water

MDPI

Supplementary Material

Quantifying the UDS Hydraulic and Social Resilience to Flooding: an Index-Based Approach vs. a Parameter-Based MCDM Method

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Graduality vs. braking capacity

By calculating the graduality of UDS, it is intended to know how the response magnitude of the system changes with the "disturbance magnitude" (i.e. rainfall value). On this basis, graduality can be obtained from dividing the UDS surcharge depth to the rainfall amount. This is while braking capacity mainly concentrates on explaining how gentle the system-performance reduction may be over "time" (Figure S-1).

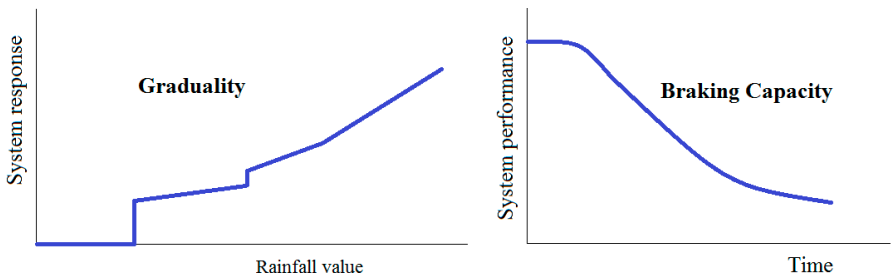

Figure S1. Graduality vs. braking capacity.

Sensitivity Analysis, Calibration and Validation of Rainfall-Runoff Model

Sensitivity analysis was performed to determine which parameters have the highest impact on the model output. For this purpose, the simple OAT[1] method was utilized, which doesn't need time-consuming, complicated calculations and hence, has been used in quite a few previous studies [41]. In this method, the model output is calculated by changing one input parameter at each time, while the rest of parameters have been kept unchanged. To accomplish the sensitivity analysis of SWMM, the values of model's parameters have been changed within a range of ±10% considering the allowable range (table S-1) for change in the given parameter's initial value to see how the discharged flow from the basin's outlet would impacted. As can be seen in table, five important parameters of SWMM model including Roughness coefficient of both pervious and impervious areas (N-Perv and N- Imperv), Depth of depression storage on pervious and impervious areas (Dstore-Perv and Dstore-Imperv), and the Percent of impervious area with no depression storage (Zero-Imperv) were focused for performing the sensitivity analysis to figure out how sensitive the flow discharge from the basin outlet would be to the value of any of these parameters.

The performed sensitivity analysis suggested that the two parameters of Zero-Imperv and N- Imperv would have the highest impact on the discharged flow from the catchment, and therefore, need to be calibrated more accurately.

The calibrated values of these two parameters were extracted from some past studies on the region and similar areas around the case study (Table S-2). The only available measured of rainfall and runoff at the end of the studied basin was the data of runoff discharge, depth and velocity time-series recorded every 10 minutes at the basin outlet by Moafi Rabari [47].

[1] One factor At a Time

These data (for a 12.5 mm rainfall) were used to validate the rainfall-runoff model. The results are representative of the acceptable performance of SWMM in simulating the rainfall-runoff process in the studied region (Table S-3).

Table S1. Some key parameters of SWMM model (for Sensitivity Analysis) and their Permissible range of change.

Parameter	Description	Range	Source
N- Imperv	Manning's N for impervious area	0.005-0.05	Li et al., 2014
N-Perv	Manning's N for pervious area	0.05-0.50	Li et al., 2014
Dstore-Imperv	Depth of depression storage on impervious area (mm)	1.3-2.5	Li et al., 2014
Dstore-Perv	Depth of depression storage on pervious area (mm)	2.5-7.6	Li et al., 2014
Zero-Imperv	Percent of impervious area with no depression storage (%)	5-25	Hashemi and Mahjouri, 2019

Table S2. The calibrated values of some important parameters of SWMM model [55].

Parameter	Optimized (Calibrated) value
N- Imperv	0,033
Zero-Imperv	21

Table S3. The results of rainfall-runoff SWMM verification.

process	variable	RMSE	MAE	NSE
Verification	Depth	0.0144	0.0109	0.61
	Velocity	0.0603	0.0617	0.75
	Discharge	0.0537	0.0415	0.70

Systems' Responses and Recovery processes under a unique disturbance

Various interpretations can be made from past studies about the behavior of system elements in the face of a disaster. In some studies, the "system response" has been considered as a combination of "absorption" and "recovery", and the "absorptive domain" has been described as the time-extent from the failure point until the point of minimum performance [56, 57]. While in other sources, such a definition has been dedicated to the "system response". Instead, the "absorptive domain" has been translated to the state that the system fully resists against the perturbation without any performance reduction [10], so-called "resistance domain". The current study introduces a novel description of the system absorptive capacity which combines two above-mentioned attitudes.

Before proceeding to the rest of the indicators, it is required to provide some explanations regarding the difference in system response and recovery processes under a similar perturbation. When a system is exposed to a disturbance, the system response could be different depending on the system characteristics and the type and magnitude of the disturbance. For instance, long-term climatic changes may cause a gradual change in the loads applied to the UDS, and the resistance condition of the system would change as a result [56]. However, some types of disasters such as earthquakes or flash floods would have an acute and rapid impact on urban critical infrastructures. It can be observed in figure S-2(a) that there is a possibility of different buffer capacities depending on the characteristics of both the system and the disturbance applied to it. Figure S-2(b) represents different types of system responses (form soft to sudden responses) to a certain disturbance. It could be understood from the figure that a unique perturbation applied to a system, could result in different braking capacities. In both (a) and (b) parts of figures S-2, the curve No.1 is representative of higher resilience in comparison with the curves No. 2 and 3.

Besides, figure S-2(c) shows various types of recovery rates and levels (i.e. improvability). Similar to figures (a) and (b), the curve No. 1 indicates a higher resilience since having a greater restoration speed. As shown in this figure, at the end of the recovery

process, the system could reach one of the three levels of "acceptable performance", "previous functionality" or an "improved functionality". The higher is the performance level at the end of the recovery phase, the higher is the resilience of the system. It should be noted that the start point of the curve in figure S-2(C), does not necessarily show the 100% performance, but the system normal performance before the disturbance occurs, which is an acceptable level of functionality, but not necessarily a hundred percent.

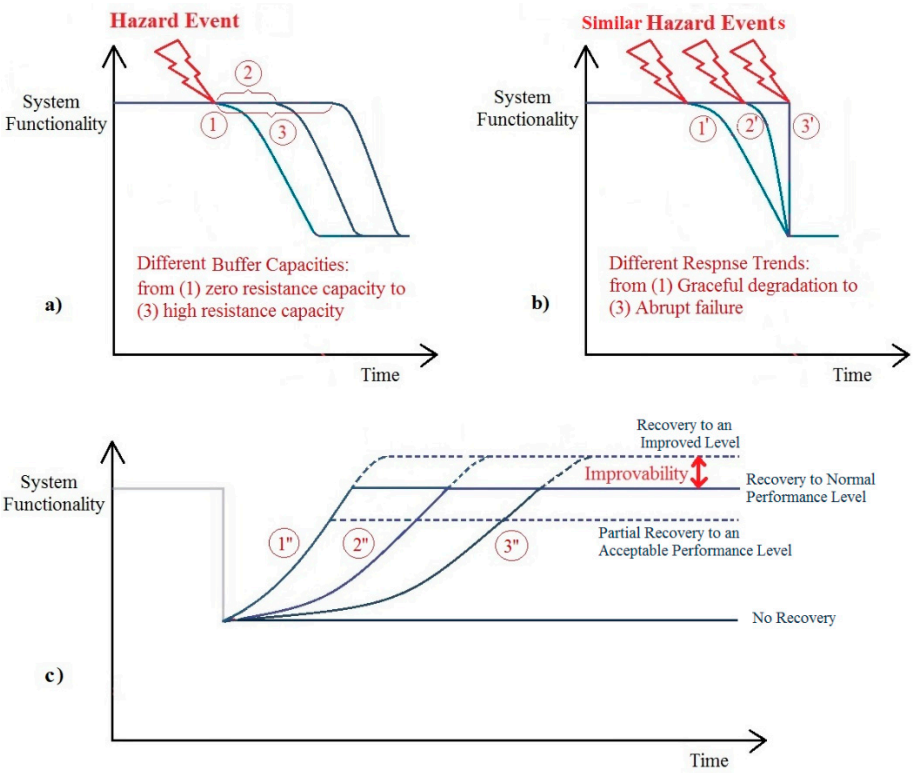

Figure S2. The difference in systems' behavior under a similar disturbance: A) resistance capacity, B) response trend and C) system recovery.

Adaptability Evaluation

Table S4. Evaluating the calculated adaptability index [37].

l) RI	The level of resiliency
0 < RI ≦ 0.2	Very low
0.2 < RI ≦ 0.4	Low
0.4 < RI ≦ 0.6	Medium
0.6 < RI ≦ 0.8	Acceptable
0.8 < RI ≦ 1.0	High

UDS Simulation in PCSWMM

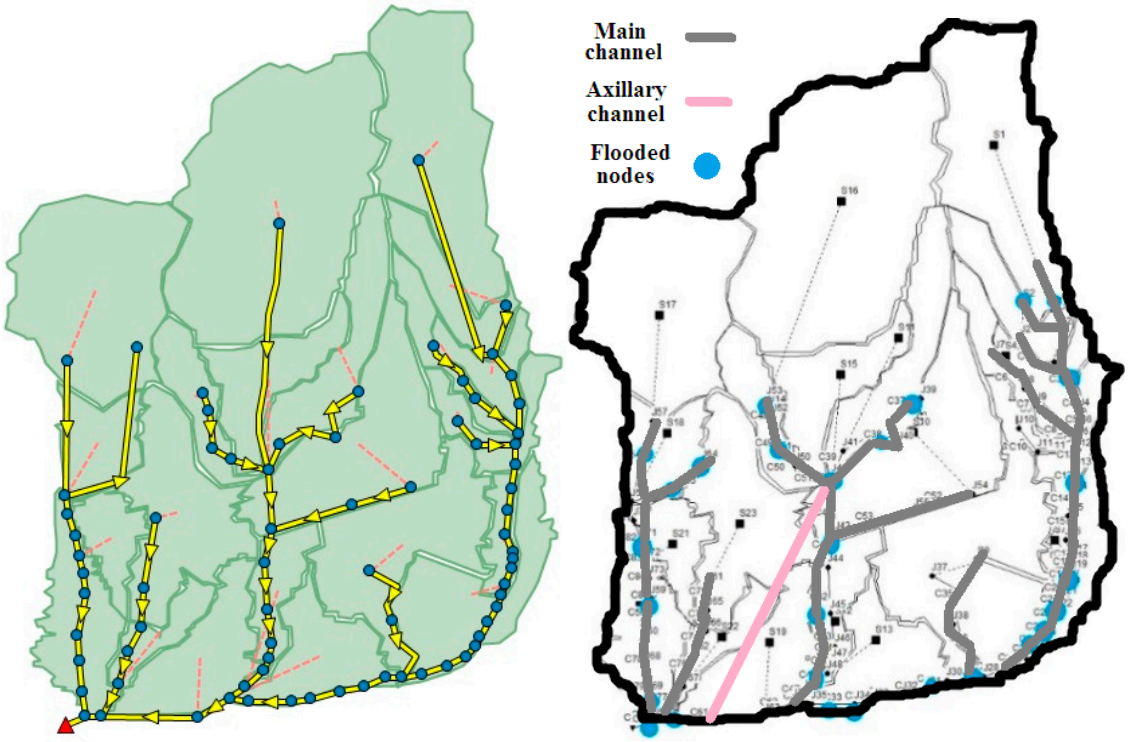

Figure S3. The WFD basin simulated by PCSWMM and the location of proposed auxiliary channel.

BMPs' ranking according to the manager's preferences

Table S5. The selected BMPs' ranking according to the manager's preferences for the northern Tehran [43].

BMPs / Managers' preferences	PP	DP
Hydraulic = environmental	1	3
Hydraulic > environmental	1	3
Hydraulic = Economic	3	1
Hydraulic > Economic	2	3
Hydraulic = Economic = Environmental	2	1
Hydraulic & Environmental > Economic	1	2
Hydraulic & Economic > Environmental	1	3
Hydraulic = Economic = Social = Environmental	5	1
Hydraulic & Environmental & Social > Economic	4	1
Hydraulic & Economic > Environmental & Social	3	1

Intensity-Duration-Frequency Curves and calculated indices regarding the system behavior

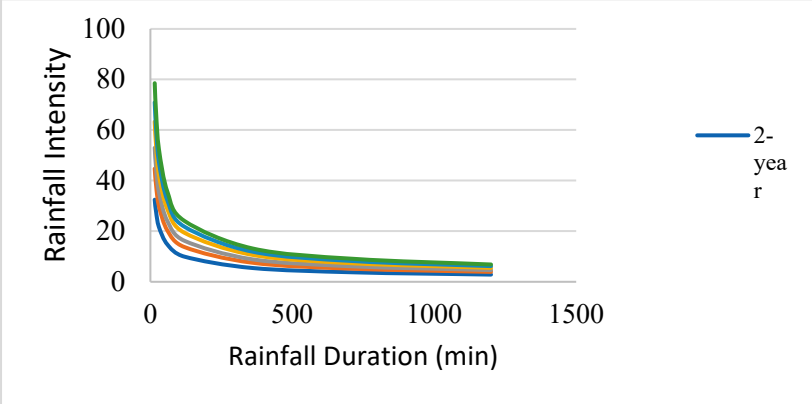

Figure S4. Calculated IDF curves for the studied region.

Table S6. Total rainfall depth for different return periods.

Return period (year)	Total rainfall depth (mm)
2	32.62
5	44.96
10	53.2
25	63.59
50	71.28
100	78.9

Table S7. The quantified (normalized) sub-factors of UDS flexibility for various scenarios for the social aspect.

Scenarios	Type of disturbance	AbC	SRV	RPD	IMP	ADP
Channel enlargement	Single-event rainfall	79.27	0.27	0.11	0.59	0.65
	Continuous rainfall	High Enough	-	-	0.53	0.62
auxiliary channel	Single-event rainfall	63.73	0.19	0.08	0.55	0.61
	Continuous rainfall	High Enough	-	-	0.47	0.58
BMP in urban areas	Single-event rainfall	High Enough	-	-	0.83	0.81
	Continuous rainfall	High Enough	-	-	0.78	0.8
BMP in both urban and non-urban sub-basins	Single-event rainfall	High Enough	-	-	0.89	0.91
	Continuous rainfall	High Enough	-	-	0.85	0.87
Existing condition of UDS	Single-event rainfall	53.31	0.11	0.01	-	-
	Continuous rainfall	High Enough	-	-	-	-

Reference

57 Javaheri, Robustness assessment of optimal management options for improving the performance of urban stormwater drainage systems, MSc. Thesis, Faculty of Engineering, University of Tehran, Tehran, Iran, 2015.
58 Lee, M. Resilience Assessment in Geotechnical Engineering, MSc. Thesis, University of Waterloo, Waterloo, Ontario, Canada, 2016.
59 Harte, D., Williams, A. and Turner, J. Reciprocity and the hyper-local journalist, Journalism Practice, 2017, 11(2–3), 160–176.