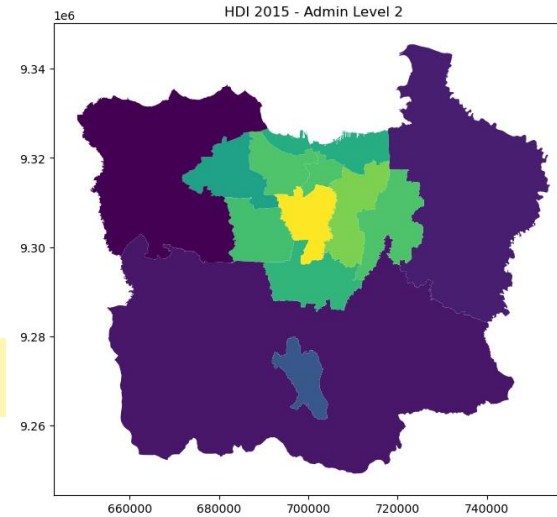
- There are currently no metropolitan-scale flood maps
- Global estimates are too imprecise for the urban growth dynamics
- Future work could include feedbacks between urbanisation and flooding



Surge and riverine flood potential estimate. Source: DeltaDTM and OSM Contributors.

The next steps aim at robustness:

- Improved calibration (e.g., granular HDI estimates for past SEP distributions)
- Testing robustness of socioeconomic results in detail with experts
- Exploring risk-risk trade-offs and policy options:
  - distance to employment
  - relocation vs. on-site upgrading





<https://doi.org/10.1038/s44168-024-00197-z>

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Check for updates

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### ENVIRONMENTAL RESEARCH LETTERS

#### LETTER

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