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# GLOBAL SENSITIVITY ANALYSIS FOR URBAN WATER QUALITY MODELLING: COMPARISON OF DIFFERENT METHODS

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# Introduction

Only few studies in urban drainage deal with GSA

Previous GSA studies mainly focused on other research fields

Limited transferability of the knowledge derived from other fields

There is a need to experience with GSA methods in urban drainage to give answers to:

What is the best method? Is any??
What are the main features of each method?
How similar are the results?
To what extend do results differ changing method?

# Aims of the study

Gain insights about the features of three GSA methods:

- SRC
- Morris screening
- E-Fast

Urban drainage water quality model
Case study
Comparison between the results of each method

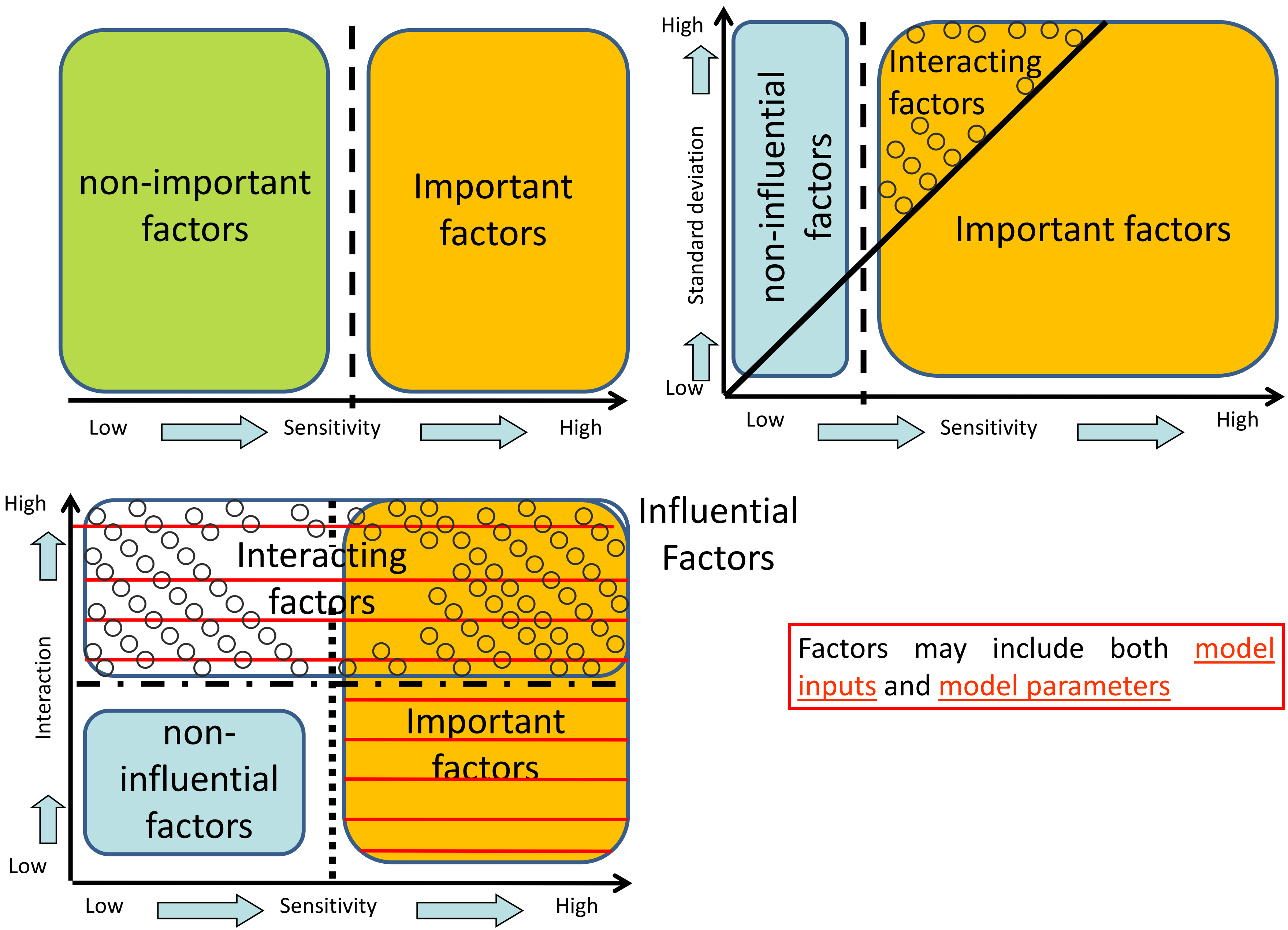
Terminology

# Introduction: Problem statement

A complete, Clear, Generally Accepted Definition
Is lacking!!

Suggest a common terminology on the basis of previous studies

# Sensitivity methods: making a framework




Factors may include both model inputs and model parameters

# Methods

# Methods

## *Standardized Regression Coefficients*

**Consists of running a Monte Carlo simulation and multivariate linear regression between the model outputs and inputs**

$$SRC(x_i) = \beta_i = b_i \cdot \sigma_{x_i} / \sigma_y$$

***standardised regression slopes***

$\sigma_{xi}$ and $\sigma_y$ represent respectively the factor and the model output standard deviation and bi the regression slope

**SRCs are valid measures of sensitivity when $R^2$>0.7 (Saltelli et al., 2004)!!!**

$\sum(\beta_i) = 1$ *Linear model*

**The sign of $\beta_i$ indicates its positive (sign +) or negative (sign -) effect**

# Methods *Morris Screening*

**It is based on a one-at-a-time (OAT) perturbation of the model input factors**

**Factor space is partitioned into p levels**

**OAT is repeated r times, computing the Elementary Effects (EEs) for the model output considering a perturbation Δ:**

$$EEs(\chi_i) = \frac{y\left(x_i,\ldots,x_{i-1},x_i+\Delta,x_{i+1},\ldots x_k\right)-y\left(x_i,\ldots,x_{i-1},x_i,x_{i+1},\ldots x_k\right)}{\Delta}$$

**Sensitivity is described by the absolute mean (μ*) and standard deviation (σ) of the cumulative distribution of the r*EEs**

# Methods

## *Extended-FAST*

**The Extended-FAST is based on the variance decomposition theorem which states that the total variance of the model output (Var(Y)) may be decomposed into conditional variances**

$$S_i = \frac{Var_{xi}\left(E_{x_{-i}}\left(Y \middle| x_i\right)\right)}{Var(Y)}$$

***First order index***

*Show by which percentage the variance would decrease if the corresponding factor was known*

$$S_{Ti} = 1 - \frac{Var_{x_{-i}}\left(E_{x_i}\left(Y \middle| x_{-i}\right)\right)}{Var(Y)}$$

***Total effect index***

*Show by which amount the variance would be reduced if all factors except for the ith were known*

# Urban drainage model
# &
# Case study

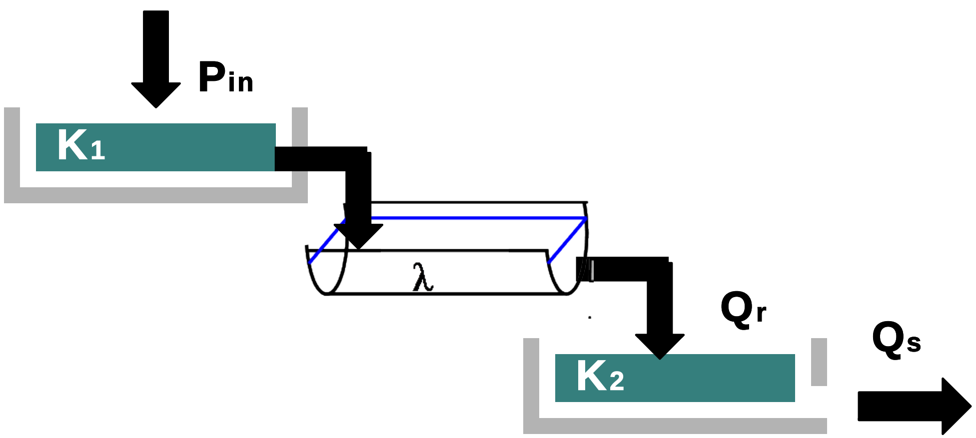
# Methods: Urban water quality model (Mannina&Viviani 2010)

| | |
|---|---|
| **Quantity Module** | Hydrographs at the inlet and at the outlet of the sewer system |
| **Quality Module** | Pollutographs at the inlet and at the outlet of the sewer system |

# Methods: Urban water quality model (Mannina&Viviani 2010)

**Quantity module**

- Rainfall
- Net rainfall (S, f)
- Rainfall - runoff processes
  Inlet sewer hydrograph
- Sewer propagation
  outlet sewer hydrograph

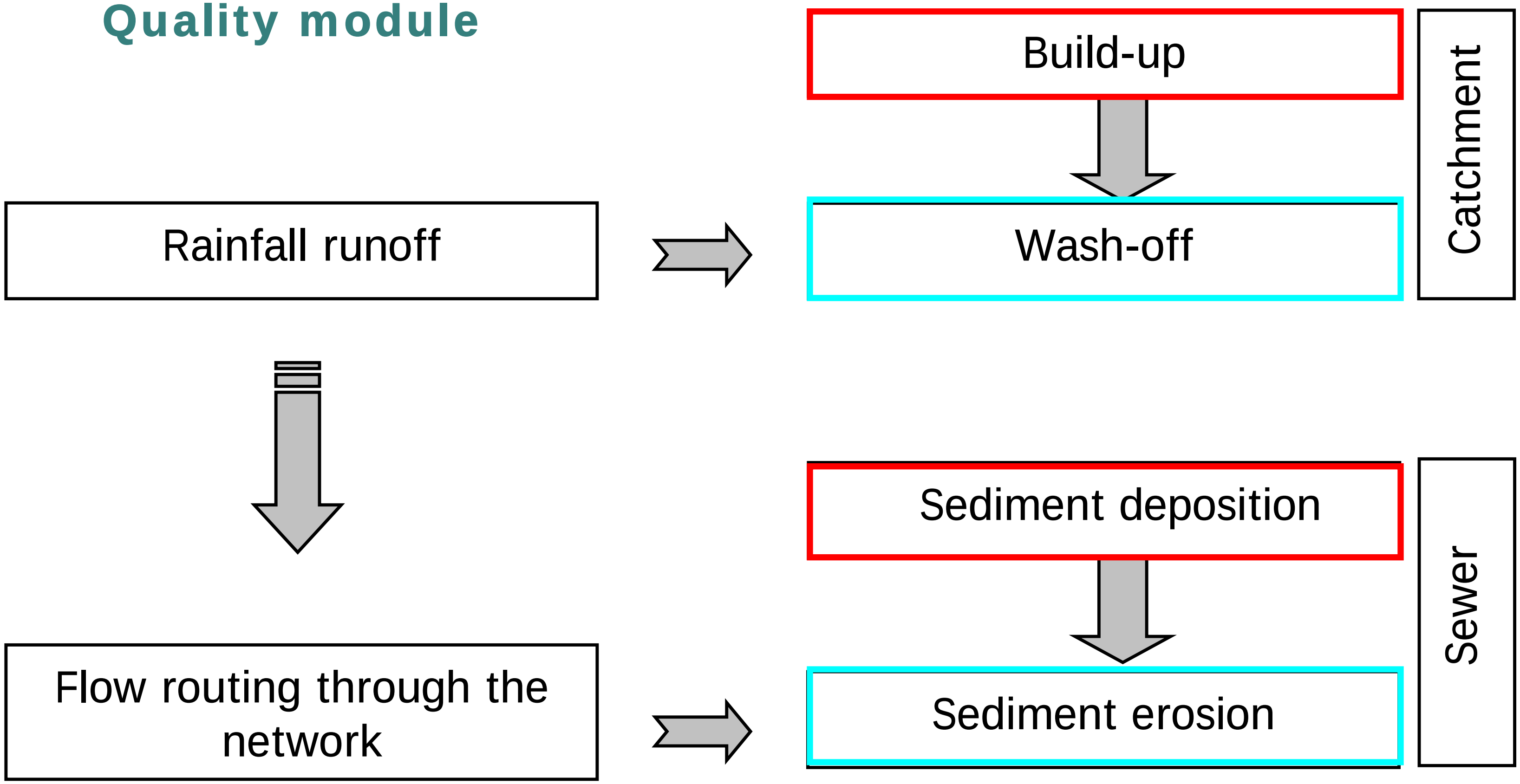



**The cascade of two linear reservoirs in series and a linear channel allow to split the hydraulic phenomena in the catchment from those in the sewer system.**

# Methods: Urban water quality model (Mannina&Viviani 2010)

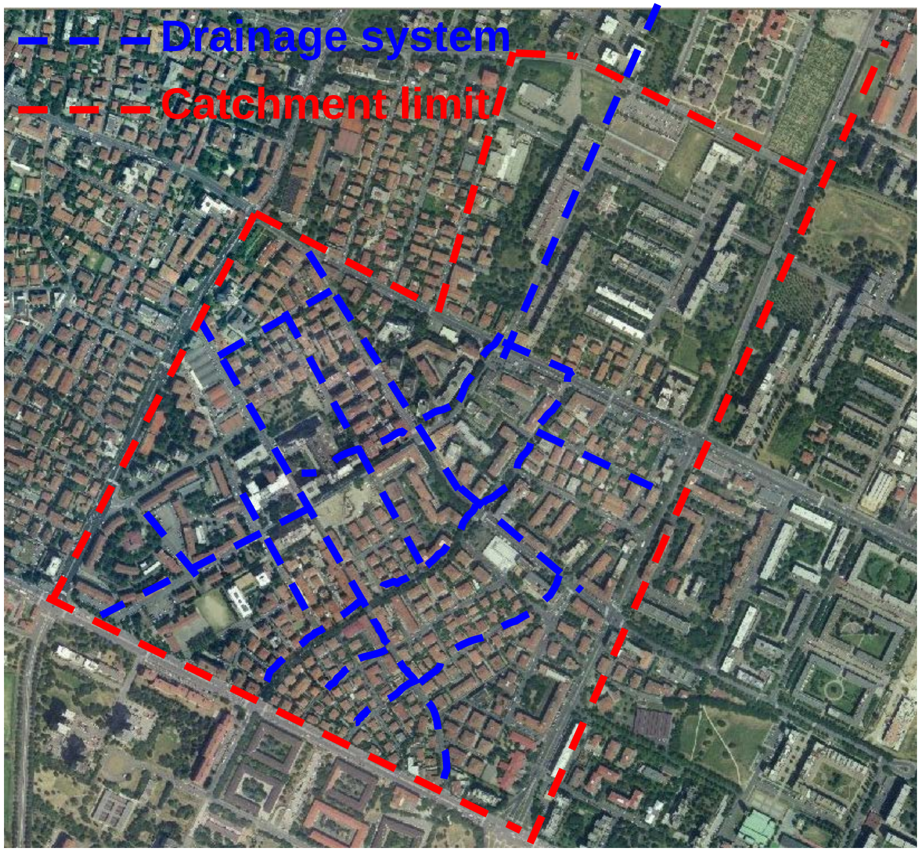
## Sewer System model:

### Quality module



# Model application: the case study

## The experimental catchment Montelepre Catchment (IT)




- 36 storm events during one year 2008
- Drained area 40 ha, with an impervious percentage of 75%
- The drainage network ends in a polycentric section pipe 144 cm high and 180 cm wide

# Methods: Application and criteria for comparison

- The model run: 1 year series - 36 events
- Seven model outputs:
  - Maximum sewer flow rate ($Q_{MAX}$)
  - Total sewer flow volume ($V_{TOT}$)
  - Maximum TSS sewer concentration ($C_{MAX,TSS}$)
  - Maximum BOD concentration ($C_{MAX,BOD}$)
  - TSS sewer load ($L_{TOT,TSS}$)
  - Average TSS sewer concentration ($C_{AVERAGE,TSS}$)
  - Average BOD sewer concentration ($C_{AVERAGE,BOD}$)
- Seventeen model input factors
- Quantity and quality input factors changed simultaneously for each MC
- Uniform distribution – input factor

# Methods: Application and criteria for comparison

- For the SRC and Morris screening: CFT = 0.1
- For E-FAST: CFT1 = 0.01 [correspondence between $\beta_i^2$ and $S_i$ (Saltelli et al., 2000)]
- For E-FAST: CFT2 = 0.1 for the value of the interaction $S_{Ti} - S_i$
- For each method a rank of importance according to factors prioritisation

**Comparison for factors prioritisation:**

- $\beta_i^2$ and $S_i$ SRC vs E-FAST;
- $\beta_i^2$ and $\mu^*$ SRC vs Morris Screening;
- $\mu^*$ and $S_i$ Morris Screening vs E-FAST;

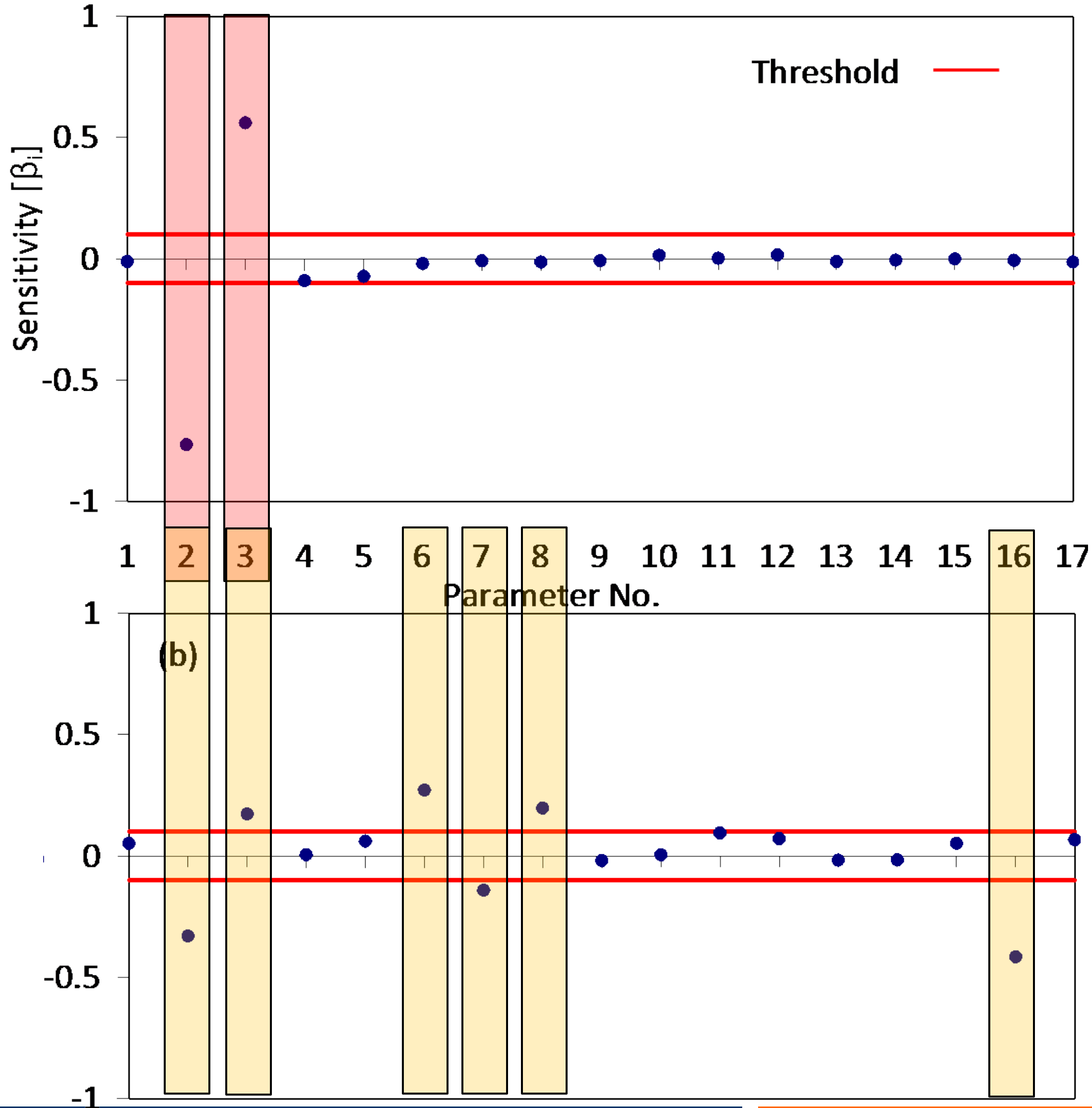
**Comparison for factors fixing (Morris screening vs E-FAST):**

- $\mu^*$ *versus* $S_{Ti}$
- $\sigma$ *versus* $S_{Ti}$

# **Results: SRC** ($Q_{MAX}$ - $C_{MAX,BOD}$)

Quantity

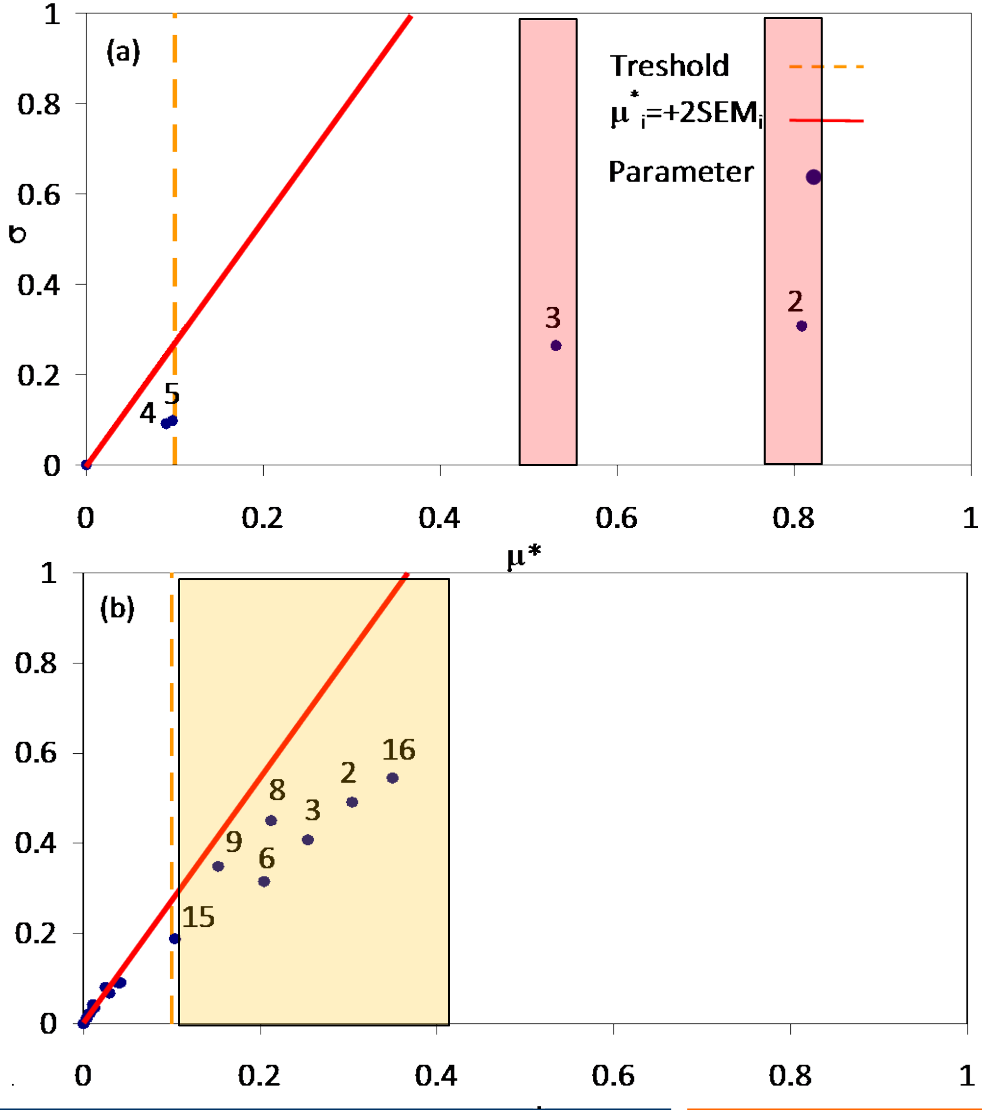
Quality



# Results: Morris screening ($Q_{MAX}$ - $C_{MAX,BOD}$)

Quantity

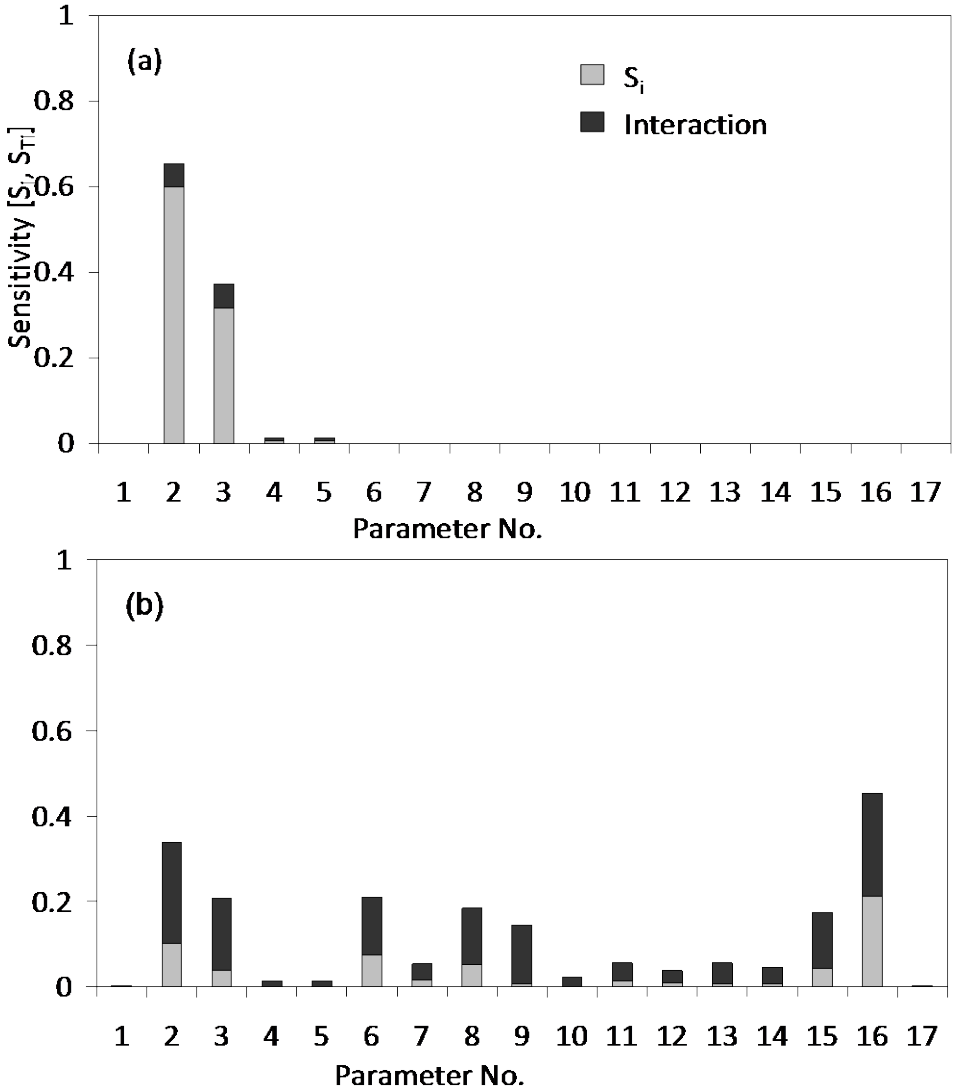
Quality



# Results: E-FAST ($Q_{MAX}$ - $C_{MAX,BOD}$)

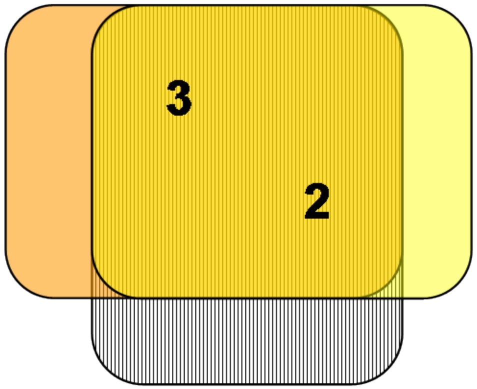
Quantity

Quality



# Results: comparison among the methods

Quantity

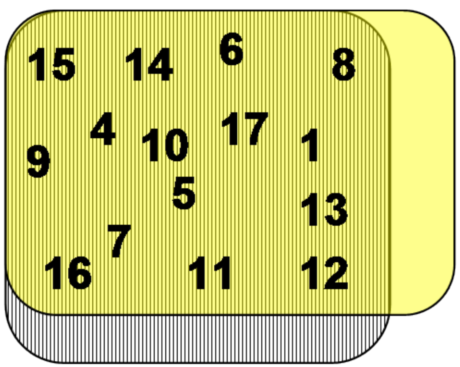



**Factors Prioritisation**

**Important Factors**

- SRC
- Morris screening
- E-FAST

Quantity




**Factors Fixing**

**Non-Influential**

- Morris screening
- E-FAST

# Conclusions

- A comparison between three GSA methods: **important, non-influential and interacting** model input factors of an urban stormwater model;
- SRC method is **inside its range of applicability** for the outputs $Q_{MAX}$, $V_{TOT}$ and $L_{TOT,TSS}$ and outside for $C_{MAX,TSS}$, $C_{MAX,BOD}$, $C_{AVERAGE,TSS}$ and $C_{AVERAGE,BOD}$.
- The quality sub-module is **non-linear**: attention to non-influential factors.
- **E-FAST** allowed the **quantification of the interactions** of model factors.
- In terms of **factor fixing** similar results were obtained between Morris screening and E-FAST methods for $Q_{MAX}$.
- For $C_{MAX,BOD}$ the Morris screening showed **some differences** (semi-quantitative method!).

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Giorgio Mannina

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