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Characterization of influent wastewater with periodic variation and snow melting effect in cold climate area

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ABSTRACT

The daily, weekly and seasonal variation of influent characteristics of wastewater treatment plants (WWTPs) highly affects the performance of wastewater treatment. In cold climate area, snow melting happens frequently in cold season and affects wastewater characteristics significantly. The dilution effect of snow melting in cold season makes it impossible to compare cold season influent and warm season influent fairly. To enable the study of influent seasonal variation, a stepwise approach was developed to determine whether the WWTP influent wastewater contains snowmelt (wet climate) or not (dry climate). This study investigated the daily, weekly and seasonal variation of WWTP influent, and provided evidence of climate effect on influent characteristics by analyzing the correlation of climatic information and wastewater characteristics. A classification model was developed to further discriminate climate conditions of influent, which will be applied to develop scenario-based soft sensor as well as support WWTP surveillance and control.

1. Introduction

The majority of existing sewer systems in European countries are combined sewer systems (Ashley et al., 2008). In spite of the continual improvement of wastewater treatment technology, combined sewer overflow brings increasingly environmental problems for both storm water management and wastewater treatment (Weyand, 2002). In the winter of some European countries, snowmelt increases the inlet flow of wastewater treatment plants (WWTPs) dramatically and the wastewater temperature may be decreased to 4 °C (Plósz et al., 2009). The European Council Directive 91/271/EEC has defined a threshold of 12 °Cthat 70% nitrogen should be removed by WWTPs. However, in cold climate area, when the combined effect of increasing influent flow and lower temperature caused by snow melting exceeds the treatment capacity, a part of the incoming wastewater bypasses the treatment process and the wastewater was discharged to natural environment without sufficient treatment (Haimi et al., 2009). As results of cold and dilution effect caused by snow melting, the nutrient removal efficiency was observed to be reduced obviously (Bixio et al., 2001).

As is suggested by Hwang and Oleszkiewicz (Hwang and Oleszkiewicz, 2007), special precautions are required in case of sudden snow melting when operating biological wastewater treatment. However, unlike rainfall event, it is difficult to detect when the snow melting starts or stops in the winter of cold climate countries. Snow melting is more likely to happen when the daily temperature is above −1.5 °C (Plósz et al., 2009), but combined sewer systems may receive varying amount of snowmelt from hour to hour within the same day. The wastewater quality and quantity in combined sewer systems are combined effects of human activities and climate conditions. As a result, the influent wastewater quality and quantity to full-scale wastewater treatment plants (WWTPs) are varying hourly, daily, weekly and seasonally (Butler, 1993; Tunçal et al., 2009). Since references related to urban snow melting modelling are rather limited (Moghadas et al., 2015), how climate and human activities interact to determine influent wastewater characteristics of WWTPs was seldom studied. The knowledge gap of this issue leads to passive control of wastewater treatment process, because the variation of wastewater characteristics is not predictable due to climate change and human activities.

Online monitoring and control enable WWTPs to manage the uncertainties caused by periodical variation and combined sewer overflow (Olsson, 2012). Soft sensors are reported as an promising tool to monitor hard-to-measure variables to achieve advanced control of WWTPs (Haimi et al., 2015; Liu et al., 2014). Previous study has developed soft sensors to predict chemical oxygen demand (COD) and total phosphorus (TP) of WWTP influent under dry climate condition (Wang et al., 2017), but the prediction accuracy will decrease when snowmelt appears in the influent. To enable advanced control as well as soft sensor monitoring of wastewater treatment process, it is necessary to characterize

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influent of WWTPs in both dry climate condition and wet climate condition. However, it is difficult to determine whether the wastewater contains snowmelt or not, because the domestic influent itself is varying from hour to hour. If the dry influent (without snowmelt) and wet influent (with snowmelt) of WWTP can be distinguished in advance by online measurement, scenario-based soft sensors could be developed to support real time control of WWTPs.

This study presents the daily, weekly and seasonal characteristics of influent wastewater of a WWTP in Norway, which provides a systematic study of influent characteristics in cold climate area. The purpose of statistical analysis was to develop an onsite decision-making technique that can continuously determine if the influent wastewater was collected in dry climate or wet climate. The ultimate goal was to provide influent characteristics of different seasons and climate to support WWTP surveillance and control. The terminology related to "season" and "climate" in this paper was defined in Table 1.

2. Materials and methods

2.1. Wastewater sampling

Data of influent wastewater characteristics of a Norwegian WWTP were collected in 2015 and 2016. As is shown in Table 2, the periods of observation included randomly selected days during warm season and cold season, including both workdays and weekends. An automatic sampler (Teledyne ISCO) was placed at the influent of the WWTP to collect and store wastewater samples hourly during the sampling period. In addition, online sensors were used to measure flow rate and water temperature. The WWTP was connected to the combined sewer system, which brought large amount of snow melting water during winter. The sampling period during cold season contains both dry climate, and wet climate samples. All the warm season samples were collected during dry climate period.

The two sampling periods cannot cover the total variation of wastewater characteristics, because unusual climate events happen occasionally and they are different in each year. However, we intended to provide a stepwise methodology to determine whether the influent was generated in dry or wet climate, and build a classifier to further support scenario-based soft sensors development. The sample quantity was sufficient to serve for model calibration and validation.

2.2. Analysis of wastewater samples

Wastewater chemical characteristics: total suspended solids (TSS), total phosphorus (TP), *ortho*-phosphate (PO_4-P), total nitrogen (TN), ammonia (NH_4-N), chemical oxygen demand (COD), soluble chemical oxygen demand (SCOD), and pH were measured according to standard methods (ApH A et al., 2012). Temperature (WaterTemp) and influent flow were monitored by online instruments.

2.3. Climate data

To study the impact of climate change on wastewater characteristics, we collected climate data from Norwegian weather website www.yr.no, which provided temperature, snow depth and wind speed data. Storm event did not happened during sampling days, but snowing and snow melting took place in the cold season. Solar radiation should be considered as one of the contributor of snow melting. Therefore, global radiation data were collected from Norwegian Institute of Bio-economy Research (NIBIO, 2016) to analyze the relation between snow melting and solar radiation.

2.4. Statistical analysis

In this context, "Climate" is a category variable with two entries, Dry and Wet. It is difficult to decide whether the influent was generated in Dry climate or Wet climate by measurement or physical feeling, because snow melting was happening quietly and invisibly. The climate category of influent can be determined bas generated in Dry climate or Wet climate by measurement or physical feeling, because snow melting was happening quietly and invisibly. The climate category of influent can be determined by its multiple features, such as flow rate, COD and water temperature. To assign the climate category to the influent, we applied principal component analysis and cluster analysis to separate the cold season dataset into two subsets, which are latterly confirmed as Dry climate influent and Wet climate influent.

Wastewater chemical constituents and inlet flow rate usually propagate with the similar trend and correlated with each other (Avella et al., 2011). Principal component analysis (PCA) is a multivariate analytical method used for detecting data collinearity and summarize patterns of covariance among variables. The mathematical procedure of PCA has been well explained and used for fault diagnosing of wastewater treatment process monitoring (Tao et al., 2013). In this study, the principal components derived from PCA describe the dominant variation of the wastewater characteristics for further analysis. The original dataset was divided into 24 segments to perform cross-validation to validate the PCA model.

Samples collected during wet climate were diluted by snow melting, but others were collected during freezing hours without any snowmelt. In this study, hierarchical cluster analysis was applied to divide the data into separated groups based on the wastewater characteristics. Ward's method with Euclidean distance was used to perform the cluster analysis (Singh et al., 2005; Merriam et al., 2015). However, as Xiao (Xiao et al., 2012) mentioned, the limitation of cluster analysis is that it can give a result no matter what kinds of input are used. It is therefore important to pre-assess the input data before clustering. Thus, we used scores of most significant principal components as input data for clustering, which screened out disturbances of the raw dataset.

In the circumstance of cold season, there are only two climate categories: Dry climate influent and Wet climate influent. The results of cluster analysis would be well acceptable, if the two clusters given by cluster analysis featured as larger amount of diluted influent (Wet climate) and normal amount of higher concentration influent (Dry climate). After evaluation of the results of cluster analysis, the two clusters was accept as Dry climate and Wet climate, and the category variable "Climate" was formed accordingly. Thus, the Dry climate wastewater characteristics in cold season can be found out and compared with that in warm season. Analysis of variance (ANOVA) was performed to study the seasonal variation of Dry climate influent.

To support online monitoring and control of wastewater treatment process, it is necessary to establish a classification function, which will continuously assign climate categories to new influent data onsite in cold season. In this study, we applied partial least squares discriminant analysis (PLS-DA) to build a classifier based on historical data and the category variable – Climate. Partial least squares (PLS) is an methodology that can be used for both regression (PLSR) and discriminant analysis (PLS-DA). The category variable Climate with "Dry" and "Wet" entries were converted to a dummy matrix with entries as "0" and "1", while the wastewater characteristics data formed another matrix – the X matrix. PLS-DA algorithm maximizes the covariance of these two matrixes and extracts dominant eigenvectors of covariance matrix (Barker and Rayens, 2003; Nocairi et al., 2005). The final classification was performed based on the scores of PLS-DA, which are computed from dominant eigenvectors and original values of wastewater