Future evolution of CSO discharges under climate change, a case study in the Mediterranean region

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Highlights

- A method to elaborate time series of future precipitation at the rainfall event scale.
- A lightweight model based on an artificial neural network (ANN) to reproduce spills.
- A method that meets a demand for urban drainage modelling in order to evaluate urban drainage system sensitivity regarding impacts of climate change.

Introduction

Climate change is a growing concern in general and particularly for urban water systems. In the Mediterranean basin, the impacts of rising temperatures in the future will produce variations in frequency and intensity of heat waves, and probably more intense rainfall events (Tramblay and Somot, 2018). Variations in precipitation patterns strongly impact the operation of sanitation systems. However, climate projection data are only available on daily time steps, whereas the response of urban drainage systems occurs on smaller time steps. Modelling future rainfall with small time steps is a challenge for hydrologists. This communication presents the methodology designed to build future rainfall timeseries, combining spatial downscaling and temporal disaggregation, plus an application to assess future overflows from an existing wastewater network. The methodology was applied to the city of Valence in Southern France, under a Mediterranean climate, for projections from 2021 to 2100. The Valence wastewater network was modelled with a NARX ANN.

Methodology

Available data

Two sources of rainfall data are used to elaborate the future timeseries of precipitation:

- The DRIAS 2020 dataset that offers results of climate simulations for France from now to 2100. The simulations on this webportal are issued from European modelling experiences coupling GCMs (Global Climate Models) and RCMs (Regional Climate Models). Results are provided for 12 GCM/RCM couples on a daily time step, on an 8x8 km grid and for different RCPs (Representative Concentration Pathways) scenarios.
- Historical rainfall data provided by Valence-Romans conurbation at a daily time step since 1997 and at a 6-minute time step since 2005.

To consider the impact of future rainfall, we chose to focus our study on the main CSO of the city of Valence which contributes to 50% of the total annual spill volume, equivalent to about 500 000 m^3 depending of the year. This site is monitored according to European and French regulations. Five-minute time step data are available for rainfall and effluent flows. We used the period from 2018 to 2020 for calibration and validation of the ANN model.

First step: building future rainfall timeseries

The spatial definition of RCMs does not allow to consider the orography in a very fine way. This causes difficulties to accurately simulate climate parameters at a precise location on the grid. To use the results at a local scale, for example at city scale, a downscaling step is necessary. It consists in correcting the

simulated rainfall data based on field observations on the studied site. In our case, we used the CDF-t method (Cumulative Distribution Function-transform method) for this purpose (Vrac, 2016). This method, derived from the quantile-quantile method, consists in determining the mathematical function allowing to adjust simulated data according to observed data over a shared period.
Then, we applied to the downscaled data a temporal disaggregation that converts daily time step data into 6-minute time step data. To do this, for each future day, we look for the best analogous day in the dataset for which the data are available at a 6-minute time step. The criteria retained for searching the best analogue between past / future days are: the season, the daily total rainfall depth, the average daily temperature and the maximum daily temperature (Herath et al., 2017). The determination of the best past analogue day was done by minimizing the Euclidean distance on all the past / future parameters considered. We suppose then that the 6-minute hyetograph for each future day will be the same as the one observed during the analogous day in the past. Values of rainfall intensity are only corrected to fit the total daily rainfall depth predicted for each day in the future.

Second step: building a well calibrated ANN model
We chose a NARX (nonlinear autoregressive exogenous model) type architecture for the network, because it is well suited to the simulation of time series. The NARX is a dynamic, looped recurrent model in which the feedback loop can encompass multiple layers of neurons. The loop is made between the output of the system and its input (Khalil, 2012).
Concerning the parameters of the network, the structure retained is one hidden layer with 10 neurons, a delay of two hours corresponding to the lag-time of the catchment, and a Levenberg-Marquardt back propagation algorithm. Data from 2019 to 2020 have been used for the learning and test steps, and data from 2018 for the validation step. Simulation over the validation period shows results as accurate as those that could be obtained using a more classic distributed model (Figure 1), i.e. uncertainties within a 15 to 30% range.

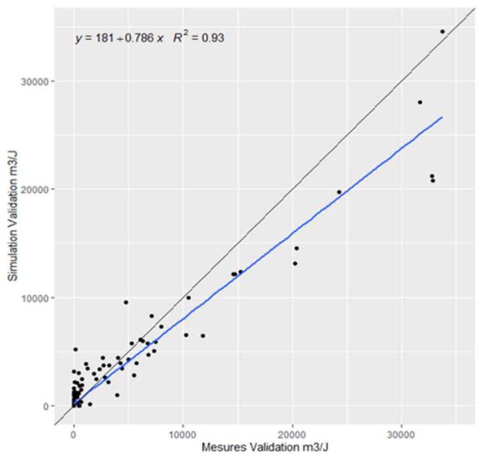

Figure 1. Simulated daily discharged volumes as a function of the measured daily discharged volumes, for the validation period (2018). The linear regressions, their equations as well as the R2 are plotted on the graphs.

Results and discussion
We used this method and the R software to yield continuous 6-minute time step rainfall projections from January 1st, 2021 to December 31, 2100. The method was applied to four DRIAS 2020 datasets based on the RCP8.5 scenario and issued from 4 different GCM/RCM simulations in order to consider a part of the uncertainty.
The validated NARX model was then run with each of the four rainfall timeseries as input.
The results show an increasing trend of the CSO discharge over the period 2021-2100 (Figure 2). Results are refined with a mobile according to a moving average over 30 years to be at least partially free from internal climate variability. Depending on the GCM/RCM couple used to build the rainfall timeseries, the increase of the annual CSO discharge volume is between 4 and 23%. Those predictions are consistent with the results of previous studies (Willems 2012).

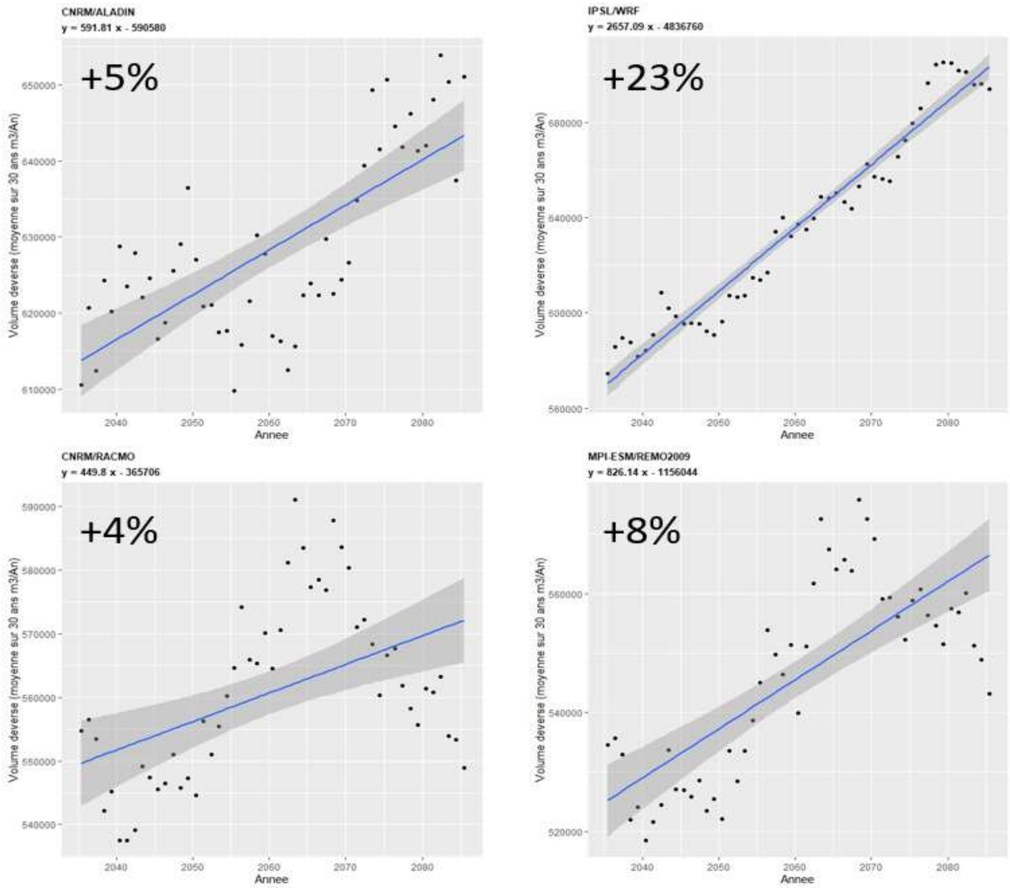

Figure 2. CSO volumes simulated over the period 2021-2100 (moving average of this volume over 30 years). The linear trendline is displayed in blue with its 95% confidence interval. The increase of the CSO volume is mentioned in the top left corner of each graph. From left to right and top to bottom, the climate models used for each simulation are: CNRM/ALADIN (Meteo France/Meteo France), IPSL/WRF (IPSL-France / NOAA USA), CNRM/RACMO (Meteo France / KNMI The Netherlands) and MPI-ESM/REMO2009 (Max Planck Institut / CSC Hamburg Germany).

Conclusions and future work

The method presented here to yield 6-minute time step rainfall projections is reproducible and relatively simple to implement. It requires local climate change simulation results, which should be made available by national or local authorities.

This work responds to a need for future rainfall information at a fine time step to feed urban hydrological models allowing to evaluate the sensibility of water urban management in a climate change context. We used it to determine the evolution of network CSOs in Valence, France. This work focused on a rain / discharge model based on an artificial neural network. Future work will consist in establishing the impact of future rainfall events on urban flooding using a traditional distributed model.

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