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Modelling soil erosion in a Mediterranean watershed: Comparison between SWAT and AnnAGNPS models

O.M.M. Abdelwahab[a], G.F. Ricci[b], A.M. De Girolamo[c,*], F. Gentile[b]

[a] Cairo University, Faculty of Agriculture, Agricultural Engineering Department, Cairo, Egypt
[b] University of Bari Aldo Moro, Department of Agricultural and Environmental Sciences, Bari, Italy
[c] National Research Council, Water Research Institute (IRSA-CNR), Bari, Italy

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ABSTRACT

In this study, the simulations generated by two of the most widely used hydrological basin-scale models, the Annualized Agricultural Non-Point Source (AnnAGNPS) and the Soil and Water Assessment Tool (SWAT), were compared in a Mediterranean watershed, the Carapelle (Apulia, Southern Italy). Input data requirements, time and efforts needed for input preparation, strength and weakness points of each model, ease of use and limitations were evaluated in order to give information to users. Models were calibrated and validated at monthly time scale for hydrology and sediment load using a four year period of observations (streamflow and suspended sediment concentrations). In the driest year, the specific sediment load measured at the outlet was 0.89 t ha^{-1} yr^{-1}, while the simulated values were 0.83 t ha^{-1} yr^{-1} and 1.99 t ha^{-1} yr^{-1} for SWAT and AnnAGNPS, respectively. In the wettest year, the specific measured sediment load was 7.45 t ha^{-1} yr^{-1}, and the simulated values were 8.27 t ha^{-1} yr^{-1} and 6.23 t ha^{-1} yr^{-1} for SWAT and AnnAGNPS, respectively. Both models showed from fair to a very good correlation between observed and simulated streamflow and satisfactory for sediment load. Results showed that most of the basin is under moderate (1.4–10 t ha^{-1} yr^{-1}) and high-risk erosion (> 10 t ha^{-1} yr^{-1}). The sediment yield predicted by the SWAT and AnnAGNPS models were compared with estimates of soil erosion simulated by models for Europe (PESERA and RUSLE2015). The average gross erosion estimated by the RUSLE2015 model (12.5 t ha^{-1} yr^{-1}) resulted comparable with the average specific sediment yield estimated by SWAT (8.8 t ha^{-1} yr^{-1}) and AnnAGNPS (5.6 t ha^{-1} yr^{-1}), while it was found that the average soil erosion estimated by PESERA is lower than the other estimates (1.2 t ha^{-1} yr^{-1}).

1. Introduction

Watershed management plays an important role in the protection of soil and water (Nikolaidis et al., 2013; Abdelwahab et al., 2014; Bisantino et al., 2015). In areas under Mediterranean climate, a quantification of soil erosion and sediment transport is a challenge, depending on the great variability of the physical characteristics of the watersheds and on the peculiarity of the hydrological regime of streams that are generally intermittents (De Girolamo et al., 2015a, 2018). Moreover, the European Commission focused its policies, on one hand, to maintain and restore the good ecological status of freshwater bodies and on the other to increase the awareness about soil erosion and to implement measures to reduce it. Therefore, within the Water Framework Directive (EC, 2000) and the Soil Thematic Strategy (EC, 2006), all the Member States are called to identify the areas having a high erosion risk and to adopt mitigation measures or Best Management Practices (BMPs) to improve water quality and decrease land degradation (Asres and Awulachew, 2010; Abdelwahab et al., 2016a; Vigiak et al., 2016).

Two methods are mainly used to assess the distribution of eroded areas: field monitoring and mathematical models. The first is laborious and expensive; hence, it can be carried out for small areas, while mathematical models need several input data and should be always applied by trained specialists. Models are fundamental tools for identifying critical source areas in large basins and, in addition, they allow to compare different scenarios such as climate change, land use change, and the impact of BMPs. For these reasons, a large number of mathematical models has been developed in recent decades able to simulate hydrological processes, as well as sediment and nutrient export at the basin scale. Merritt et al. (2003) analysed a number of empirical, conceptual and physically based models commonly used for modelling erosion and sediment transport. The Authors concluded that there is not "the best model" for all the applications, as the models differ significantly in complexity, data requirements, equations used to formalize

* Corresponding author.
E-mail address: annamaria.degirolamo@ba.irsa.cnr.it (A.M. De Girolamo).

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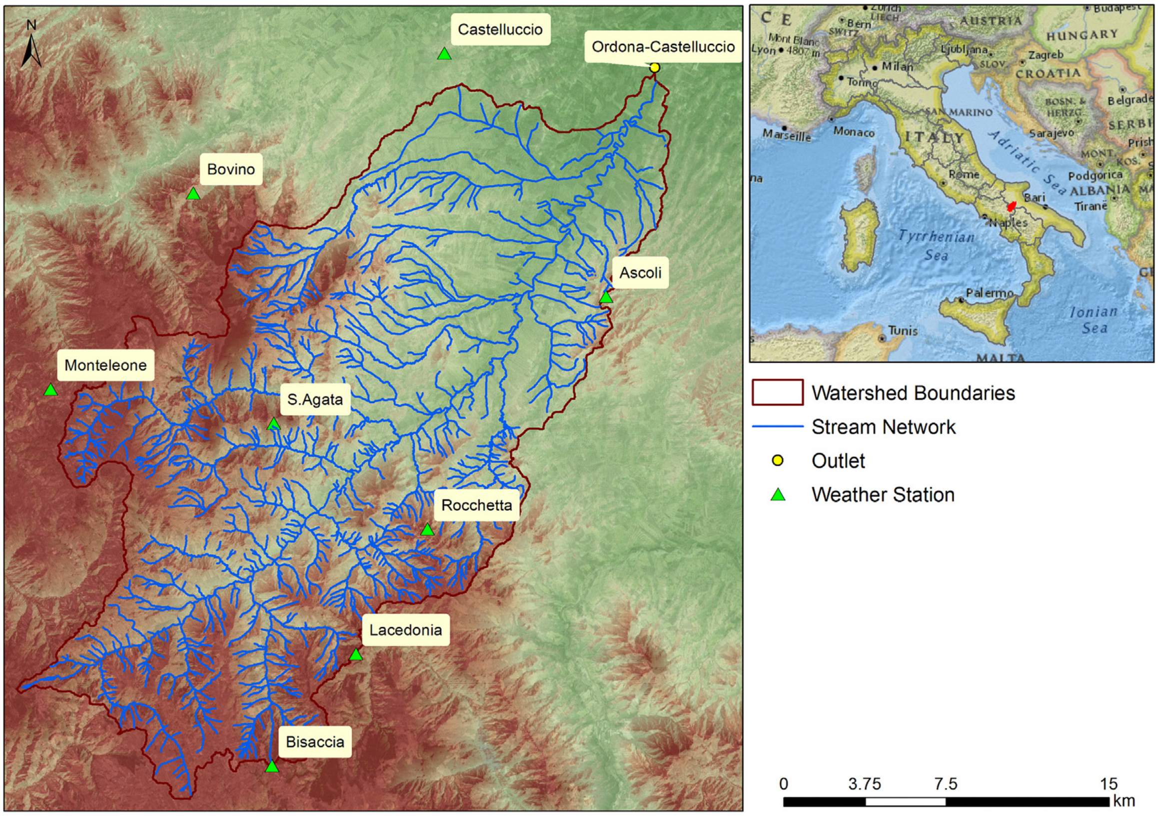

Fig. 1. Study area: Carapelle Watershed (Apulia region, Italy), gauging station at the outlet and spatial localization of the weather stations.

processes and finally for the outputs they provide. The choice of a model should be done having in mind the general principle "a model right for the right reasons". Hence, taking into account the final objective of the study and the scales at which the outputs are required, before selecting a model there is a need to examine carefully the extensity and quality of required data, the complexity of the model, the physical characteristics of the watershed (Singh, 1995; Surfleet et al., 2012). A large number of research articles have been published describing model applications at basin (Yuan et al., 2011; Abdelwahab et al., 2013; Chahor et al., 2014; Vigiak et al., 2015; Zhang et al., 2015; Boithias et al., 2017) or regional scale (Kirkby et al., 2004; Panagos et al., 2015a). Despite the ample debate on model applications provided in the literature, the choice of an appropriate model for a certain watershed remains a critical phase (Clark et al., 2008; Parajuli et al., 2009). Indeed, few studies compare the performances of erosion models based on different theoretical background and data requirements (Jattena et al., 1999; Chandramohan et al., 2015). Few studies, however, are based on a comparison between AnnAGNPS and SWAT in predicting runoff and sediment load (Sadeghi et al., 2007; Das et al., 2007; Heathman, 2008; Parajuli et al., 2009), and no one of them has been conducted in Mediterranean watersheds. In these basins, due to the extreme spatial variability of both rainfall and physical characteristics, it is more difficult to simulate runoff and sediment transport than in other regions. Indeed, the dry season may constitute a critical point in the performances of the models especially in temporary streams, where the extreme low flow is generally overestimated (De Girolamo et al., 2017; Ricci et al., 2018).

The use of soil erosion modelling approaches at the large scale is fundamental (i.e. European scale) for decision-makers to address the Common Agricultural and Environmental Policies (Matthews, 2013) and the Soil Thematic Strategy (EC, 2006). Models at European scale operating on standard datasets constitute a methodology that provides a basis for estimating the overall costs attributable to erosion and that objectively identifies areas where detailed studies and remedial measures are needed (Kirkby et al., 2008). However, erosion assessment at the local scale remains a key point in order to implement soil protection practices at the watershed scale (Panagos et al., 2015a).

The first objective of the present work was to analyse two of the most used models at basin scale for simulating streamflow and sediment load: Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) and Annualized Agricultural Non-Point Source (AnnAGNPS) (Theurer and Cronshey, 1998; Bingner et al., 2015) in terms of main outputs, input data and time requirements. The models were applied using the same dataset in the Carapelle (Apulia, Italy; 506 km^2), a typical Mediterranean watershed. The second objective was to analyse the effects of the different theoretical background and data resolution on soil erosion and sediment yield estimation. At this aim the results of the SWAT and AnnAGNPS models were compared with those provided by two important erosion models applied at European scale that have a different theoretical basis and use data with a different resolution in space and time: the Pan-European Soil Erosion Risk Assessment (PESERA) (Kirkby et al., 2008) and the Revised Universal Soil Loss Equation (RUSLE2015) (Panagos et al., 2015a).

The PESERA model (Kirkby et al., 2008) is a process-based model for soil erosion risk assessment at 1 km resolution across Europe. The RUSLE2015 (Panagos et al., 2015a) has been developed for soil loss estimation in the European Union at 100 m resolution using free and up to date database at the European scale. SWAT and AnnAGNPS models operate at basin scale. Both models have already been applied in the Mediterranean environment in recent years (Abouabdillah et al., 2014; De Girolamo et al., 2015b; Gamvroudis et al., 2015; Bisantino et al., 2015; Abdelwahab et al., 2016b). Literature does not report studies comparing the performances of models applied at a specific area using data having a different resolution or comparing models at European scale with a model at the basin scale.

The analysis of such modelling applications is useful to help water resource managers in selecting a model on the basis of the physical characteristics of the watershed and availability of input data. In