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Impact evaluation of Wet-weather Events on Influent Flow and Loadings of a Water Resource Recovery Facility

Sina Borzooei[1], Ramesh Teegavarapu[2], Soroush Abolfathi[3], Youri Amerlinck[4], Ingmar Nopens[4], Maria Chiara Zanetti[1] and Lorenza Meucci[5]

[1] Politecnico di Torino, Department of Civil and Environmental Engineering, Torino, Italy
[2] Florida Atlantic University, Department of Civil, Environmental and Geomatics Engineering, Florida, United States
[3] Coventry University, Flow Measurement & Fluid Mechanics Research Centre, Coventry, United Kingdom
[4] Ghent University, Department of Mathematical Modelling, Statistics and Bio-informatics, Gent, Belgium
[5] SMAT (Turin Metropolitan Water Society), Corso XI Febbraio 14,10152, Torino, Italy

Abstract (maximum 250 words): Since the introduction of environmental legislation and directives in Europe, the impact of combined sewer overflows (CSO) on receiving water bodies has become a priority concern in water and wastewater treatment industry. Time-consuming and expensive local sampling and monitoring campaigns have been carried out to estimate the characteristic flow and pollutant concentrations of CSO water. This study focused on estimating the frequency and duration of wet-weather events and their impacts on influent flow and wastewater characteristics of the largest Italian water resource recovery facility (WRRF) in Castiglione Torinese. Eight years (viz. 2009-2016) of routinely collected influent data in addition to the arithmetic mean daily precipitation rates (PI) of the plant catchment area, were elaborated. Relationships between PI and volumetric influent flow rate (Q_{in}), chemical oxygen demand (COD), ammonium concentration ($N\text{-}NH_4$) and total suspended solids (TSS) are investigated. Time series data mining (TSDM) method is implemented for segmentation of time series by use of sliding window algorithm to partition the available records associated with wet and dry weather events based on the daily variation of PI time series. Appling the methodology in conjunction with results obtained from data reduction techniques, a wet-weather definition is proposed for the plant. The results confirm that applied methodology on routinely collected plant data can be considered as a good substitute for time-consuming and expensive sampling campaigns and plant monitoring programs usually conducted for accurate emergency response and long-term preparedness for extreme climate conditions.

Keywords: Wet weather; wastewater; rainfall, combined sewer system

1. INTRODUCTION

Combined sewer systems (CSSs) are sewage collection systems designed to collect surface runoff in addition to municipal and industrial wastewater. During heavy precipitation events when the volume of wastewater in CSSs exceeds the capacity of the collection system or treatment plant, combined sewer overflows (CSOs) discharge directly to surface water bodies (Burian et al., 1999). Significant chemical, physical and biological impacts of CSOs on receiving water bodies are well documented (e.g. Field and Sullivan, 2001). The adaptation of urban water and wastewater framework directives (CEC, 1996;1991) made these untreated or partially treated wastewater streams, a priority concern for the municipalities across Europe (Mostert, 2003). To study the adverse impacts of CSO on the receiving water quality, attentions have been focused on the qualitative and quantitative analysis of wet-weather flow (WWF) and its influence on treatment plant performance (Clark et al., 2007). The quality and quantity of WWF depends on several factors including the size and layout of the sewer system, land use and contours, duration, intensity and areal extent of precipitation events (Kothandaraman, 1972). Since considering all of these parameters is not a straightforward task, an analysis of historical, routinely collected data of the WWTPs can be a potential alternative providing this crucial information for managing the fluctuating load during wet-weather events (Suarez and Puertas, 2005). Several studies have focused on elucidating empirical relationships between precipitation intensity (P_I), influent flowrate (Q_{in}), and wastewater characteristics (among others, Berthouex and Fan, 1986; Giokas et al., 2002; Karagozoglu and Altin, 2003; Mines et al.,2007; Rouleau et al., 1997).

The majority of the reviewed studies were focused on seasonal and monthly average P_I for investigating the impact of wet-weather on different influent parameters of WRRFs, while little attention has been paid to daily variability of rainfall quantities. Two main reasons stop researchers to consider daily P_I : 1) High incidence of zero values in rainfall records 2) Non-identified minimum amount of precipitation which can affect specific plant influent data (P_{th}) and plant upset time (t_u) after each wet-weather event (Oliveira-Esquerre et al., 2004).

In this study, a quantitative analysis of daily precipitation impacts on influent flowrate and associated water quality constituents for the Castiglione Torinese WRRF was performed on 7 years of historical data. Application of Segmentation of time series by use of Sliding Window algorithm was studied and a plant specific wet-weather definition is proposed.

2. MATERIALS AND METHODS

Castiglione Torinese WRRF is located about 11 km Northeast of Turin, capital of Piedmont, Northwest of Italy. From 2009 to 2015, 2440 consecutive days, wastewater quality parameters were measured by 24 hours composite sampling from the plant's influent. Inlet $N\text{-}NH_4^+$ concentration (IAC) and concentration of COD and TSS were determined based on CNR-IRSA methodology (IRSA, 1994). Influent flowrate of the plant was continuously measured with 5-minute interval by ultrasonic flowmeters installed at the entrance of each module of the plant. Precipitation data used in this study was provided by Piedmont Environmental protection agency (Arpa Piemonte, 2016). Eight meteorological stations (Bauducchi, Torino Vallere, Pino Torinese, Rivoli La Perosa, Turin via della Consolata, Torino Reiss Romoli, Castagneto Po, Caselle) equipped with tipping bucket rain gauges were selected in the catchment area to collect the daily precipitation data from 2009 to 2015. An arithmetic mean method was adapted to convert point precipitation values at different meteorological stations into a uniform value for the whole catchment area. All collected data sets (except P_I) were screened to identify missing elements, detect and exclude outliers. To minimize the loss of data, a statistical parametric approach of generalized extreme studentized deviate (GESD) method (Rosner, 1983) was adapted to determine the outliers of each univariate data set.

In this study, 5 time series of the recorded variables were considered as a sequence of time dependent values arranged by chronological order in successive time period of a day. Symbolically, each of the time series (T), as a set of 2428 pairs of data is represented as follows:

$$T_v = \{(v_1, t_1), (v_2, t_2), \ldots, (v_i, t_i)\}$$

where for $i = 1, 2, \ldots, n = 2428$ as a number of available observations, v_i is the value of observed variables (P_I, Q_{in}, COD, TSS and $N\text{-}NH_4$) and t_i is the time (day) in which the value was recorded. In the segmentation process, each time series is divided into series of segments as consecutive portions of time series. Each segmentation (S) represents the time series (T) in a form of a set of m consecutive segments as follows:

$$S = \{S_1, S_2, \ldots, S_j\}$$

Where for $j = 1, 2, \ldots, m$, each segment, S_j, consists of a certain number of pairs of data from the original time series. A sliding window algorithm (SWA) (Fig.1) method was implemented for segmentation of each time series.

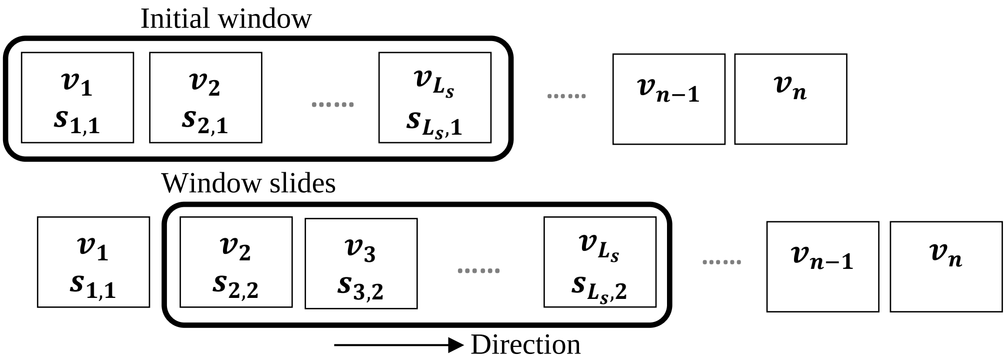

Figure. 1 Schematic description of sliding window algorithm

Integrating the results obtained from regression analysis of the treated time series with the sliding windows methodology, the best weather partitioning scenario was determined as a scenario which results in the highest coefficient of determination of positive correlation between P_s and Q_{in} of wet-weather data. For identification of the best combination of the L_S (length of windows) and P_{th} (threshold precipitation) parameters, 25 scenarios with different values of P_{th} (0,1,2,3,5 mm/day) and L_S (1,2,3,5,7 days) were developed and datasets were partitioned accordingly. Assuming the linear relation between Ps and Q_{in}, the partitioning scenario with highest coefficient of determination of positive correlation between P_s and Q_{in} of wet-weather data was selected and wet weather definition was proposed accordingly.

3. RESULTS AND CONCLUSIONS

From 25 developed scenarios for identification of the best combination of the LS and Pth parameters, the best correlation between Ps and Q_{in} (R^2 = 0.35) was obtained for the scenario with P_{th} = 3 mm and L_S = 2 days. Therefore, for the Castiglione Torinese WWTP, wet-weather condition was defined as an event with accumulated precipitation rate (Pa) greater than 3 mm which occurs at least 48 hours after previous measurable wet-weather. Further, according to the wet-weather definition, the data sets were partitioned to wet and dry weather data. From total number of 2728 data, 991 observations (36%) were identified as wet-weather and the remaining as dry weather data. Further, statistical analyses were conducted to identify significant differences in the influent loadings and concentrations under wet and dry flow conditions. Kernel density estimation (KDE) was performed to estimate and compare the probability density functions of the dry and wet sets of observations. In KDE a Gaussian kernel was used as a weighting function and the probability density functions (PDF) were assessed by computing the geometric mean of kernel functions for all data sets. Given the importance of optimally chosen bandwidth of the kernel on the resulting estimate, normal distribution approximation method proposed in Silverman (2018) was implemented to identify the optimum bandwidths. Figure. 2 demonstrates the Kernel density estimations of wet and dry weather data sets. As anticipated, the influent flowrates in wet-weather condition are higher by 15-25 % than those of dry weather condition. On the other hand, the reduction of influent TSS, COD and N-NH4 in the wet-weather condition with dilution factors of (0.06-0.08), (0.15-0.17), (0.18-0.2) were observed (Figure. 2 a, b and c respectively).

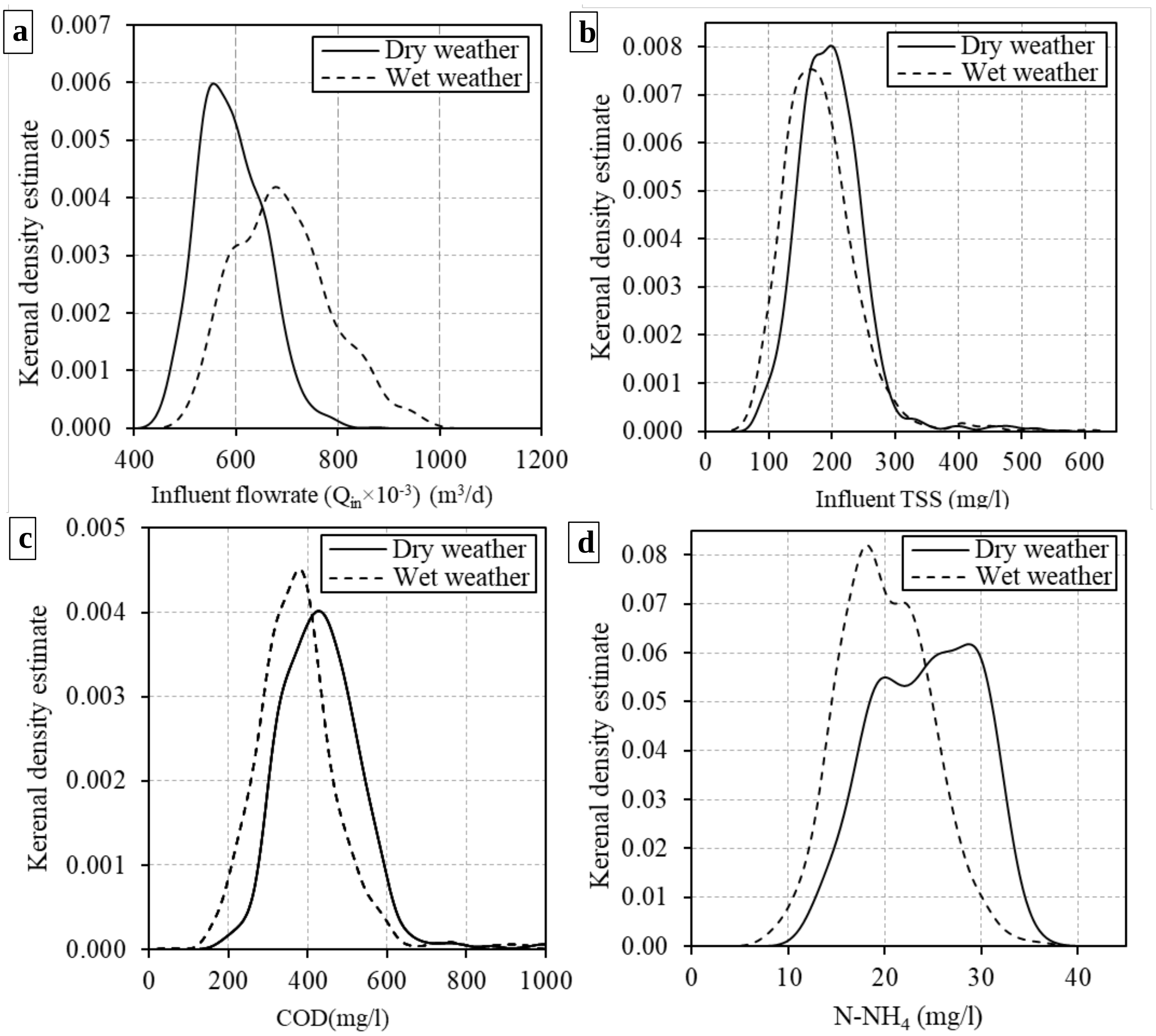

Figure. 2 Kernel density estimations of wet and dry weather Influent flow (a), TSS (b), COD (c) and N-NH_4 (d)

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