Assessment of evapotranspiration effect on water balance for a constructed-wetland/reservoir-tank system (CWRT), in a tropical Andean zone.

Evaluation de l'évapotranspiration sur le bilan hydrique d'un filtre planté en zone tropicale Andine.

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RÉSUMÉ

Les objectifs de cette étude étaient de: (i) déterminer l'ET des périodes sèches d'un filtre planté horizontal (FH) installé à l'université La Javeriana à Bogota (Colombie) à partir des pertes d'eau du système, (ii) utiliser des paramètres météorologiques simples, provenant d'une station météorologique située 2 km du site, pour créer un modèle qui correspond à l'ET déterminé. Dix capteurs de niveau d'eau à ultrasons continus, ont enregistré les niveaux d'eau du FH de décembre 2013 à juin 2016. Les données des périodes sèches ont été utilisées pour calculer les coefficients de pertes d'eau et donc de l'évapotranspiration. Les ET estimés ont été ensuite obtenus en utilisant la régression non linéaire carrée (nls), puis des méthodes statistiques tels que la régression partielle des moindres carrés (pls) combinée avec la méthode "Hill-climbing". Les résultats montrent qu'un modèle avec l'humidité relative, le rayonnement solaire maximum et la pression atmosphérique est le modèle le plus simple et le plus efficace testé. Cependant, par rapport aux ET déterminés, les résultats n'étaient toujours pas concluants car l'analyse d'erreur effectuée présentait des résultats importants.

ABSTRACT

The objectives of this study were to: (i) determine the coefficient of evapotranspiration (ET) from the dry period water losses of a horizontal subsurface flow wetland (HSSF) installed inside the university La Javeriana in Bogota, Colombia. (ii) use simple meteorological parameters from a weather station at 2 km from the site, to create a model that fits the determined ET. Ten continuous ultrasonic level sensors were used to measure the HSSF water levels from December 2013 to June 2016. The data from dry periods were used to compute coefficients of water losses and therefore estimations of ET. First, the ET estimates were obtained using nonlinear, then statistical methods were used such as the Partial Least Square Regression (pls) combined with Hill-climbing method. The model with the relative humidity, the maximum solar radiation and the atmospheric pressure was the simplest and the more effective model tested. However, compared to the determined ET the results were still not conclusive as the analysis error conducted showed important values.

MOTS CLÉS

Colombie, Cyperus papyrus, evapotranspiration, hydrologie, zones humides.

INTRODUCTION

Constructed wetland system (CWs), used for stormwater harvesting and wastewater treatment, can be considered as a “green” treatment system that uses wetland ecosystem - vegetation, soil, and its microbial population - to collect, store and improve the stormwater quality. Despite a large volume of research on constructed wetland performances, very few studies on wetlands’ evapotranspiration are found in the literature, and even fewer on CWs evapotranspiration. Evapotranspiration is the combination of water-loss to the atmosphere from open water, or subsurface water, and through emerging plants. (Allen *et al*., 1998). It is an important phenomena in wetlands as it is their primary mechanism of water loss (Papaevangelou *et al.,* 2012). In small constructed wetlands (CW), evapotranspiration is even more important as the influence of the advective air becomes more important and increases evapotranspiration rates (Papaevangelou *et al.*, 2012 ; Kadlec, 2009). Moreover, evapotranspiration can have a significant impact on the CW performances and increases its efficiency by amplifying the gas transfer (Chazarenc *et al.*, 2010 ; Milani *et al.*, 2013). Therefore, it is important to develop models and techniques in order to evaluate and quantify evapotranspiration in CWs, but little can be found on that subject in the literature. However, the existing models, although precise, need too many parameters, and implementing them for a systematic surveillance of CW is not possible for all municipalities or CW owners. Thus, this research aims to find a simplified and site-specific model that would predict the evapotranspiration of the CW located in the university Pontificia Universidad Javeriana of Bogota (Colombia), with very easily accessible variables.

MATERIALS AND METHODS

A constructed-wetland/reservoir-tank (CWRT) system located inside the campus of PUJB (Pontificia Universidad Javeriana, Bogota) served as the experimental site. The CWRT was constructed to collect and enhance the quality of runoff water to reuse it for non-potable purposes inside the campus. It is a horizontal subsurface flow wetland (HSSF) of 22.1 m x 4 m, planted with a local species, *Cyperus papyrus*. This work uses the water levels recorded by Galarza Molina from December 2013 to June 2016, through ten continuous ultrasonic level sensors (resolution of 1 mm). Two sampling points were used to evaluate the hydraulic performance: one in the inlet of the CW (captor 1) and the other at the outlet of the CW (captor 5). In those sampling points, levels of water were monitored employing two sharp-crested weirs and continuous ultrasonic level sensors. Seven more continuous ultrasonic level sensors were installed to monitor the hydraulic behavior inside the CWRT. The distribution of those new sampling points was chosen to get the best overview of the system. Meteorological records were obtained from a weather station located 2 km from the CWRT site (station IDEAM 21206960). The pretreatment consisted on discarding the aberrant values in the recorded data and smoothing the water level to make them usable.

The dry periods, i.e. periods without inflows or outflows of the CWRT system, were detected using the geometry of the two sharp-crested weirs. We defined two critical levels; 37.5 cm for the captor 1 and 46.5cm for the captor 5; that, once reached, reflects a period without inflows in the CWRT. For each dry period, coefficients of water losses (COEF) were estimated from the measured dry period levels as follows. COEF is related to the coefficient of evapotranspiration (ET) but also influenced by the vacuum index of the CW. Indeed, the water levels variations are not the variations of the volumes of water inside the CW since CW is full by water but also gravels, roots and vegetable deposits. Thus, it was assumed that the relationship between ET and COEF was modeled by equation: ET = k*COEF with k: coefficient undetermined

First, the Nonlinear Least Squares (nls) function of the software R (Kass, 1990; Bates et al., 1992) was used to estimate the parameters of nonlinear equations from literature (Turc, Hargreaves, Hargreaves and Samani, Abtew, Irmak and Ravazzani models), so that the equation results fit our water loss results. Nevertheless, as assessed by the coefficient of determination (R) and the Root Mean Square Error (RMSE), the results were not good enough to select it as a definitive model. Therefore, statistical methods were used to estimate ET: the Partial Least Square Regression (pls) function of the software R (Mevik, 2016) was chosen to solve the difficulties encountered by nls with the Turc’s formula (for having to estimate too many parameters with a too small database) and combined with hill-climbing method to compute Bayesian networks between the data, so that the main variables would appear, and could then be processed with pls for the same dry periods. Those statistical methods were used on two sets of data, one with only the dry period meteorological parameters and the other with more parameters on the previous rain event.

RESULTS AND CONCLUSION

1 WATER LOSS

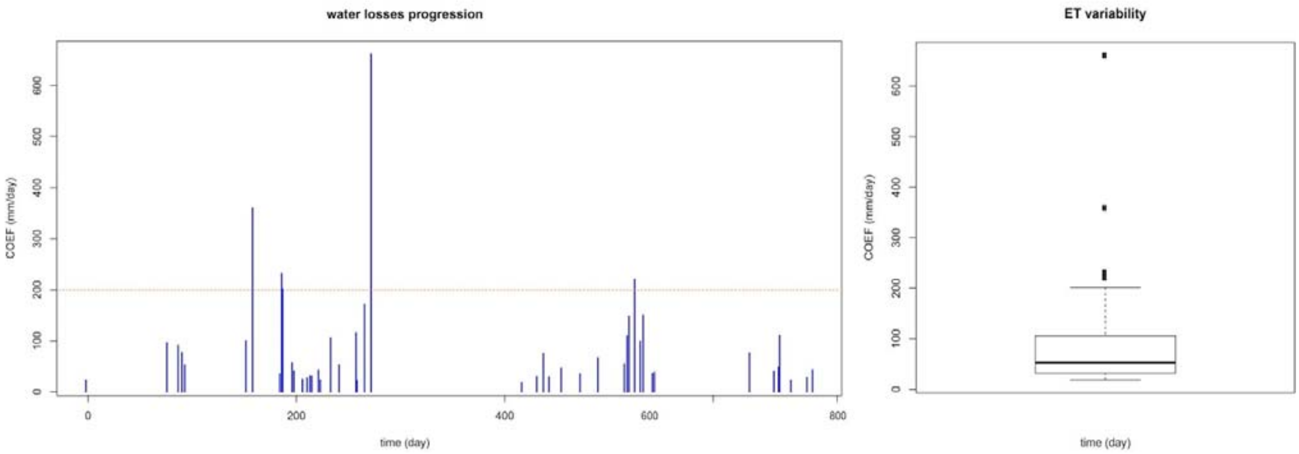

Figure 1. Evolution of water losses during dry periods.

Figure 1 shows COEF median progression and variability for the 46 dry periods detected among the water levels from 2013 to 2016. The COEF results without outliers range from 0 to 200 mm/day, with a median value of 52.89 mm/day. The progression graph shows no general tendency.
However, COEF of dry periods [7, 9, 10] and [31: 37] that occurred during April/May 2014 and 2015, and [19:24] that occurred during July and August 2014, seem higher. Little changes of climate characterize Bogota's equatorial climate. The only parameters which show significant variations are the water precipitations. Nevertheless, while the period April/May in Bogota is marked by a rainy period, July and August have a "normal" average of precipitation. Thus, the variations do not show a pattern that could be related to a seasonal variation. This absence of pattern could illustrate the equatorial climate of Bogota or could be explained by the fact that the measured COEF is not continuous due to the decision of studying only dry periods, and also to some interruptions in the water level recordings. Thus it is not possible to recognize a pattern in the progression of the evapotranspiration rate inside the HSSF.

2 MODELS

First, the comparison between the measured and the estimated COEF (in cm/min) obtained with nls shows that the result ranges present significant differences: while the determined COEF ranges from 0 to 5 cm/min, the estimated one ranges from 0 to 1.5 cm/min for the majority of the tested equations, and from 0 to 3 in the worst case, with Irmak model. The outliers of determined ET could explain those differences since the majority of determined COEF range from 0 to 3 cm/min. The best model in terms of both RMSE and R values is based on Hargreaves *et al.*, 1982 modificated as written in Table 1. Nevertheless, RMSE values, 0.4694 and 0.8706, and R values, 0.931 and 0.2089, show that the results obtained with NLS regression are not conclusive.

Therefore, the hill-climbing method was used to select the parameters for PLS regression. Thereby, Bayesian network were computed with the basic parameters first: COEF, the relative humidity at 2m (HUMA in %), the atmospheric pressure (PRES in Hpa) and the daily values of minimal temperature at 2m (T.med, Tmax, Tmin in °C), the boxplot results (minimum, second quintile, median, third quintile, maximum) for the solar radiation during the dry period (RADG.min, RADG.Q3, RADG.med, RADG.Q2, RADG.max in W/m²) and the cumulative radiations over the dry period (CUMU in W/m²). The Baysians network produced show a not negligible relation (42% of probability) between COEF and HUMA, and a perfect relation between HUMA and RADG.max. The PLS method was used with HUMA and RADG.max (PLS0), then tentatives were made in order to improve the results adding main parameters (PLS1), and informations on the last previous precipitation before the beginning of the dry period (PLS2): duration (PREC.d), amount of water which entered the CW (PREC). Because of NA in the water levels, some information on rain events were not available. Therefore the database was reduced from 46 dry periods to 27 useful dry periods. Thus the error analysis results of PLS1 and PLS2 are not comparable.

Finding a model that fits the estimated water losses was particularly difficult. Table 1. summarizes the best results obtained with the different methods. Among them, the simpler and more efficient model would be model from PLS 1, with HUMA, RADG.max and PRES. Nevertheless, the results remain not conclusive. It is possible that the particular meteorological conditions of the site (equatorial climate and altitude temperate climate) were not adapted to the selected models for NLS. The use of statistical methods allows us to improve a little the results of the error analysis performed on the tested models. They might be improved by adding other meteorological data like the wind that is an important parameter for evapotranspiration and was not taken into account in this study. Estimate ET from the rainy period would also help to improve the results by completing the database. Finally, other methods could be explored to continue this work: neural networks, support vector machines.

operation	models	RMSEc	RMSEv	Rc	Rv	Evolution
nls	Hagreaves *et al.,* 1982 *modificated* ET0 = a*(Tmed+b)*(Tmax-Tmin)*Ra	0.8706	0.4694	0.0931	0.2089	-
pls 0	HUMA-RADG.max	0.4152	1.7323	0.8543	-0.0407	-
pls 1	**HUMA-RADG.max-PRES**	**0.7955**	**0.3442**	**0.4391**	**0.2391**	+
pls 2	TEMP.max-RADG.max-PRES-PRES.max-HUMA-RADG-Tmed-TEMP.min-PREC-PREC.d	0.4945	0.4877	0.5430	0.3823	not comparable

Table 1. Comparison of the summary of the error analysis performed on the best models found in this study between measured and estimated ETo value, for the CW of the university Pontificia universidad Javeriana (Bogota). *RMSE/R "c" for the correlation obtained with nls or pls on a randomly choosen 2/3 of the data, RMSE/R "v" for the verification on the remaining 1/3 of the data with the fitted parameter obtained.*

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