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Sediment yield and erosion rate estimation in the mountain catchments of the Camastra artificial reservoir (Southern Italy): A comparison between different empirical methods

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ABSTRACT

The sedimentary budget assessment is an important topic for the scientific and social community, because it is crucial to understand the dynamics of orogenic belts and cope with a number of practical problems, such as soil conservation and sediment accumulation in reservoir. Sediment yield or denudation rate estimates in southern-central Italy are generally obtained either by applying simple empirical relationships based on the statistical regression between the geomorphic parameters of the drainage network and the suspended sediment yield measured at the drainage basins outlets, or by using qualitative–quantitative sediment delivery ratio or erosion models. In this work, we carry out a study of catchment dynamics and a sedimentary yield computation of several mountain catchments of the central-western sector of the Basilicata region (southern Italy), which are located upstream of an artificial reservoir. The sediment yield and erosion rate have been computed through both an indirect assessment of the suspended sediment yield, based on the *Tu index* (mean annual suspension sediment yield), and the application of the RUSLE and USPED empirical methods. The results obtained have been compared with the historical data of sediment accumulation, measured in the artificial reservoir of the Camastra dam where a detailed evaluation of the volumes of historical (i.e. about 40 years) sediment storage was collected. The collected dataset represents a basic tool both for the investigation of the morpho-dynamics of a typical mountain catchment of the Mediterranean area and the evaluation of sediment budget related to fluvial and hillslope processes. The 38-year-long record of the sediment storage in the Camastra artificial reservoir located at the outlet of the studied mountain catchments permits the validation of empirical relationships based on the geomorphic and climatic parameters of the drainage basin. Among the three different methods of sediment yield evaluation (*Tu index*, RUSLE and USPED), the *Tu index* showed the best prediction ability, although USPED erosion model also furnished a good estimation. As also confirmed by other works, the indirect estimation of sediment yield based on Ciccacci's empirical relationships can represent a good proxy of short-term denudation rates in the Mediterranean areas with geological and geomorphological features similar to the study area but the use of empirical models with increasing complexity such as the USPED erosion model can help to explore the spatial distribution of the sediment yield sectors of the drainage basin, the erosion hot-spots, and the role of landslides in sediment mobilization and hillslope-channel connectivity processes.

1. Introduction

The sedimentary budget estimate is one of the major topics in applied geomorphology, especially when it is crucial to understand catchment dynamics as well as study and work out practical problems, such as the assessment of soil erosion and the estimation of sediment deposition in artificial reservoirs. The theoretical concepts used for assessing the sediment budget are relatively simple and based on mass estimations in source and sink areas (de Vente et al., 2006; Brown et al., 2009). Nevertheless, the complex relationships between erosion and accumulation systems and the introduction of several simplifications can influence the quality of such estimates (Brown et al., 2009). In recent years, advances in computer technology have led to the proliferation of physically-based predictive models aimed to the quantitative investigation of both soil erosion and sediment flux evaluations in catchments (Merritt et al., 2003). The refinement of estimation models of catchment-scale denudation rates often requires an increase in the number of parameters, which are difficult to assess and assume as spatially and temporally homogeneous (Boardman, 2006; Vanmaercke et al., 2011). Another important limitation is the evaluation of the complex interactions and feedback mechanisms between the different

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parameters used to describe erosion and sedimentation (de Vente and Poesen, 2005). Due to all these limitations, the physically-based prediction models of soil erosion showed controversial results and poor reliability (de Vente and Poesen, 2005; Boardman, 2006; De vente et al., 2006) and their application is limited to small areas where a large amount of data are available (de Vente and Poesen, 2005).

The difficulty in applying the physically-based erosion models to natural landscapes lies in the fact that sediment yield predictions are still widely based on very simple empirical models developed by multiple regression methods between morpho-climate parameters and limited measurements of sediment yield and/or sediment fluxes (Jansen and Painter, 1974; Ciccacci et al., 1980; Mulder and Syvitski, 1996; Poesen et al., 2003).

In Italy, sediment yield and denudation rate evaluation are quite rare and are greatly affected by most of the above-mentioned problematic aspects. Short-term denudation rates are generally obtained either from simple regression equations which involve hydro-geomorphic parameters and the suspended sediment yield estimates of several Italian drainage basins (Ciccacci et al., 1980; Della Seta et al., 2007, 2009; Santangelo et al., 2013; Vergari et al., 2013; Borrelli et al., 2014; Gioia et al., 2014) or from empirical sediment delivery ratio and/or erosion models (Onori et al., 2006; Capolongo et al., 2008a; Fagnano et al., 2012; Conoscenti et al., 2013). The validation of sediment yield assessment is frequently difficult to achieve and the predictive ability of these equations is limited to the specific regions for which they have been developed (de Vente and Poesen, 2005). Another limit is the impossibility to fully consider the spatial variation of sediment yield within the catchment. Moreover, direct measurements of sediment flux in streams are extremely rare and limited to a few years and one of the most implemented approaches to estimate sediment yield is based on sediment storage in closed systems, such as lakes and artificial reservoirs (Van Rompaey et al., 2005; de Vente et al., 2006).

In this work, we have estimated sediment yield in a mountain catchment of the central-western sector of the Basilicata region, southern Italy, (Fig. 1) by draining an artificial reservoir (i.e. the Camastra dam, Fig. 2). Specifically, the sediment yield evaluation has been obtained through both an indirect estimation of suspended sediment yield based on the *Tu index* (mean annual suspended sediment yield, Ciccacci et al., 1980) and the application of the RUSLE (Renard et al., 1997) and the USPED(Mitasova et al., 1996) empirical methods.

The main purpose of the work is to compare the results coming from these different empirical models of sediment yield estimation with the mid-term (i.e. about 40 years) record of sediment accumulation in the artificial reservoir. The validation of such estimations of sediment yield at the scale of large catchments using sediment storage in reservoir allows testing the reliability and the predictive ability of different empirical estimations based on drainage network morphometric properties. Furthermore, we performed an in-depth geomorphological analysis of the area in order to outline the main geomorphological processes acting within the studied catchment and their role on the spatial distribution of the sediment yield. This kind of approach allows us to compare the results of erosion models with the erosional processes of the study area.

2. Geological and climatic setting

The test area is located in the axial-outer belt of the southern Apennines (Fig. 1), featured by an alternation of tectonic basins and morphostructural ridges related to Pliocene and Early Quaternary phases of thrusting and folding (Amato and Cinque, 1992; Bonini and Sani, 2000).

The southern Apennines (Fig. 1) are a north-east verging fold-and-thrust belt, derived from the deformation of the western border of the Apulian plate from late Oligocene to Pleistocene time (Pescatore et al., 1999). The belt is mainly made of shallow- and deep-water sedimentary deposits derived from the deformation of Mesozoic–Cenozoic circum-Tethian domains and Neogene–Pleistocene syntectonic and foredeep deposits (Pescatore et al., 1999; Menardi Noguera and Rea, 2000; Lazzari, 2008). Starting from Langhian–Tortonian times, the Apennine thrust front moved progressively toward the east and was followed by a back-arc extension, responsible for synchronous extensional collapse of the inner domains of the thrust belt and Tyrrhenian sea opening (Malinverno and Ryan, 1986). The Pliocene to Pleistocene post-collisional history of the southern Apennines is characterized by strike-slip and extensional tectonics, which promoted the creation of longitudinal and transversal fault-bounded basins (Cinque et al., 1993; Schiattarella et al., 2006; Gioia et al., 2011b).

The study area is located at about 10 km to the south of the Potenza town and it is mainly characterized by strongly deformed geological units of the Lagonegro basin and flysch deposits of Miocene syntectonic basins. The middle Triassic-to-Miocene Lagonegro units are characterized by shallow-water, basinal and shelf-margin facies and limestone and siliciclastic deposits of pelagic environment, affected by dome-and-basin folds (Pescatore et al., 1999). Middle Cretaceous to Oligocene gray and reddish clays and marls (Argille Varicolori and Corleto Perticara Fms) and upper Oligocene to lower Miocene marls and volcaniclastic sandstones (Tufiti di Tusa Fm) also outcrop widely in the study area. The upper Miocene deposits are mainly constituted by deep-sea conglomerates, sandstones and pelites (Gorgoglione Flysch Fm.), unconformably overlying the Lagonegro units (Pescatore et al., 1999).

The Lower Pliocene–Early Pleistocene clastic deposits of the Calvello piggy-back basin, mainly made of a 300 m-thick succession of gray silty clays with rare shell fragments, interbedded with fine sands, unconformably overlay the deformed pre-Pliocene bedrock (Amato and Cinque, 1992; Bonini and Sani, 2000). A 100 m-thick succession composed of Early Pleistocene marine/transitional gravels with intercalations of sandy levels unconformably overlies the upper Pliocene–Early Pleistocene marine sediments (Amato and Cinque, 1992).

From a geomorphological point of view the main streams of the study sector cut across the NW–SE trending contractional structures, with minor channels arranged in a dendritic pattern (Fig. 2). The belt tops are frequently characterized by remnants of ancient polycyclic erosional land-surfaces, elevated by the Quaternary regional uplift and displaced by fault activity (Amato and Cinque, 1999; Schiattarella et al., 2013).

The climatic context has been defined using temperature data from Potenza and rainfall data record of the Calvello and Laurenzana stations.

Fig. 1. (a) Geological setting of the southern Apennines. The study area is represented in the box. Legend: 1) Pliocene to Quaternary clastic deposits and volcanic products; 2) Miocene syntectonic deposits; 3) Cretaceous to Oligocene ophiolite-bearing internal units; 4) Mesozoic–Cenozoic shallow-water carbonates of the Apennines platform; 5) lower–middle Triassic to Miocene shallow-water and deep-sea successions of the Lagonegro-type Monte Arioso unit; 6) Mesozoic to Miocene deep-sea successions of the Lagonegro-type Groppa d'Anzi unit; 7)Cretaceous to Miocene deep-sea successions of the Lagonegro-type Campomaggiore unit; 8) Mesozoic–Cenozoic shallow-water carbonates of the Apulian platform; 9) volcanoes; 10) thrust front of the chain. (b). Geological sketch map of the Camastra catchment. Legend: 1) alluvial deposits (Upper Pleistocene to Holocene sand and gravel) 2) slope deposits (Upper Pleistocene to Holocene matrix-supported breccias); 3) Upper Pliocene to Early Pleistocene matrix-supported gravels with intercalations of sandy levels; 4) Upper Pliocene sand, gray-blue silty clays and gravels; 5) Lower-Upper Pliocene gray-blue silty clays rarely interbedded with coarse sand and gravels; 6) Lower Pliocene sand with intercalations of clay, calcarenites and gravels levels; 7) Gorgoglione Flysch Fm (upper Miocene syntectonic siliciclastic turbidites); 8) Tufiti di Tusa Fm (upper Oligocene to lower Miocene marls and volcaniclastic sandstones; 9) Argille Varicolori and Corleto Perticara Fms (middle Cretaceous to Oligocene varicoloured clays and marls with calcarenites and calcilutites); 10) Galestri Fm (lower–middle Cretaceous siliceous marls and shales); 11) Scisti silicei Fm (Jurassic radiolarites and cherts); 12) Calcari con selce Fm (upper Triassic cherty limestones); 13) Monte Facito Fm (lower–middle Triassic shallow-water siliciclastic sediments, organogenic limestones and, toward the top, siliciclastic basinal deposits; 14) Mesozoic–Cenozoic shallow-water carbonates of the Apenninic platform.