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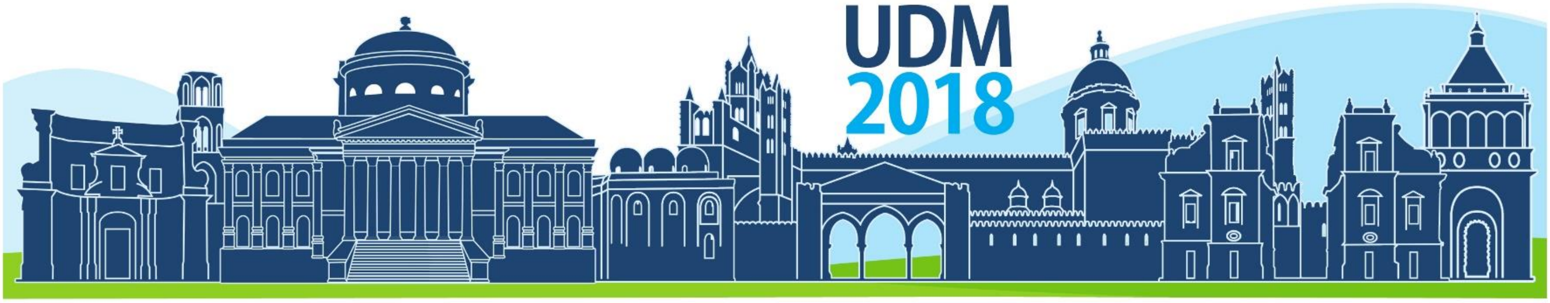

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Multiregression analysis of the kinetic constants in ephemeral rivers: the case study of the Oreto river

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Abstract: Profuse efforts have been committed to develop efficient tools to measure the ecological status of the receiving water body quality state. The recurrence to mathematical models as support tools for the receiving water body quality assessment can be an optimal choice. Indeed, mathematical models can allow to build-up the cause effect relationship between polluting sources and receiving water quality. Regarding the river water quality modelling, two different kinds of river can be single out: large and small rivers. In the modelling approach, the main differences between the two types of rivers are reflected in the model kinetic constants. Indeed, the main quality processes which control and govern the quality state play a differ rule. As a results, the application of model approaches as well as kinetic constants derived for large river, can lead to wide biases thus misevaluating the river quality state. The paper presents a study where a multiregression analysis was carried out for assessing relationships to be employed for the evaluation of the kinetics constants for small rivers. To accomplish such a goal, the kinetic constants derived by a previous application of a river water quality model applied to a real case study were used. Such kinetics constants were employed for deriving new multiregression equations for the assessment of the kinetics constants for small rivers.

Keywords: Water quality modelling, reareation constants, model calibration

1. INTRODUCTION

Environmental quality preservation is one of the main goals of the EU Water Framework Directive in order to achieve a good quality status in surface waters (Even et al., 2007; Ani et al., 2009; Wagenscheinand and Rode, 2008). However, such water quality models require accurate model calibration, in order to specify model parameters, that requires an extensive array of water quality data that are, generally, rare and resource-intensive. Many of the major results from studies of large rivers could not be applicable to small rivers (Mannina and Viviani, 2010a,b,c). Indeed, small rivers, as ephemeral Mediterranean rivers are, have certain unique features, due to the fact that for them, the role played by physical/chemical/biological processes is different, and parameter values for modelling these processes can differ by as much as an order of magnitude from larger riparian systems. Indeed, for instance as pointed out by Kirk (1994) the atmospheric reaeration can be much higher for small rivers due to the fact that they are characterized by shallow water depths (which have higher surface area-to-volume ratios than larger rivers) and, especially during storm events when the discharged flow is generally higher compared to the base flow; in such a case, the major oxygen contribution comes from the reaeration with the atmosphere due to the intense flow turbulence. These facts constitute major complications in the application of water quality models, such as those provided by the US Environmental Protection Agency: QUAL2E (Brown and Barnwell, 1987), QUAL2K (Chapra and Pellettier, 2003), WASP6 (Wool et al., 2006), or the IWA River Quality Model No. 1 (Reichert et al., 2001), which require more information regarding the river system than is often available. To cope with such a problems parsimonious models are advisable which, as every model, need to be calibrated. Despite the potentiality of such empirical equations, attention has to be paid on their usage due to the fact that they were derived almost for large rivers. Indeed, as recently demonstrated by Mannina and Viviani (2010a), kinetic constants for small rivers can be order of magnitude different from those of small river. Bearing in mind such considerations, the paper explore the possibility to adapt previous empirical equations first derived for large rivers to small ones.

2. MATERIALS AND METHODS

2.1 The river water quality model

The model is based on a modified version of the Streeter–Phelps model. It takes into account the following processes: degradation of dissolved carbonaceous substances; ammonium oxidation; algal uptake and denitrification; dissolved oxygen balance including depletion by degradation processes and supply by physical reaeration and photosynthetic production. It is described, in details in Mannina and Viviani (2010a).

2.2 Case study

The analysis was applied to an Italian river: the Oreto river. Its catchment is located near Palermo in the north-western part of Sicily, Italy (Fig. 1) and covers an area of 110 km^2. Residential, commercial, agricultural, and industrial settlements cover almost the entire area. The hydrological response of this basin is dominated by long dry seasons followed by wet periods during which even large inputs of rainfall may produce little or no response at the basin outlet. The measurement network consists of six rain gauges managed by the Regional Hydrographic Service, and one level gauge, located 10 km upstream on the river’s mouth. The river receives a number of point-source discharges from small villages and some periurban areas on the outskirts of Palermo, most of them untreated. The river has been divided into 12 cross sections for monitoring. Five point sources have been identified along the river and these contribute significantly to the evaluation of the receiving water body quality state (Fig. 1).

For each cross section, both flow and water quality data were collected, in terms of: water temperature, O_2, BOD, COD, NH_4, NO_3, SST, total phosphorus, and ortho-phosphate, in order to describe the physical, chemical and microbiological characteristics of the river water. Stream water samples were collected approximately once every three months from Jan 1998 to Dec 1999. Therefore, a total of six measuring campaigns were carried out, building a discrete data set for the assessment of the river’s water quality. Concerning the river’s morphology, two main stretches have been identified for the Oreto, with average slopes of 4.6% and 1.1%. and model parameters have been calibrated separately for each stretch. The Oreto’s catchment is affected by point sources rather than non point sources, the latter constitute a small amount of the total load, less than 5% (Candela et al., 2004). For such a reason, in the presented modelling approach, diffuse sources have been neglected.

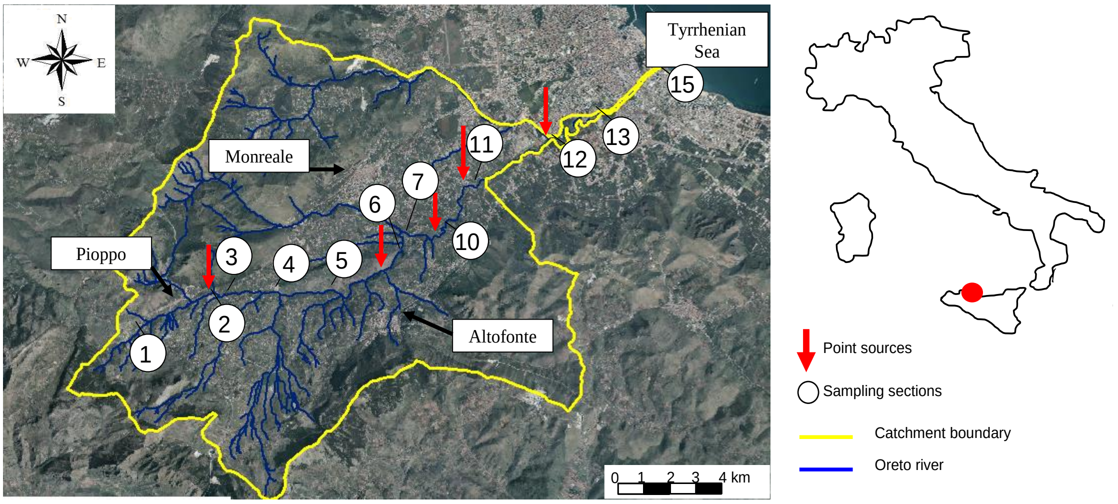

Figure 1. Oreto catchment and sampling sections considered in the monitoring campaign.

3. RESULTS AND DISCUSSION

The river water quality model was calibrated to the Oreto river. The results of the calibrated river quality model showed satisfactory agreement with the measured data and results revealed important differences between the kinetic river constants used to model small rivers as compared to those for large rivers (Mannina and Viviani, 2010a; Mannina, 2011). Particularly, in terms of reareaction coefficient, the calibrated values for the Oreto river were of orders of magnitude higher than the literature values (O' Connor and Dobbins, 1956; Owens et al., 1964; Bennett and Rathburn, 1972; Thyessen et al., 1987). These results appeared related to the different roles played by physical–chemical–biological processes in small rivers as compared to larger systems. As a consequence, a multiregression analysis has been carried out in order to point out general relationships for small rivers between kinetic river constants (i.e. reareaction coefficient, K_R) and river characteristics, both morphological and hydraulic. Particularly, it was hypothesised that K_R coefficient could be expressed as a function of one or more of the following variables:

$$K_R = f(U, H, S, T) \qquad (5)$$

where U [m/s], H [m], S [m/m] and T [°C] are, respectively, the mean flow velocity, the mean flow dept, the river slope and the water temperature in the generic river cross section.

The data was subject to different regression equations: multiple linear (LIN), multiple exponential (EXP) and sum of exponential (EXPSUM) to establish possible relationship for K_R coefficient and the various river characteristics. Two statistical indicators were used to assess the goodness of fit of the resultant formulae and these were the sum of squared errors in the form of Nash and Sutcliffe (1970) Efficiency Criterion (NS), and the Root Mean Square Error (RMSE) as measure of accuracy of prediction. The calibration of all regression equation was carried out considering all monitoring campaign for each river stretch taking into account the different river slope values. A Monte Carlo procedure was used to generate large numbers (10^4) of sets of parameters for all models, each parameter value being drawn from feasible ranges. Simulations were performed for each stretch and for each parameter set for comparison with calibrated reareaction coefficients. Specifically, 10000 Monte Carlo runs were generated considering a uniform random sets of regression coefficients and using these sets to perform model simulation in terms of NS efficiency and RMSE.

As example figure 2 shows for a particular regression equation (EXPSUM01 for stretch 2) scatter plots for the efficiency based on NS for each parameters sampled. Each dot represents one run of the model with different randomly chosen parameter values within the feasible ranges. These dotty plots are projections of the surface of the likelihood measure within a three dimension parameter space into single parameter axes. In particular, the most parameters are c_0 and c_1, meanwhile, c_2 shows a classical equifinality behaviour; indeed, different combinations of model parameters values are capable of producing outputs with similar performance statistics (Beven and Binley, 1992). A best fit parameter set has been fixed for all parameters distributions; these sets have been chosen corresponding to maximum efficiency values in terms of NS and to minimum values of RMSE.

For each river stretch, parameter set values for maximum efficiency and corresponding NS and RMSE values have been assessed. Particularly, for the first stretch NS value ranging from 0.02 to 0.64 and the RMSE ranging from 300.00 to 155.27; for the second stretch the NS values ranging from 0.17 to 0.99 and the RMSE ranging from 237.29 to 2.59. Comparing results, in terms of NS and RMSE values, is difficult to assess the best configuration model. On the whole, the best regression equations are functions of *U* and *H* variables.

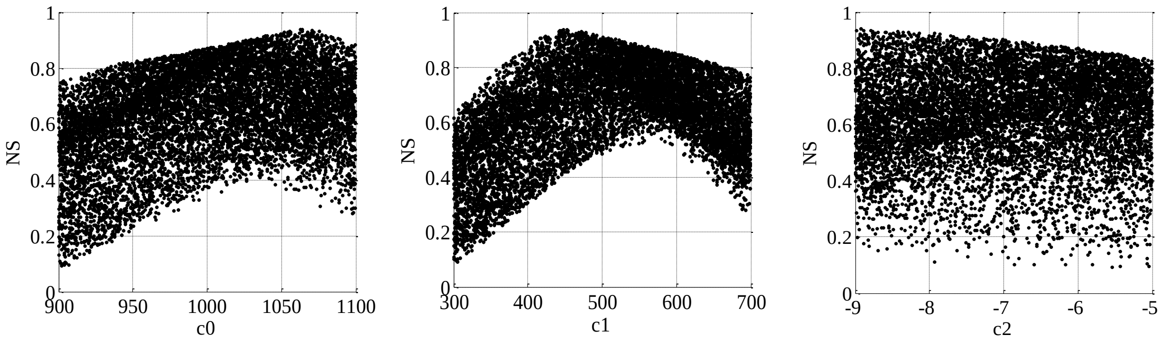

Figure 2. Scatter plots of EXPSUM01 model parameters.

The coefficients of the equations are site specific and are function of the river characteristics, both morphological and hydraulic. With further similar analysis of data from others similar catchments it may be possible to establish standard coefficients for application to made to a range of small catchments and ephemeral river systems

CONCLUSIONS

Multiregression analysis were carried out in order to point out general relationships for small rivers between kinetic constants and river characteristics, in terms of flow velocity, flow dept, the river slope and the water temperature along a river. The modelling methodology proposed was used in order to select and develop the most appropriate models to simulate kinetic constants in ephemeral rivers. The usefulness of the regression models was assessed by comparing the results of a river water quality model developed in previous studies with calibrated kinetic constants. Reasonable agreement was observed for the majority of the configuration empirical equations. Comparing results, in terms of NS and

RMSE values, it was difficult to assess the best equations, although U and H variables seemed to be the most significant.

It was concluded, therefore, that within the limitations of the regressional approach adopted, the kinetic river constants may be predicted, with reasonable confidence, using the derived relationships between the flow velocity, the flow depth, the river slope and the water temperature along the river. The derived equations, which at this stage are site specific, may be used to establish significant relationship, more general, between the kinetic river constants and river characteristics.

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