Economic modelling for selection of river flood adaptation measures in Jakarta: an optimization approach

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Overview of Presentation

- Background
- Research objectives
- Analytical framework
- Application to different cases in Jakarta
  1. In one area
  2. In multiple areas
  3. In multiple areas by including temporal dimension
- Conclusions

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Background

- Jakarta has to deal with river flood and coastal flood (Aerts et al., 2009).
- To reduce the flood risk, a combination of structural and non-structural flood measures is needed (Ward et al., 2012).
- Investment on both types of measures has been increasing (Caljouw et al., 2005).
- Jakarta could benefit greatly from integrated flood risk management (Ward et al., 2012).

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Background

- The central government and local authority have a limited budget on implementing flood adaptation measures. Economic consideration is needed.
- The decision makers need to know the costs and the benefits of these measures.

> - The costs include investment costs, and operational and maintenance costs required during the lifetime of flood adaptation measures.
> - The benefits refer to the expected flood damages reduction due to implementation of such a measure.

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Research Objectives

- To identify the **optimal level**.

Such a "level" indicates the level where under the given costs the resulting expected damage is lowest.

- To develop an **economic model**, which assists us to select optimal flood adaptation measures.
  - By considering spatial aspects and temporal aspects

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Analytical Framework

- The objective function is to minimize the total costs, *TC*, of implementing flood adaptation measures.

$$\min_{M} TC = TCM(M) + TCD(M)$$

Control variable: *M*, level of measure.

TCM: total measure costs, a function of *M*.

TCD : total damage costs, a function of *M*.

- Subject to several constraints, e.g. budget constraint and the hydrological system.

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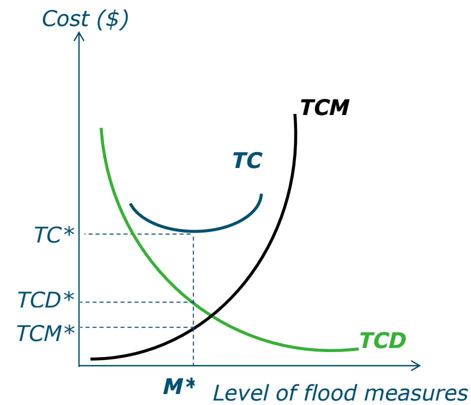
Analytical Framework: TCM and TCD

- **TCM**:
  construction costs and operational costs of the flood measure during its lifetime
- **TCD**:
  the expected value of flood losses in a specific area after a measure is implemented.



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TDC and flood characteristics

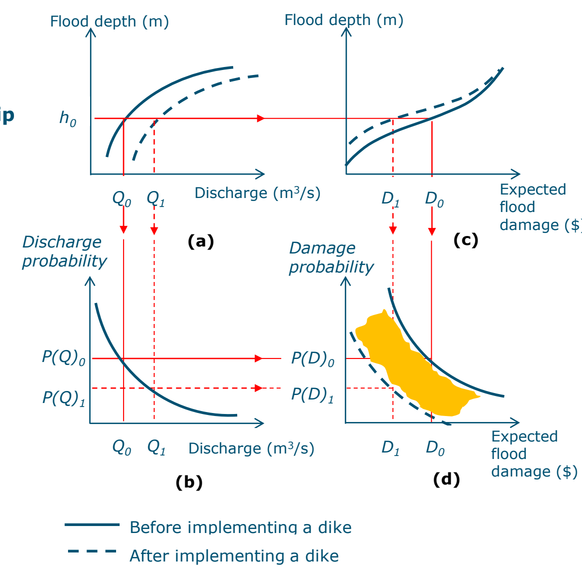
River stage-damage relationships

(a) stage-discharge relationship

(b) annual exceedence probability of discharge

(c) stage-damage relationship

(d) probability occurrence of flood damages



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Application to one area

The objective function:

$$\min_{M_i} TC = TCM + TCD \qquad (1)$$

Subject to:

$$TCM \leq B \qquad (2)$$

$$TCM = \sum_{i=1}^{N} \alpha_i (M_i)^2 \qquad (3)$$

$$TCD = D0 - \sum_{i=1}^{N} \beta_i M_i \qquad (4)$$

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A simple illustrative example:

The Jakarta government is planning to implement three flood measures i.e. dike, river normalisation, and polder. The maximum budget to implement those measures is USD 600 million.

What are the optimal levels of those measures?

Applying the optimization model in this example, the optimal level for the design level of dike, normalisation, and polder areas, are found to be 2 m, 3 km, and 10 ha, respectively. Those levels will require TC of about USD 590 million.

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Application to multiple areas

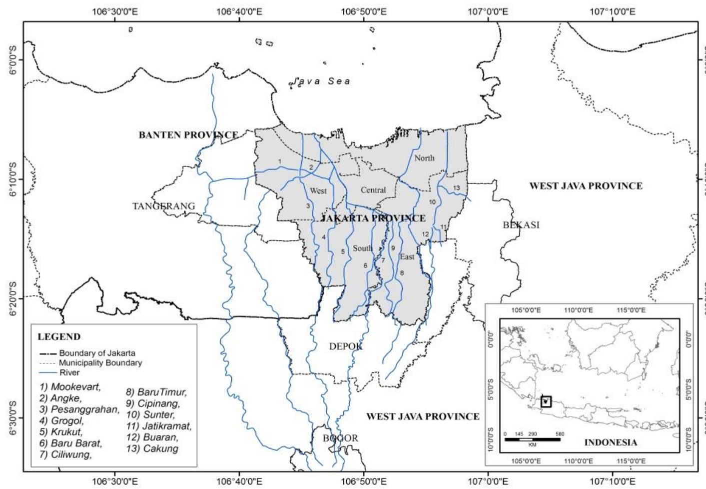

Figure 1. Jakarta and its surrounding cities

Application to multiple areas

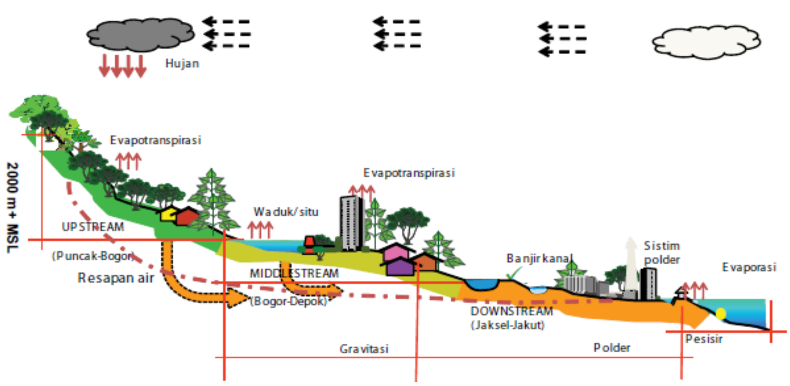

Figure 1. An illustration of the *Ciliwung* watershed from upstream to downstream (Mirah Sakethi, 2010)

Application to multiple areas

The objective function:

$$\min_{M_{i,j}} TC = \sum_{j=1}^{K} TCM_j + \sum_{j=1}^{K} TCD_j \qquad (5)$$

Subject to:

$$\sum_{j=1}^{K} TCM_j \leq B \qquad (6)$$

$$TCM_j = \sum_{i=1}^{N} \alpha_{i,j} \left(M_{i,j}\right)^2 \qquad (7)$$

$$TCD_j = D0_j - \sum_{i=1}^{N} \beta_{i,j} M_{i,j} - \underbrace{\sum_{i=1}^{N}\sum_{j=1}^{K} \gamma_{i,j-1} M_{i,j-1}}_{\text{Dual effect}} \qquad (8)$$

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Extended to temporal dimension (1)

- Different flood adaptation measures can be constructed and utilized in different time periods (different life times).

The objective function:

$$\min_{M_{i,j,t}} NPVTC = PVTCM + PVTCD \qquad (9)$$

Subject to:

$$PVTCM = \sum_{j=1}^{K}\sum_{i=1}^{N}\sum_{t=0}^{Tc_i} \frac{1}{(1+r)^t} \alpha_{i,j} M_{i,j,t} \qquad (10) \quad \text{Where: } Tc < T$$

$$PVB = \sum_{j=1}^{K}\sum_{i=1}^{N}\sum_{t=0}^{Tc_i} \frac{1}{(1+r)^t} B_{i,j,t} \qquad (11)$$

$$PVTCM \leq PVB \qquad (12)$$

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Extended to temporal dimension (2)

Subject to:

$$\sum_{i=1}^{N} \alpha_{i,j} M_{i,j,t} \leq \sum_{i=1}^{N} B_{i,j,t} \quad (13)$$

$$PVTCD = \sum_{j=1}^{K} \left(D0_j - PVTRD_j \right) \quad (14)$$

$$PVTRD_j = \sum_{i=1}^{N} \sum_{t=Tc_i}^{T} \frac{1}{(1+r)^t} \beta_{i,j} M_{i,j,t} + \sum_{i=1}^{N} \sum_{j=1}^{K} \sum_{t=Tc_i}^{T} \frac{1}{(1+r)^t} \gamma_{i,j-1} M_{i,j-1,t} \quad (15)$$

Dual effect

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Conclusions

1. A limited budget calls for a careful choice on flood adaptation measures in Jakarta.
2. It is possible to determine the "optimal level" of adaptation measures based on optimization.
3. Based on the modelling framework, flood management can be achieved for different cases in Jakarta.
4. This requires better information on the cost structure of the various measures and the hydrological impacts.
5. To have a good result, further studies are needed to integrate the economic and the hydrological analysis.

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Thank you

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