Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 119 (2015) 1181 – 1191
Procedia Engineering
www.elsevier.com/locate/procedia

13th Computer Control for Water Industry Conference, CCWI 2015

Sustainable development of storm-water systems in African cities considering climate change

Francesco De Paola[a*], Enzo Galdiero[a], Maurizio Giugni[a] and Francesco Pugliese[a]

[a]*Department of Civil, Architectural and Environmental Engineering, Via Claudio, 21, 80125 Naples, Italy*

Abstract

The present paper analyses the problem of the sustainable design and development of urban storm-water systems in response to the climate change and anthropic modification. In particular, the work focuses on the case of the African areas that are characterized by high vulnerability towards these issues. A disaggregation procedure is adopted to estimate the Intensity-Duration-Frequency (IDF) due to climate change starting from daily rainfall data. An integrated approach is used which combines an optimization algorithm (Harmony Search) and a hydraulic simulator to carry out the optimal design of intervention strategies with low economic impact. The methodology is described and discussed with reference to a case study located in the city of Dar es Salaam (Tanzania).

Peer-review under responsibility of the Scientific Committee of CCWI 2015

Keywords: Climate change impacts; adaptive planning; sustainable urban drainage systems; storm-water management; African cities.

1. Introduction

Nowadays, climate change represents one of the greatest challenges to face in the management of the urban water systems. This problem is particularly crucial in the least developed countries of the world, where an uncontrolled expansion of the cities and of the anthropic activities is often observed [1].

* Corresponding author.
E-mail address: depaola@unina.it

Peer-review under responsibility of the Scientific Committee of CCWI 2015
doi:10.1016/j.proeng.2015.08.970

In this regard, new strategies should be developed in order to mitigate the social and the environmental impacts caused by the climate change on urban areas. In the context of the urban water management, a predominant role can be played by innovative approaches, for example based on optimization techniques and new technologies for Low Impact Development (LID), in the design and the operation of Sustainable Urban Drainage Systems (SUDS). The main goal of these strategies should be the improvement of the resilience of the cities against the increase of the storm-water flows and the risk of flooding (urban flash-floods), which could be responsible of significant impacts on the present and the future development.

The present paper aims at providing further insight about the problem, with specific reference to the African cities. In particular, an applicative example is developed that is related to the city of Dar es Salaam, in Tanzania. The optimal design of a portion of the sewer system in response to the climate change is analysed. To this aim, an Intensity-Duration-Frequency (IDF) curve calibrated through the rainfall data provided by the climate projection of the CMCC (Euro-Mediterranean Center on Climate Change) is considered [2]. One of the main issues related to the study of climate change in least developed areas is the lack of data. Moreover, when present, the information presents an aggregation level that is not suitable for the purposes. Therefore, in this work the IDF curve is estimated according to a disaggregation model of rainfall data that is described in details.

Then, an efficient optimization algorithm is applied, namely the Harmony Search method [3], with the aim of providing effective designs of possible intervention strategies. The algorithm is interfaced with SWMM 5.0 [4], a dynamic rainfall-runoff model for continuous simulation released by the U.S. Environmental Protection Agency (EPA).

Nomenclature

h	Rainfall height
d	Rainfall duration
T	Return Period
a	IDF Coefficient
n	IDF Exponent
P	Cumulative probability function
u, ν	Parameters of Gumbel distribution
μ	Mean value
σ	Standard deviation
K_T	Growth factor
λ	Event frequency
τ	Rainfall inter-event
η	Fitted coefficient of Poisson distribution
N	Number of rainfall events
γ	Mean value of exponential distribution
β	Shape parameter of Gamma distribution
α	Scale parameter of Gamma distribution
U	Uniform random number
X	Highest series value
PMP	Probable Maximum Precipitation
k_M	Frequency factor

2. Disaggregation method for rainfall data and climate change prediction

The Intensity-Duration-Frequency (IDF) is the classical and synthetic approach to define the maximum rainfall depth (h) and intensity (i) associated to a rainfall event with duration d and return period T at a given location. Typical IDF formulation is:

$$h(d,T) = a(T) \cdot d^{n} \tag{1}$$

where *a(T)* and *n* are the parameters obtained through the probabilistic analysis of the rainfall data of the addressed basin.

The Gumbel distribution is usually adopted to describe extreme rainfall events. The corresponding cumulative distribution function $P(h)$ is provided by the following:

$$P(h) = \exp\left\{-\exp\left[-u(h-v)\right]\right\} \tag{2}$$

where u and v depend on the mean value (μ) and the standard deviation (σ) through Eq. (3) and (4):

$$u = \frac{1.28}{\sigma} \tag{3}$$

$$v = \mu - 0.45\sigma \tag{4}$$

The tail distribution defines the probability of not exceeding h, and it is a function of the return period:

$$P = 1 - \frac{1}{T} \tag{5}$$

Consequently, it is possible to express *a(T)* as:

$$a(T) = a_{\mu} \cdot K_{T} \tag{6}$$

where a_{μ} is a coefficient related to the mean value of the maximum annual rainfall depth, while K_T is the growth factor depending on T.

Rainfall data are usually available at daily observation scale. However, De Paola et al. [2] developed a disaggregation procedure to define the extreme rainfall depths for events with duration less than 24 hours. In particular, they considered two disaggregation models:

- Cascade-based disaggregation model
- Short-time intensity disaggregation method.

The basic assumption of this procedure is that the daily rainfall can be modeled through a Poisson process and that the rainfall inter-event time (τ) and depth can be represented by exponential probability density functions. Therefore, a stochastic model consisting of a succession of Poisson processes with frequency λ can be adopted to describe the succession of daily rainfall, while the distribution of τ can be modeled through an exponential function with mean value equal to $1/\lambda$. Finally, rainfall depths are exponentially distributed with mean value γ.

Based on a cascade disaggregation model [5] based on the principle of multiplicative cascade processes, rainfall data for the durations of 3, 6 and 12 hours can be obtained from the information about daily precipitations. For each year, starting from γ and λ, disaggregated values can be generated by extracting the maximum value for each time window of 3 h, 6 h, 12 h.

The cascade structure can be correlated to the rainfall times series at given resolution, and its modulation should represent the transfer from a cascade level to the higher one according to a doubling resolution. In the disaggregation model, two entities must be defined: *box,* that is a time interval at an arbitrary cascade level associated to a precipitation amount; *branching,* that defines the break-up of a wet box into two equally-sized sub-boxes. The model assumes the mass conservation, and here a multiplicative cascade branching number equal to 2 is adopted.

A short-time intensity disaggregation model [6] is considered as well, and it is used for the fine-resolution time repartition in 10, 30 and 60 minutes (1 hour). A single Poisson distribution parameter defines the number of events N on a rainy day, and it is expressed by Eq. 7, which was adjusted in order to obtain $N \geq 1$:

$$f(N) = \frac{\eta^{N-1} \cdot e^{-\eta}}{(N-1)!} \tag{7}$$

in which η is a fitted coefficient while mean μ_N and variance σ^2_N are obtained by the following equations:

$$\mu_N = \eta + 1 \tag{8}$$

$$\sigma_N^2 = \eta \tag{9}$$

The simulated number of event N represents the lowest integer value which satisfies:

$$\sum_{i=1}^{N} \frac{\eta^{i-1} \cdot e^{-\eta}}{(i-1)!} \geq U \quad N \geq 1 \tag{10}$$

where U is a uniform random number ranged between 0 and 1.

It is assumed that the duration of each event D is well represented by a Gamma distribution with shape parameter β equal to 2 and scale parameter α to be estimated through Eq. 11:

$$f(D) = \alpha^2 \cdot D \cdot e^{-\alpha \cdot D} \tag{11}$$

Therefore, a uniform random number U is and the event duration D is estimated by solving the cumulative density function of Gamma distribution through Newton's method:

$$1 - (1 + \alpha \cdot D) \cdot e^{-\alpha \cdot D} = U \tag{12}$$

The rainfall probability curve is obtained by using software CRA.clima.rain [7]. At the same time the Probable Maximum Precipitation (*PMP*) parameter is considered. It represents the maximum rainfall depth for a given duration that is meteorologically possible for a watershed or a given storm area at a particular location and a particular time of year, with no allowance made for long-term climatic trends [8]. It is estimated by considering the Hershfield's technique, based on Chow [9] general frequency equation:

$$PMP = \overline{X_n} + k_m \cdot \sigma_n \tag{13}$$

and

$$k_m = \frac{X_M - \overline{X}_{n-1}}{\sigma_{n-1}} \tag{14}$$

where X_M, $\bar{X}_n$ and σ_n are, respectively, the maximum, the mean and the standard deviation of a series of n annual maximum rainfall values for a given duration; $\bar{X}_{n-1}$ and σ_{n-1} are the mean and the standard deviation of the same series, less than the highest value from the series; k_m is a frequency factor. The latter is evaluated by using Eq. (14) and by considering the WMO nonmograph [8].

The climate simulation is performed according to the IPCC (Intergovernmental Panel on Climate Change)

20C3M protocol for the 20th Century. The initial conditions are derived from the equilibrium state reached by integrating the model for 200 years with constant greenhouse gases (GHGs) concentrations referred to 1950s conditions. Once the climate model has reached the equilibrium with the prescribed constant radioactive forcing (GHG and aerosol concentrations), the simulations are developed by increasing the GHG and the aerosol concentrations, as per the observed data.

The projections are executed by considering the RCP4.5 and the RCP8.5 emission scenarios, in compliance with the framework of the 5th Coupled Model Intercomparison project [10].

The simulations are developed as function of a spatial resolution of about 8 km, by downscaling a set of climate simulations performed by the CMCC (Centro Euro-Mediterraneo sui Cambiamenti Climatici, Capua, Italy) with the coupled global model CMCC-MED, in reference to a resolution of 80 km and the time period 1950-2050. The adopted model is COSMO-CLM, the climate version of the COSMO model, implemented by the German Weather Service.

The available daily rainfall data are disaggregated in 7 durations. As first step, by using the cascade-based model, the values for 3, 6 and 12 hours are obtained while the short time intensity disaggregation model is used for evaluating the duration of 1 h, 30 and 10 min. As function of the maximum value, for each duration, the Gumbel distribution and the IDF curves are defined, as per Eqs. (1) to (6) and return periods of 5, 10, 30, 100 and 300 years are considered.

The procedure is applied to the climate simulations over the time period 2010-2050, provided by CMCC. Two emission scenarios RCP4.5 and RCP8.5 and two spatial resolutions, 8 km and 1 km, are developed. The elaborations highlighted how, with reference to the same spatial resolution, the two different emission scenarios did not determine consistent deviations. On the other hand, a significant discrepancy is highlighted for different downscaling. In particular the 1 km downscaling is able to reproduce the extreme events. At the same time, climate changes would determine a rise of frequency of extreme events.

3. Harmony Search for optimal design of sewer systems

In the present work, the Harmony Search (HS) optimization algorithm is applied to design the sewer system. The assumed objective is the minimization of the construction cost. The HS has been successfully applied in a large number of applications, such as: pipe network design [11, 12], setting of Pressure Reducing Valves in Water Distribution Networks [13], vehicle routing [14, 15], design of grillage systems [16, 17], scheduling of multiple dam systems [18], mooring cost optimization [19] and also music composition [20].

The main steps of the HS algorithm are summarized below:

- Step 1. Initialize the problem and algorithm parameters;
- Step 2. Initialize the Harmony Memory (HM);
- Step 3. Improvise a new harmony;
- Step 4. Update the harmony memory;
- Step 5. Check the stopping criterion.

where each “harmony” is a possible solution to the addressed problem.

The different parameters of the HS, as well as the decision variables and the constraints, are here defined in order to obtain optimized and hydraulically feasible solutions. An integrated approach is applied, which is based on the combination of the HS with the EPA SWMM [4] routines. In fact, at every iteration of the optimization algorithm, hydraulic simulation is carried out in order to check the feasibility of the provided solutions (Fig. 1).

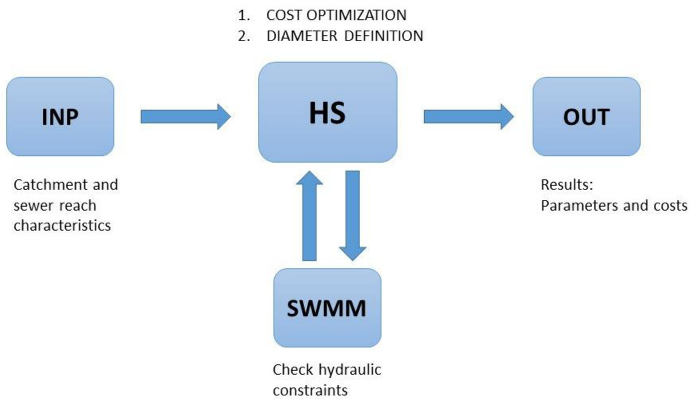

Fig. 1. Integrated HS – SWMM approach framework

The sustainable development of a sewer system in response to the climate change is here formulated as the problem of minimizing the objective function corresponding to the total cost due to every component of the sewer system. The IDF curve calibrated through the procedure described in the previous section is adopted as rainfall input, and the following constraints are considered:

- Constant sewer slope between two nodes (manholes) and fixed burial depth (1.5 m);
- Flow velocity in every section ranged between 0.5 m/s and 5.0 m/s;
- No nodes were flooded;
- Diameter of sewer pipes not smaller than those flowing into their upstream sections;
- Top alignment of the pipes also in diameter change sections.

The hydraulic simulation is carried out by considering the Dynamic Wave routing, with ponding allowed. In the following section, the application to a simple case study is discussed, which was used to show the possible uses of the developed model and to analyse the relevant technical and hydraulic outcomes.

4. Case Study: the storm-water system of Dar es Salaam (Tanzania)

In this study, the case study of the African city of Dar es Salaam (Tanzania) is analysed. Dar es Salaam is the largest city in Tanzania with an estimated population of 3.4 million and an annual population growth of 4.1 % [21]. It is the fastest growing region among 26 others in Tanzania and ranked amongst the ten fastest growing cities worldwide. The population is expected to exceed 4.5 million in 2020 [21, 22]. The city is located on the East African coast and has a wider city-region covering almost 1,400 km^2. The present day climate of Dar es Salaam is characterized by the strong seasonal rainfall cycle, with the “long rains” from March to May, and the “short rains” from November to January. These rainfall maxima are induced by meridional displacements of the Inter-tropical Convergence Zone. It experiences peak temperatures during the austral summer from December to February, due to the peak in solar radiation [23]. The city is particularly susceptible to climate threats like sea level rise and coastal erosion, drought, heat waves and water scarcity, strong winds and flooding [21, 24].

The proposed methodology is applied to a small portion of the sewer system of the city. More in detail, the study area consists of five subcatchments (Fig. 1), whose main features are summarized in Tab. 1. A rectangular design hyetograph with critical duration of 12 minutes is assumed as reference rainfall impulse at present time. For the IDF, the following parameters are used: a_μ = 36.44 mm/h^n, n = 0.25 and K_T=1.23 (a return period of 5 years is adopted) [2].

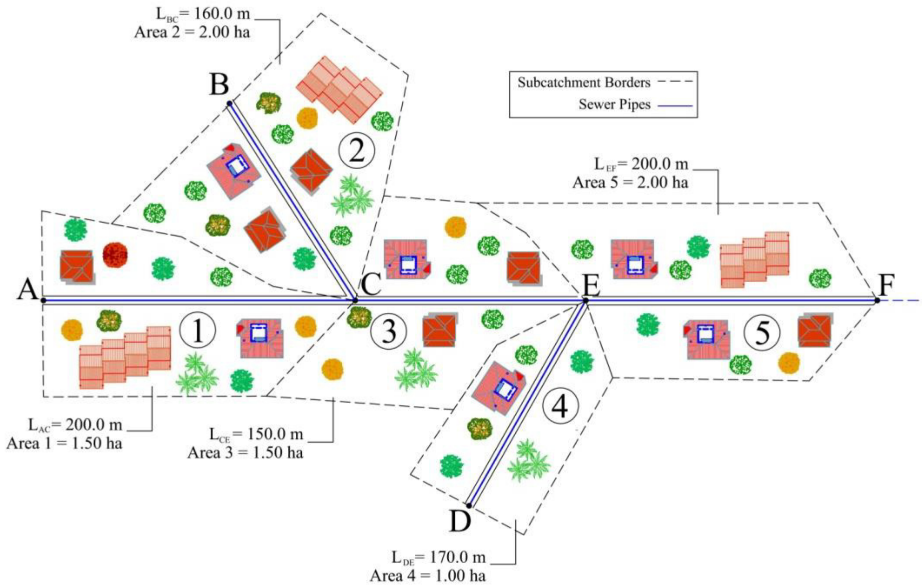

Fig. 2. Example sewer system layout

Table 1. Subcatchment and sewer pipes properties

Subcatchment	Area (*ha*)	Impervious Area Percentage (*%*)	Sewer Pipe Length (*m*)	Sewer Pipe Length Slope (*m/m*)
1	1.50	57.0	200.0	0.015
2	2.00	57.0	160.0	0.010
3	1.50	57.0	150.0	0.020
4	1.00	57.0	170.0	0.010
5	2.00	57.0	200.0	0.015

The HS algorithm is firstly applied to find the cheapest design of the sewers according to the present hydrological regime. Commercial diameters for different pipe materials are considered: cast iron, concrete, HDPE, LDPE, FGRP, PVC.

The best obtained solution involves the use of HDPE pipes for all of the five subcatchments. The diameters and the corresponding cost of the sewer pipes are reported in Tab. 2. The results of the hydraulic simulation performed on the updated model of the sewer system are reported in Tab. 3, which shows the compliance of the detected values with the problem constraints.

Table 2. Least-cost design of the sewer pipes at present time

Subcatchment	Sewer Length (*m*)	Internal Diameter (*mm*)	External Diameter (*mm*)	Pipe Unit Cost (€/*m*)	Sewer Cost (€)
1	200	500	580	95.70	19,140.00
2	160	600	700	151.25	24,200.00
3	150	800	930	279.40	41,910.00
4	170	500	580	95.70	16,269.00
5	200	1,025	1,200	421.30	84,260.00
Total					**185,779.00**

Table 3. Hydraulic features of the designed sewer system

Subcatchment	Peak Discharge (m^3/s)	Maximum Velocity (m/s)	Max Filling Rate (%)
1	0.356	2.11	81
2	0.502	2.02	84
3	1.214	3.25	70
4	0.238	1.69	68
5	1.898	3.28	66

In order to verify the feasibility of the obtained solution in response to the predicted climate change, a 10% increase of the rainfall intensity is assumed. Furthermore, with the aim of reproducing the effects of the anthropic evolution in Dar es Salaam, a change in the land use corresponding to a 20% increase of the impervious area is considered.

As shown in Tab. 3, the filling rates of the sewers due to the optimal design are very close or even equal (in case of subcatchment 3) to the upper limit. Therefore, an increase in the rainfall intensity and in the land imperviousness is likely to produce an infeasible operation of the storm-water system. Hence, three different intervention scenarios are subsequently analysed.

4.1. Scenario 1: Insertion of Storm-water Detention Tanks

With the aim of facing the expected increase of the peak flow and in order to reduce the connected overflow risk, a first scenario is analysed which is based on the BMPs, and in particular on the introduction of storm-water detention tanks (SDTs).

The developed model is then applied to determine the volumes of the SDTs to install at the upstream section of every trunk of the sewer system. The total cost (i.e. the objective function value) is obtained as the sum of the construction costs of every SDTs, which are functions of the relative water volumes (i.e. the decision variables).

Three different runs were performed with 10,000 iterations per each in order to ensure the convergence of the results. The initial condition adopted involves the construction of just four SDTs, whose locations are supposed to be in all the receiving junctions (Fig. 3).

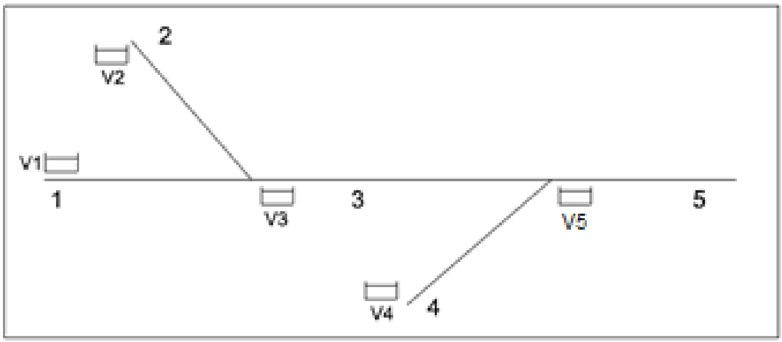

Fig. 3. Locations of the storm-water detention tanks

After the runs of the mentioned algorithm, the construction costs for this scenario are summarized in Tab. 4. It is interesting to observe that only the tanks V1 and V2 are effective. The proposed model also provides the best locations of the STDs in order to reduce the total cost.

Table 4. Hydraulic features and construction costs for scenario 1

Subcatchment	Peak Discharge (m^3/s)	Maximum Velocity (*m/s*)	Max Filling Rate (*%*)	Detention Tank	Max Detention Tank Volume (m^3)	Costs per Tank (*€*)
1	0.384	2.12	92	V1	89	18,621.00
2	0.512	2.01	89	V2	134.40	27,341.00
3	1.354	3.31	76	V3	0	0
4	0.306	1.79	83	V4	0	0
5	2.237	3.36	75	V5	0	0
				Total		**45,962.00**

4.2. Scenario 2: Adaptation of sewer pipes

A second alternative approach is described here, that is the redesign of the existing sewer pipes in order to accommodate the increased flows due to climate change and land use development.

In this case, the HS based model is used to detect the sewers to substitute with larger pipes in order to verify the compliance with the hydraulic constraint. The optimal solution involves the adaption of pipes relevant to subcatchments 1 and 2. The revised diameters, compared to previous ones, are reported in the Tab. 5, in which the unit cost of pipes and total costs are also indicated.

Table 5. Construction costs for scenario 2

Subcatchment	Sewer Length (*m*)	Initial Internal Diameter (*mm*)	Adapted Internal Diameter (*mm*)	Pipe Unit Cost (*€/m*)	Sewer Cost (*€*)
1	200	500	533	119.02	23,804.00
2	160	600	690	204.60	32,736.00
Total					**56,540.00**

4.3. Scenario 3: Design with a preventive approach

Scenario 3 is developed with the aim of verifying the adoption of the diameters calculated in the scenario 2 in the early design of the sewer system. In this scenario, here indicated as “preventive approach”, the effect of the larger diameters assigned to the sewer of subcatchments 1 and 2 should be assessed with reference to the initial rainfall intensity and impervious area. The relevant hydraulic entities are reported in Tab. 6, together with the costs of the single sewers and of the whole system.

Table 6. Construction costs for scenario 3

Subcatchment	Peak Discharge (m^3/s)	Internal Diameter (*mm*)	Maximum Velocity (*m/s*)	Max Filling Rate (*%*)	Pipe Unit Cost (€/*m*)	Sewer Cost (€)
1	0.457	533	2.23	90.0	119.02	23,804.00
2	0.655	690	2.06	83.0	204.60	32,736.00
3	1.558	800	3.37	91.0	279.40	41,910.00
4	0.306	500	1.79	83.0	95.70	16,269.00
5	2.441	1025	3.38	82.0	421.30	84,260.00
Total						**198,979.00**

4.4. Comparison between scenarios

The presented scenarios are then compared in terms of both total construction costs and corresponding increases respect to the initial cost reported in Tab. 2. In fact, it is useful to emphasize that the values reported in Tabs. 4 and 5 represent additional costs to incur in order to meet the hydraulic design criteria following the change in climate and land use. In case of scenario 3, the increment should be evaluated only for the share due to the enlarged diameters, that is equal to 13,200.00 €.

The quantities summarized in Tab. 7 clearly show the effectiveness of the preventive approach, and therefore, of the improved design of the storm-water system performed in consideration of the climate change.

Table 7. Comparison between different intervention scenarios

Intervention	Additional Cost (€)	Cost Increment Percentage (%)
Detention Tanks	45,962.00	24.74
Sewer Pipe Adapting	56,540.00	30.43
Preventive Approach	13,200.00	7.11

5. Conclusive Remarks

In the present work, the impact of climate changes on the sustainable development of storm-water systems in African cities was addressed. An integrated approach involving the evaluation of the long term evolution of the rainfall intensity, an optimization algorithm and a hydraulic solver was presented and discussed with reference to a real case study.

Different scenarios were proposed as additional alternatives to the initial design of the storm-water system of a portion of Dar es Salaam. The objectives was that of minimizing the total cost while preserving the system performance against the modification in the hydrological regime assessed through the disaggregation methodology on rainfall data. The impact of the urban development was considered as well, and it was implemented as in terms of the soil imperviousness due to change in the land use.

The obtained results confirmed the effectiveness of the methodology, and in particular they showed, for example, that the SDTs are particularly useful because they involve a very strong reduction of the peak discharge in every section of the considered system. On the other hand, under the financial point of view, the same outcomes emphasized the benefits due to a preventive approach in designing the sewers compared to the insertion of storm-water detention tanks or the subsequent re-design of a limited number of pipes.

References

[1] CLUVA (CLimate Change and Urban Vulnerability in Africa), Introduction to the CLUVA Project, http://www.cluva.eu.
[2] F. De Paola, M. Giugni, M.E. Topa, E. Bucchignani, Intensity-Duration-Frequency (IDF) rainfall curves, for data series and climate projection in African cities, Springer Plus 3:133 (2014).
[3] Z.W. Geem, J. Kim, G.V. Loganathan, A new heuristic optimization algorithm: harmony search, Simulation, vol. 76, n. 2 (2001).
[4] U.S. Environmental Protection Agency, http://www2.epa.gov/water-research/storm-water-management-model-swmm, Storm Water Management Model (SWMM), 2010.
[5] A. Günter, J. Jonas Olsson, A. Calver, B. Gannon B, Cascade-based disaggregation of continuous rainfall time series: the influence of climate. Hydrology and Earth System Sciences, 5(2) (2001) 145-164.
[6] R.D. Connolly, J. Schirmer, P.K. Dunn, A daily rainfall disaggregation model. Agricul Forest Meteorol, 92 (1998) 105-117.
[7] Agricultural Research Council – CLIMA version 0.3 (2009) http://agsys.cra-cin.it/tools/clima/
[8] World Meteorological Organization, Manual for estimation of probable maximum precipitation. Operational hydrology, Report 1, WMO-No.332 (1986) 269.
[9] V.T. Chow, A general formula for hydrologic frequency analysis, Trans Am Geophysical Union 32 (1991) 231-237.
[10] CMIP5 (2013) http://cmippcmdi.llnl.gov/cmip5/
[11] Z. Geem, J. Kim, Y. Yoon, Optimal layout of pipe networks using harmony search, in: Proceedings of 4th International Conference on Hydro-Science and Engineering, Seoul, South Korea, 2000.
[12] Z. Geem, J. Kim, G. Loganathan, Harmony search optimization: application to pipe network design. Intern. Journal of Modelling & Simulation, 22 (2) (2002) 125–133.
[13] F. De Paola, E. Galdiero, M. Giugni, A jazz-based approach for optimal setting of Pressure Reducing Valves in water distribution networks.

Eng. Opt. (accepted March 12, 2015).
[14] Z. Geem, C. Tseng, Y. Park, Harmony search for generalized orienteering problem: best touring in China. Lecture Notes in Computer Science, 3612 (2005a) 741.
[15] Z. Geem, K. Lee, Y. Park, Application of harmony search to vehicle routing. American Journal of Applied Sciences, 2(12) (2005b) 1552-1557.
[16] F. Erdal, M. Saka, Optimum design of grillage systems using harmony search algorithm, in: Proceedings of 8th International Conference on Computational Structures Technology (2006), Las Palmas de Gran Canaria, Spain, 2006.
[17] F. Erdal, M. Saka, Effect of beam spacing in the harmony search based optimum design of grillages. Asian Journal of Civil Engineering (Building and Housing), 9(3) (2008) 215–228.
[18] Z. Geem, Optimal scheduling of multiple dam system using harmony search algorithm. Lecture Notes in: Computer Science, 4507:316 (2007b).
[19] S. Ryu, A. Duggal, C. Heyl, Z. Geem, Mooring cost optimization via harmony search. In Proceedings of the 26th ASME International Conference on Offshore Mechanics and Arctic Engineering (2007).
[20] Z. Geem, J. Choi, Music composition using harmony search algorithm. Lecture Notes in Computer Science, 4448:593 (2007).
[21] N. Jean-Baptiste, C. Kuhlicke, A. Kunath, S. Kabisch, CLUVA deliverable D2.11 review and evaluation of existing vulnerability indicators in order to obtain an appropriate set of indicators for assessing climate related vulnerability. CLUVA-EC FP7 project (2011).
[22] UN-Habitat, The state of African cities 2008. A framework for addressing urban challenges in Africa. United Nations Human Settlements Programme, Nairobi (2008).
[23] CSIR, CMCC, CLUVA deliverable D1.7 climate maps and statistical indices for selected cities. CLUVA-EC FP7 project (2013).
[24] D. Dodman, E. Kibona, L. Kiluma, Tomorrow is too late: responding to social and climate vulnerability in Dar es Salaam, Tanzania. Case study prepared for the global report on human settlements 2011. UN-Habitat, Nairobi (2011).