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Exploring the performance of the SEDD model to predict sediment yield in eucalyptus plantations. Long-term results from an experimental catchment in Southern Italy

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Abstract. In this paper, long-term sediment yield data, collected in a small (1.38 ha) Calabrian catchment (W2), reafforested with eucalyptus trees (*Eucalyptus occidentalis* Engl.) are used to validate the performance of the SEdiment Delivery Distributed Model (SEDD) in areas with high erosion rates. At first step, the SEDD model was calibrated using field data collected in previous field campaigns undertaken during the period 1978-1994. This first phase allowed the model calibration parameter β to be calculated using direct measurements of rainfall, runoff, and sediment output. The model was then validated in its calibrated form for an independent period (2006-2016) for which new measurements of rainfall, runoff and sediment output are also available. The analysis, carried out at event and annual scale showed good agreement between measured and predicted values of sediment yield and suggested that the SEDD model can be seen as an appropriate means of evaluating erosion risk associated with manmade plantations in marginal areas. Further work is however required to test the performance of the SEDD model as a prediction tool in different geomorphic contexts.

1. Introduction

Soil erosion by water is a serious environmental problem in many areas of the world, and more particularly in the semiarid zones of Southern Italy, where rates of soil loss of ca. 100-150 t ha^{-1} year^{-1} have been documented during the last few decades. Problems of accelerated soil erosion and land degradation as well as the associated offsite impacts have emphasized the need for improved information on rates of soil loss and thus for reliable means of assessing soil erosion rates across a range of environments. Traditional approaches to soil erosion assessment, involving erosion plots and experimental catchments, have been used in many geographic contexts. It is well recognized that they have some limitations both in terms of cost and the representativeness of the results. For example, their operation for a sufficient time to produce reliable estimates of soil loss rates lies beyond the resources of most institutions and the scope of most short-term investigations. However, when long-term measurements are available, they represent a precious resource to calibrate and validate theoretical and empirical models able to predict soil erosion. The use of simulation models represents in fact an important tool to understand some of the key processes governing a catchment and also to extend the knowledge in areas where no measurements are available. Some of these models predict rates of soil loss and sediment yield using a distributed approach. However, in order to provide reliable results, it is important that such models are calibrated and validated using local parameters.

This paper presents some results based on the use of long-term sediment yield measurements obtained in the catchment W2 (1.38 ha in size) located in Calabria, southern Italy, aimed at exploring the performance of the SEDD (SEdiment Delivery Distributed) model which was originally developed in the same area [1]. The measurements of sediment yield derived from the suspended sediment loads at the catchment outlet and obtained for the period 1978-1994, have been used to calibrate the model specific parameter β of the sediment delivery component. Then, the SEDD model was successfully validated at the event and annual timescale using corresponding values of sediment yield related to the period 2006-2016.

2. The Sediment Delivery Distributed (SEDD) Model

The SEdiment Delivery Distributed (SEDD) model [1] has been extensively used to predict erosion rates and sediment yield in different areas of the world [1, 2, 3, 4, 5, 6, 7, 8]. The SEDD model requires a spatially distributed approach based on a subdivision of the catchment into morphological units. It consists of two components: the first component is RUSLE based and allows estimates of soil detachment from each morphological unit, i; the second component accounts for the sediment delivery ratio SDR_i.

For a given temporal scale t (event, annual, mean annual), and for areas with homogeneous soil and vegetation cover, the model provides estimates of sediment yield at the catchment outlet by the following equation:

$$Y_{c,t} = R_{c,t} K_c C_c P_c \sum_{i=1}^{N_u} L_i S_i SDR_i S_{u,i} \quad (1)$$

in which $R_{c,t}$ is the rainfall erosivity factor (t ha^{-1} per unit of K_c); K_c is the soil erodibility factor [9] (t h kg^{-1} m^{-2}); C_i (dimensionless) is the cover and management factor [10]; P_i (dimensionless) is the support practice factor; $L_i S_i$ (dimensionless) is the topographic factor [11, 12]; and $S_{u,i}$ (ha) is the area of each morphological unit.

According to Ferro and Minacapilli (1995) [13], SDR_i represents the probability of the eroded particles, detached from the considered morphological unit i, to arrive to the nearest stream reach. It can be represented by the following expression:

$$SDR_i = \exp\left(-\beta t_{p,i}\right) = \exp\left(-\beta \frac{l_{p,i}}{\sqrt{s_{p,i}}}\right) = \exp\left[-\beta\left(\sum_{j=1}^{N_p} \frac{\lambda_{i,j}}{\sqrt{s_{i,j}}}\right)\right] \quad (2)$$

in which $t_{p,i}$ expresses the travel time of the soil particles of each morphological unit; $l_{p,i}$ and $s_{p,i}$ are, respectively, the length and the slope of the hydraulic path from the i-th morphological unit to the nearest stream reach; N_p is the number of morphological units localized along the hydraulic path j; $\lambda_{i,j}$ and $s_{i,j}$ are, respectively, length and slope of each morphological unit i localized along the hydraulic path j; β is the only calibration parameter. The latter can be estimated using the approach suggested by Ferro and Porto (2000) [1] that requires a recursive use of Eq. (1). In other words, if some independent measurements of sediment yield are available at the catchment outlet, these can be used to derive the value of β that provides the best agreement between measured and simulated values of sediment yield. Based on this assumption, Ferro and Porto (2000) [1] proposed two criteria to derive the 'best fitting' value. The first is based on a single, representative value corresponding to the median value of the theoretical distribution of β (namely, *MV* approach); the second, event-dependent is based on an empirical correlation existing between β and the runoff coefficient *RC* (namely, *RC* approach). Both the approaches require a calibration using an independent set of measurements. In this contribution, the measurements obtained from 1978 to 1994, corresponding to 52 single events, have been used to provide the empirical distribution of the β coefficient and the basic relationship between β and RC. Then, the measurements obtained for the period 2006-2016, consisting of 81 single events, served for validation.

3. The experimental catchment W2

The W2 (1.38 ha in size) is an ephemeral catchment within the larger Crepacuore basin which drains to the Ionian sea and is located near Crotone (35 m a.s.l., 39°09'02"N, 17°08'10"E) (figure 1). The catchment W2 was afforested in 1968 with Eucalyptus trees (*Eucalyptus occidentalis* E.) and was coppiced twice in 1978 and 1990 for wood production. The catchment was equipped in 1978 for measuring rainfall and runoff using respectively a mechanical raingauge located in the upper part of the catchment and an H-flume weir [14] coupled with a mechanical streamgauge located at the catchment outlet. Sediment yield records are also provided using a Coshocton wheel placed downstream the H-flume. Measures of rainfall, runoff and sediment yield are generally obtained at event scale. However, when short-time interval occurred between two or more consecutive events, only one measurement of sediment yield was possible, and the corresponding data of rainfall and runoff responsible for that sediment output were aggregated accordingly.

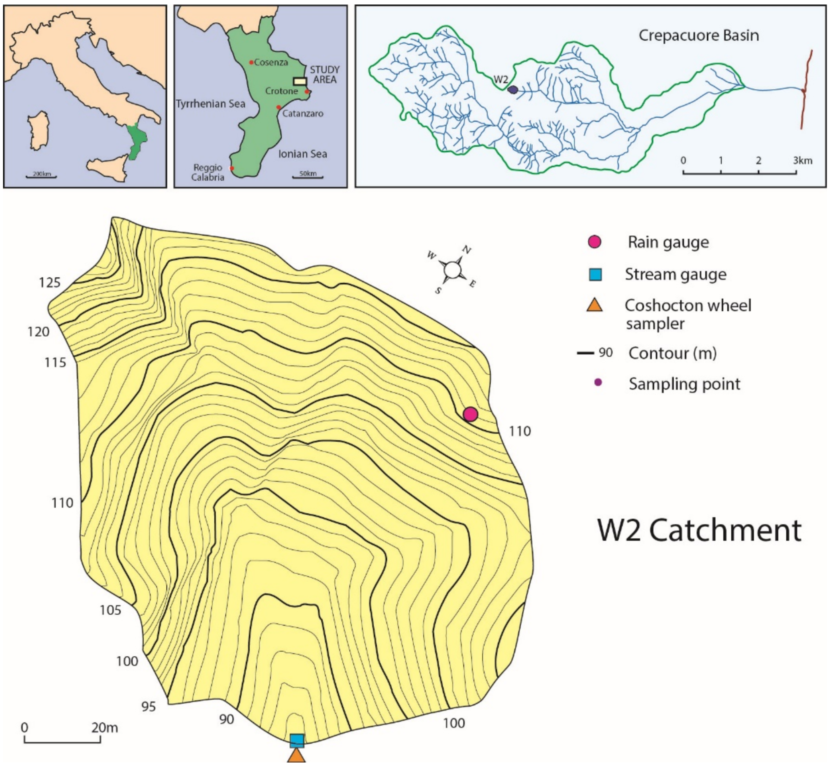

Figure 1. The study area and the experimental catchment W2.

4. Results and discussion

The model calibration – The dataset used for calibration relates to the period 1978-1994 during which 52 single events and the corresponding sediment yield values have been recorded. The model required, at first, the evaluation of the RUSLE parameters for the basic component. More specifically, the rainfall erosivity factor R_t for a given temporal scale t was obtained from rainfall data available for the raingauge station located in the catchment. A value of R_j from each single event, j, was calculated as the product of the storm rainfall kinetic energy E and the maximum rainfall intensity related to a 30-min time interval I_{30}. Because of the small size of the catchment, the values of the rainfall erosivity factor obtained at event scale were considered spatially invariant ($R_{c,t}$) over the catchment area. Similar assumptions were made for the soil erodibility factor K_c that was estimated using the properties of the soil samples collected within the catchment. The cover and management factor C_c, again assumed constant for the catchment was calculated using field data. Considering that no management works were carried out in the catchment, the support practice factor P_c was assumed equal to one. The topographic factor L_iS_i was calculated, for each morphological unit i, using the following equations coupled with a subroutine provided by the LIBERTYBASIC software.

$$L_iS_i = \left(\frac{\lambda_i}{22.13}\right)^{m_i} \left(10.8\sin\alpha_i + 0.03\right) \qquad \text{if } \tan\alpha_i < 0.09 \qquad (3a)$$

$$L_iS_i = \left(\frac{\lambda_i}{22.13}\right)^{m_i} \left(16.8\sin\alpha_i - 0.5\right) \qquad \text{if } \tan\alpha_i \geq 0.09 \qquad (3b)$$

in which λ_i = slope length of the i-th morphological area, α_i = slope angle, $m_i = f_i/(1 + f_i)$ and $f_i = \sin\alpha_i / 0.0896\left(3\sin^{0.8}\alpha_i + 0.56\right)$.

Once the input of the basic component was obtained, Eq. (1) was adopted to calculate 52 values of β (one for each event) using the recursive approach. The empirical frequency of β is shown in figure 2a together with the Gaussian distribution. Following the MV approach a median value $\beta = 0.0142$ to use, as a representative value in the validation phase, was obtained.

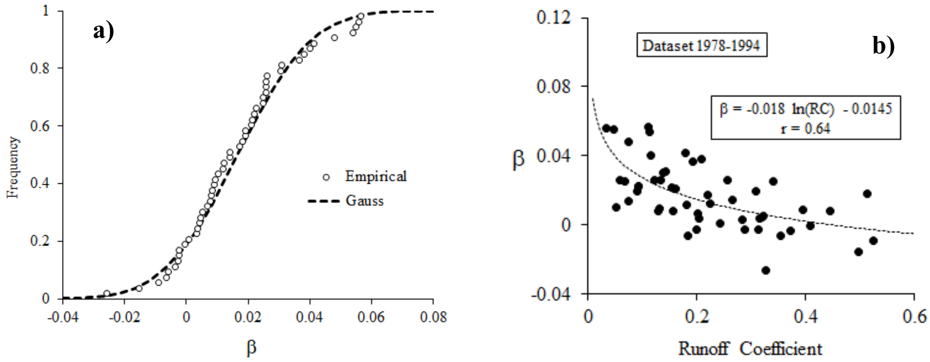

Figure 2. Comparison (a) between the empirical frequency and the Gaussian distribution of β and relationship (b) between β and RC for the 52 events.

The empirical relationship between β and RC, for the same 52 events, is provided in figure 2b and can be approximated by the formula $\beta = a \ln RC - b$, where a and b are parameters.

The model validation – The results provided in figure 2a,b afford a basis for validating the SEDD model at the event scale for the new dataset (81 events) obtained during the period 2006-2016. The validation has been conducted using both the *MV* approach and the *RC* approach. The results of this validation are presented in figure 3a,b.

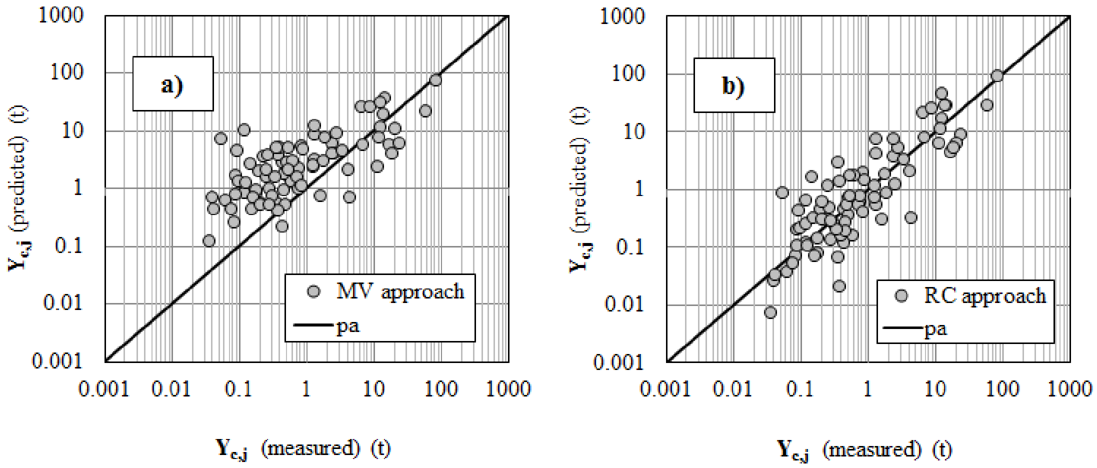

Figure 3. Comparison between the measured and predicted values of sediment yield for the validation period using (a) the MV approach and (b) the RC approach.

Clearly, perfect agreement between measured and predicted values of sediment yield cannot be expected because the SEDD model neglects any contribution due to channel erosion. However, looking at figure 3a, it seems evident that some overestimation for the small-medium values of sediment yield occurred. These results suggest that the β calibration parameter cannot be assumed time invariant for the entire period of measurements. This assumption is confirmed by a visual inspection of the graph presented in figure 3b where a better agreement with no systematic under- or overestimation between measured and predicted values of sediment yield can be observed. Figure 3b reports the results obtained using the *RC* approach which assumes that the β parameter has an inter-event variability and is dependent on the runoff coefficient. The use of runoff measurements to improve the prediction given by similar models was already emphasized by other authors. For example, Kinnel and Risse (1998) [15] and Bagarello et al (2011) [16] suggested to incorporate the runoff measurements to improve the prediction of the USLE model. Obviously, the recourse to runoff measurements means that one more variable must be taken into account when using the model, and the need to measure or predict event runoff, may limit the possibility to apply it. However, other investigations suggest that a reliable prediction of event runoff should be possible and this would simplify the applications [17, 18, 19, 20]. If the comparison is limited to the results of this study, the prediction shown in figure 3b provided a Nash and Sutcliff efficiency index of 0.69 that is higher than that obtained for the prediction presented in figure 3a (EI = 0.61). In other words, the reasonable agreement between the measured and predicted values of $Y_{c,t}$ suggests that the SEDD model provides meaningful estimates of event sediment yield for the study area, especially if the parameter β is calibrated using the runoff measurements.

In order to confirm this hypothesis, a further validation of the SEDD model, using the *RC* approach for estimating β, can be carried out at annual scale. The results of this validation are presented in figure 4, where the annual values $Y_{c,a}$ are obtained by summing the values of $Y_{c,t}$ for the events occurring during that year.

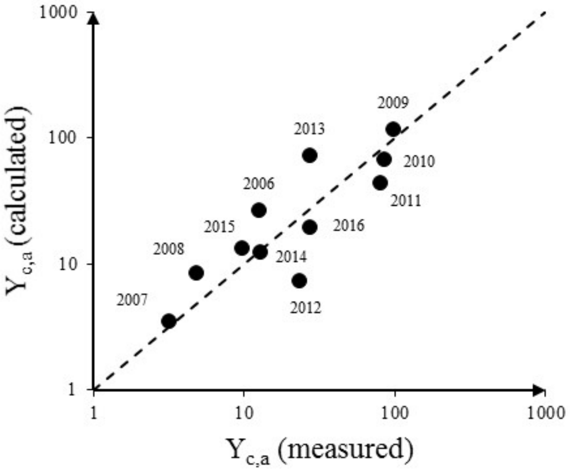

Figure 4. Comparison between the measured and predicted values of annual sediment yield (t) for the validation period using the RC approach.

Again, the model provides meaningful estimates of annual values of sediment yield with no systematic under- or overestimation between measured and predicted values.

5. Conclusions

The SEDD model that integrates a RUSLE input with a sediment delivery component through a distributed approach proved to be very effective in predicting sediment yield at catchment scale. In this context, if long-term measurements of sediment yield are available calibration and validation of this model is possible and its potential can be exploited further.

The study reported here involved the use of sediment yield data collected from a small catchment located in Calabria, southern Italy.

The results demonstrated that the sediment delivery component of the model and, more particularly, its parameter β, can be calculated using a first calibration dataset consisting of 52 erosive events occurred during the period 1978-1994. At event scale, the prediction capability of the model was tested by comparing measured sediment yield values and calculated ones for 81 independent events occurred during the period 2006-2016. The validation exercise established that the approach that allows calculation of β through the runoff coefficient gave the best performance and can be used if runoff data are available or can be easily estimated. This analysis is confirmed when the validation is extended at the annual scale where the performance of the model allowed to get reliable estimates of annual sediment yield.

However, further work is required to explore the potential for estimating the β parameter from alternative variables that can be easily measured and to establish the contribution of channel erosion in larger catchments.

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References

[1] Ferro V and Porto P 2000 *Journal of Hydrologic Engineering* **5**(4) 411–422
[2] Bhattarai R and Dutta D 2007 *Water Resources Management* **21** 1635–47
[3] Bhattarai R and Dutta D 2008 *Hydrological Sciences Journal* **53** 1253–69
[4] Di Stefano C, Ferro V and Porto P 1999 *J. Agric. Engng. Res.* **74** 41–62

[5] Fu G, Chen S, and Mc Cool D K 2006 *Soil and Tillage Research* **85** 38–49
[6] Porto P and Walling D E 2015 *Journal of Hydrologic Engineering* **20**(6) 10.1061/(ASCE)HE.1943-5584.0001058.
[7] Taguas E V, Moral C, Ayuso J L, Pérez R, and Gómez J A 2011 *Geomorphology* **133** 47–56
[8] Vigiak O, Borselli L, Newham L T H, McInnes J and Roberts A M 2012 *Geomorphology* **138** 74–88
[9] Wischmeier W H, Johnson C and Cross B 1971 *J. Soil Water Cons.* **26**(3) 189–193
[10] Wischmeier W H and Smith D D 1965 *Predicting rainfall erosion losses from cropland East of the Rocky Mountains USDA Agr. Hand.* No 282 (Washington, USA)
[11] Renard K G, Foster G R, Yoder D C, and Mc Cool D K 1994 *Journal of Soil and Water Conservation* **49** 213–220
[12] Mc Cool D K, Brown L C, Foster G R, Mutchler C K and Meyer L D 1987 *Transaction of ASAE* **30**(5) 1387–96
[13] Ferro V and Minacapilli M 1995 *Hydrol. Sci. J.* **40**(6) 703–717
[14] Brakensiek D L, Osborn H B and Sheridan J M 1979 *Field Manual for Research in Agricultural Hydrology. Agriculture Handbook* no. 224 (US Department of Agriculture Science and Education Administration, Washington)
[15] Kinnell PIA and Risse LM 1998 *Soil Science Society of America Journal* **62** 1667–72
[16] Bagarello V, Di Stefano C, Ferro V, Kinnell P I A, Pampalone V, Porto P and Todisco F 2011 *Journal of Hydrology* **400** 267–273
[17] Yu B, Rose C W, Coughlan K J and Fentie B 1997 *Transactions of the ASAE* **40**(5) 1295–1303
[18] Vandervaere J P, Vauclin M, Haverkamp R, Peugeot C, Thony J L and Gilfedder M 1998 *Soil Science* **163** 9–21
[19] Gao G Y, Fu B J, Lü Y H, Liu Y, Wang S and Zhou J 2012 *Hydrology and Earth System Sciences* **16** 2347–64
[20] Mc Cool D K, Foster G R, Mutchler C K and Meyer L D 1989 *Transaction of ASAE* **32**(5) 1571–76