International Congress on Environmental Modelling and Software  
9th International Congress on Environmental Modelling and Software - Ft. Collins, Colorado, USA - June 2018

Jun 27th, 2:00 PM - 3:20 PM

**Space-time Uncertainty Propagation of Input Precipitation across a coupled Rainfall-Runoff Urban Drainage Model**

Arturo Torres-Matallana  
*Luxembourg Institute of Science and Technology, arturo.torres@list.lu*

Ulrich Leopold  
*Luxembourg Institute of Science and Technology, ulrich.leopold@list.lu*

Follow this and additional works at: [https://scholarsarchive.byu.edu/iemssconference](https://scholarsarchive.byu.edu/iemssconference)


This Oral Presentation (in session) is brought to you for free and open access by the Civil and Environmental Engineering at BYU ScholarsArchive. It has been accepted for inclusion in International Congress on Environmental Modelling and Software by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.
Space-time Uncertainty Propagation of Input Precipitation across a coupled Rainfall-Runoff Urban Drainage Model

J.A. Torres-Matallana\textsuperscript{a, b}, Ulrich Leopold\textsuperscript{b}

\textsuperscript{a}Soil Geography and Landscape Group, Wageningen University, The Netherlands
\textsuperscript{b}Environmental Informatics Research Unit, Department for Environmental Research and Innovation, Luxembourg Institute of Science and Technology, Luxembourg (arturo.torres@list.lu, ulrich.leopold@list.lu)

Abstract Rainfall is one important source of uncertainty in the simulation of combined sewer overflows and the emissions of pollutants to the receiving water body. Studies often ignore the spatial dimension treating input rainfall as a non-spatially distributed time series. Neglecting spatial and space-time distribution of rainfall entering urban drainage systems may result in inaccurate quantification of rainfall and, hence, in substantial uncertainties associated to water quantity and quality predictions. We developed a space-time interpolation model for rainfall, based on space-time Kriging, using point rainfall measurements as the primary variable. We then interpolated rainfall over space and time and built a 90% confidence interval of rainfall for the Haute-Sûre urban drainage system catchment in North-West Luxembourg. The resulting rainfall maps were fed into a rainfall-runoff model simulating the routing of the runoff across the catchment. The space-time rainfall uncertainty propagation demonstrated that an over estimation of CSO spill volume and consequently pollutants (COD and NH\textsubscript{4}) is done when we consider only the deterministic simulation without taking into account the space-time model for rainfall. Furthermore, the presented methodology is generic and can be applied to a wider range of integrated environmental assessment models. Future work will focus on the space-time simulation implementation to replace space-time Kriging to produce more realistic and less smooth rainfall maps to propagate through the run-off model. Also, this will be realised as a generic approach to be applied to spatio-temporal integrated environmental assessment models.

Keywords: space-time uncertainty characterisation; space-time uncertainty propagation; space-time kriging; integrated environmental assessment modelling.

1 Introduction

Recent practice in urban drainage modelling incorporates characterisation of model input uncertainty in the temporal domain. Previous studies show that rainfall is one important source of uncertainty when uncertainty propagation is performed in the simulation of water volume in the combined sewer overflow tank and the emissions of pollutants to the receiving water body. However, studies often ignore the spatial dimension treating input rainfall as a non-spatially distributed time series, typically originated from rain gauge measurements. Neglecting spatial and space-time distribution of rainfall entering urban drainage systems may result in inaccurate quantification of rainfall and, hence, in substantial uncertainties associated to water quantity and quality predictions. This paper has the aim of developing a more realistic characterisation of rainfall as an input to urban sewer models in order to better evaluate its impacts on these predictions.
2 METHODS

We developed a space-time model for predict rainfall fields at 10-minute temporal resolution and 500 meters as spatial resolution. We use ordinary global Kriging for prediction of the mean value and variance of rainfall over the entire country of Luxembourg by using 25 rain gauge stations. The region of study is the Haute-Sûre catchment in North-West Luxembourg. Given the mean and the variance maps, we compute rainfall maps for the lower and upper boundary of the 90% confidence interval. The mean, lower and upper boundaries are the main inputs for propagating uncertainties through an integrated rainfall-runoff and sewer system modelling approach. We compare the deterministic temporal simulations made with a simplified sewer model and a complex mechanistic model with the space-time approach considering model input uncertainty.

2.1 Kriging in the space-time domain

To model precipitation fields in the spatio-temporal domain we use the concept of spatio-temporal variogram for ordinary global Kriging (Gräler et al., 2016). We implemented routines using the R package gstat (Pebesma, 2004) for defining spatio-temporal covariance models. Five models are available in gstat: Separable; Product-sum; Metric; Sum-metric; Simplified sum-metric. The method for Kriging prediction in space and time, considers the definition of one covariance model (or variogram) for the space domain and one covariance model (or variogram) for the time domain. In the Sum-metric model the covariance is represented as (Gräler et al., 2016):

\[ C_{sm}(h, u) = C_s(h) + C_t(u) + C_{joint}(\sqrt{h^2 + (\kappa \cdot u)^2}) \]  

(1)

where \( h \) represents the separation distance across space, \( u \) is separation distance in time, and \( \kappa \) is a parameter accounting for space-time anisotropy. The variogram is derived similar to the covariance Gräler et al. (2016):

\[ \gamma_{sm}(h, u) = \gamma_s(h) + \gamma_t(u) + \gamma_{joint}(\sqrt{h^2 + (\kappa \cdot u)^2}) \]  

(2)

2.2 Selection of event

In order to calculate the theoretical spatio-temporal variogram, we selected a one-day period where the cumulative precipitation of the time series is maximum, retrieving a precipitation event in all stations. The selected period of the event was 16 December 2011 from 00:00 to 10:00.

2.3 Rainfall-runoff model

The rainfall-runoff model used is itzï (Courty et al., 2016). Itzï is a numerical model written in Python, and can be used to simulate surface flows induced by intense rainfall in the urban domain. The model is integrated into the open source GIS software GRASS, which allows a seamless integration of geospatial data as input for the model and model output in the native GRASS format for spatio-temporal raster datasets. Itzï uses an explicit finite-difference scheme to solve the simplified partial inertia shallow-water equations described by De Almeida et al. (2012) and De Almeida and Bates (2013). Besides rainfall maps stored in GRASS GIS as spatio-temporal raster datasets (strds) in [mm/h], itzi requires of maps for the coefficient of roughness of Manning [–] and the infiltration rate [mm/h]. Maps for defining the boundary conditions in the computational domain are also required.

Infiltration. In the study area the typical soil texture expected is between clay loam and loam. According to the Food Agriculture Organisation (FAO) for clay loam soil texture is defined an infiltration rate of 10 mm/h. We define for 20% of the area 10mm/h and for 80% 0mm/h (no infiltration), which is equivalent to a uniform infiltration rate of 2 [mm/h].

Roughness coefficient. The land use in Goesdorf catchment corresponds to arable land with crops on it, which behavior is most likely as grassland. Also important areas are covered by forest. The lower proportion
of land use correspond to urban infrastructure i.e. village and road network. Table 1 shows the roughness coefficients and the percentage of land. In average, a roughness coefficient of 0.30 is defined for Goesdorf sub-cathment.

<table>
<thead>
<tr>
<th>Manning, GOE (percentage)</th>
<th>Manning, GOE (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban (village + road network)</td>
<td>0.06</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.35</td>
</tr>
<tr>
<td>Forest</td>
<td>0.35</td>
</tr>
</tbody>
</table>

2.4 Sewer system model

Two sewer system models are used to compute the deterministic CSO spill volume, and loads and concentrations of COD and NH$_4$, based on the point precipitation measured at Dahl station. One model is a simplified sewer system model (EmiStatR Torres-Matallana et al. (2018)), that can be fed with point data of precipitation or runoff volume. The results of the deterministic simulations are compared with the second model, a complex mechanistic model which represented the flow routing in the sewer network through the ‘de Saint-Venant’ equations. The computation from the runoff volume is done only with the simplified model.

3 Results and discussion

3.1 Kriging in the space-time domain

We fitted the sum-metric model to the observed event to predict the rainfall by using the 25 point measurements distributed over Luxembourg territory. Figure 1 shows the empirical variogram and the sum-metric model fitted. Also the difference between the empirical and fitted variograms are illustrated in this Figure. Given the duration of the rainfall event selected for calibrate the sum-metric model, 10 hours, we define as temporal range of the fitted model 5 hours (300 minutes). The extension of the Luxembourg’s territory is about 80 Km from North to South and 60 Km from West to East, therefore, the spatial range of the fitted model was defined in 50 Km. Figure 2 illustrates the location of the 25 rain gauge stations over the territory of Luxembourg, used as primary data, and the 8 CSOC outlets of the Haute-Sûre catchment sewer system. The experimental variogram (1a) shows all variogram parameters visually identifiable spatial, temporal and spatio-temporal nugget, range and sill. The space-time anisotropy is 40. The fitted sum-metric model and its parameters are presented in Table 2.
Table 2. Space-time variogram model.

<table>
<thead>
<tr>
<th>Component</th>
<th>Partial Sill</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Space component</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nugget</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Spherical</td>
<td>0.021</td>
<td>10</td>
</tr>
<tr>
<td><strong>Time component</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nugget</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Exponential</td>
<td>0.129</td>
<td>201.9</td>
</tr>
<tr>
<td><strong>Joint component</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nugget</td>
<td>0.016</td>
<td>0</td>
</tr>
<tr>
<td>Spherical</td>
<td>0</td>
<td>1506</td>
</tr>
</tbody>
</table>

3.2 Predicted space-time rainfall

Upon the definition of the sum-metric model for predicting in space and time the rainfall fields, we proceed to computed the mean and variance maps for the Haute-Sûre catchment. Figures 3 shows the predicted mean value. We computed the lower boundary of the 90 percent confidence interval (Figure 4) using the kriging mean minus twice the root squared kriging variance, and the upper boundary (Figure 5) was computed as the kriging mean plus twice the the root squared of the variance. It is worth noting that, although the prediction temporal interval is 10 minutes and the spatial resolution corresponds to a squared grid of 500 m x 500 m, the maps shown in Figures 3 to 5 have a resolution of 70 minutes just for illustration purpose.

3.3 Rainfall-runoff model

The mean precipitation maps together with the lower and upper boundaries of the 90 percent confidence interval were fed into the rainfall-runoff model. The roughness coefficient and infiltration maps were also taken into account. We have chosen the Goesdorf sub-catchment to illustrate the results of the rainfall-runoff model, which corresponded to runoff depth over the land (Figure 6). Then the routing flow through the CSOC outlet was computed.

3.4 Sewer system model – Deterministic temporal simulation

In order to compare the space-time approach for computation of the CSO spill volume, and loads and concentrations of COD and NH₄, we computed the deterministic simulation only in the temporal domain, i.e. taking into account the point rainfall as measured in the rain gauge Dahl. Figure 7 shows the deterministic temporal simulation with the simplified model and the CMM.

3.5 Sewer system model – Spatio-temporal simulation

Finally, we computed the CSO spill volume, and loads and concentrations of COD and NH₄, based on the spatio-temporal rainfall fields predicted with the boundaries of the 90 percent confidence interval. Figure 8 shows the results. Comparing these results with the deterministic simulation (Figure 7), we can infer that the deterministic model over estimates the runoff volume and, therefore, an over estimation of the CSOC volume and CSO spill volume. Consequently, the water quality variables, (COD and NH₄) are over estimated as well. Indeed, the mean value of the predictions does not reflect any CSO spill volume and therefore no load nor concentration of pollutants. The deterministic simulations are comparable more to the upper boundary of the 90 percent confidence interval of the space-time simulation.
Figure 2. Location of the 25 rain gauge stations (red crosses) distributed over the country of Luxembourg and used for the spatio-temporal Kriging model, and the eight CSOC outlets (red triangles) of the Haute-Sûre catchment sewer system. GOE = Goesdorf CSOC.

Figure 3. Predicted rainfall [mm] with spatio-temporal sum-metric model for the Haute-Sûre catchment. (Red crosses represent rain gauge stations and red triangles represent CSOC outlets).
Figure 4. Prediction with spatio-temporal sum-metric model (lower boundary of the 90 percent confidence interval) for the Haute-Sûre catchment. (Red crosses represent rain gauge stations and red triangles represent CSOC outlets).

Figure 5. Prediction with spatio-temporal sum-metric model (Upper boundary of the 90 percent confidence interval) for the Haute-Sûre catchment. (Red crosses represent rain gauge stations and red triangles represent CSOC outlets).
Figure 6. Rainfall-runoff model output for water depth [m]. (a) Sub-plot for the lower bound of the 90% confidence interval; (b) Sub-plot for the mean value predicted; (c) Sub-plot for the upper bound of the 90% confidence interval. (Red triangle represent the Goesdorf CSOC outlet). The time frame in each subplot is different because the maximum value of each one is presented in the middle and one hour before to the left, and one hour after to the right. The maximum does not occur at the same time in each subplot.
Figure 7. EmiStatR (blue line) and CMM (red line) deterministic output. Goesdorf sub-catchment.

Figure 8. EmiStatR output. Prediction value (blue line) and boundary of the 90 percent confidence interval (gray band). Goesdorf sub-catchment.
4 Conclusion

We developed a space-time interpolation model for rainfall, based on space-time Kriging, using point rainfall measurements as the primary variable. We then interpolated rainfall over space and time and built a 90% confidence interval with the mean, lower and upper boundary for the Haute-Sûre urban drainage system catchment in North-West Luxembourg. The resulting space-time rainfall maps for mean, lower and upper bounds of 90% confidence interval were fed into a rainfall-runoff model simulating the routing of the runoff across the catchment to finally enter the urban drainage system model to predict water quantity and water quality in the combined sewer overflows (CSOs). The predicted space-time rainfall uncertainty propagation demonstrated that an over estimation of CSO spill volume and consequently pollutants (COD and NH₄) is done when we consider only the deterministic simulation without taking into account the space-time model for rainfall. Also we demonstrated that we can achieve a more realistic range of the physical processes for runoff generation and urban drainage hydraulics. Furthermore, the presented methodology is generic and can be applied to a wider range of integrated environmental assessment models. Future work will focus on the space-time simulation implementation to replace space-time Kriging to produce a wider range with more realistic and less smooth rainfall maps to propagate through the run-off model. Also, this will be realised as a generic approach to be applied to integrated environmental assessment models.

References


