Towards pluvial flooding hazard assessment in an urban environment

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Background

- Urbanization and the intensification of extreme rainfall events are increasing pluvial flooding frequency in many cities.
- Identification of flood prone areas can be considered as one of the fundamental initial steps in strategic urban planning.
- Hydrodynamic models are most realistic representation of the urban drainage systems but they are not widely applied as:
  - They are Computationally expensive.
  - They require large amounts of input data Resource-intensive
  - Require manual processing
Research question

- How simple approaches can mimic the behavior of 2D-hydrodynamic model with regard to inundation depth and inundated areas.
- Explore the performance of simple approaches depending on the severeness of the rainfall.
Overview

Data
DEM, Soil type, Land-cover, rainfall

2D Hydrodynamic model
Fill-spill-merge (FSM) approach
Preprocessing
Depressions selection, Elevation-storage curves, vertical hierarchy
FSM approach
Estimate water depth and flood extent

Topographic wetness index (TWI) approach
Preprocessing
Model mesh, Roughness, Curve number, Boundary conditions
2D Hydrodynamic simulations
TELEMAC 2D model

Analysis
Sensitivity analysis for the two approaches with considering the TELEMAC 2D model as gold-standard

Conclusion
Study Area

- Berlin city has been repeatedly subject to pluvial flooding in the last decades.

- The city is characterized by:
  - Flat terrain.
  - Decentralized stormwater management system.
  - Annual precipitation is 591 mm.

- The flood inventory was used to identify the case study based on the density of the flooded locations.
Data

Digital elevation model \((1m \times 1m \text{ resolution})\)

Land cover:
- OpenStreetMap data
- Soil hydrologic condition (Ross et al. 2018)
- CN tables to estimate the generated excess runoff

Rainfall:

*Hourly rainfall depth ranging from 30mm to 150mm estimated from the flood inventory for Berlin collected between 2005 and 2017*
TELEMAC-2D model

- TELEMAC-2D model is a free open source 2D Hydrodynamic model.
- Computations are based on an irregular triangular mesh.
- Solves the full Shallow Water (Saint Venant) equations in two dimensions.
- The model supports both finite-volume and finite-element schemes.
- Rainfall–runoff module is based on the SCS-CN approach.
Fill-spill-merge (FSM) approach

FSM approach identifies pluvial flood inundation areas based on:
- Selected depressions (based on depression depth, volume and area)
- Vertical and Horizontal hierarchy between the depressions
- Accumulated precipitation volume in depressions
Topographic wetness index (TWI) approach

The TWI was initially introduced by (Kirkby 1975):

\[ TWI = \ln \left( \frac{a}{\tan \beta} \right) \]  

TWI approach:

- Aims to identify a TWI threshold (\( \tau \)) above which an area is considered as flood-prone.
- TWI threshold (\( \tau \)) is estimated based on the maximum likelihood analysis of TWI map and flood plain.

\[ L(\tau|W) = P(FP, IN|\tau, W) + P(IN, FP|\tau, W) \]  

Where:

- \( P(FP, IN|\tau, W) \) is the probability that a point is flooded by TWI method and inundated by TELEMAC-2D model (Orange area)
- \( P(IN, FP|\tau, W) \) is the probability that a point is neither flooded by TWI method nor inundated by TELEMAC-2D model (Green area)

(Jalayer et al., 2014)
Analysis

Fig. Flood risk areas in Berlin based on TWI approach (Precipitation depth = 50mm)
Analysis

FSM Method

(a) Rainfall depth = 100mm

(b) Rainfall depth = 150mm

TWI Method

(a) Rainfall depth = 100mm

(b) Rainfall depth = 150mm
Analysis

$$\text{Sensitivity (TPR)} = \frac{TP}{TP + FN}$$

$$\text{Specificity (TNR)} = \frac{TN}{TN + FP}$$

*Matthews correlation coefficient*

$$\frac{TP \times TN - FP \times FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}}$$

Where:
- TP: True positive
- TN: True Negative
- FP: False positive
- FN: False negative
Conclusions

- FSM approach is a fast tool for estimating flood plain in urban areas comparing to the 2D hydrodynamic models. However, it requires time to set up the model.
  - FSM approach performance improves with increasing the precipitation depth.
- FSM approach has a better performance than the TWI approach.
- TWI approach can specify the pluvial flood risk areas in the whole city but it has the following limitations:
  - TWI approach failed to estimate TWI threshold ($\tau$) for low precipitations (< 40 cm).
  - The estimation of the TWI threshold ($\tau$) is influenced by the definition of inundated areas. The approach defined the inundated area based on water depth (water depth > 0). Based on this definition, the pluvial flood plain is not increasing with increasing the precipitation depth, only the flood water depth increase which influenced the estimated TWI threshold ($\tau$).