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# Modelling net erosion responses to enviroclimatic changes recorded upon multisecular timescales

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**Abstract**

Land use change has been recognized throughout the Earth as one of the most important factors influencing the occurrence of rainfall-driven geomorphological processes. However, relating the occurrence of historical soil erosion rates is difficult because of the lack of long-term research projects in river basins. Also, complex models are not adequate to reconstruct erosion rate changes because they require significant input data not always available on long timescales. Given the problems with assessing sediment yield using complex erosion models, the objective of this study is to explore a parsimonious scale-adapted erosion model (ADT) from the original Thornes and Douglas algorithms, which aims at reconstruction of annual net erosion (ANE) upon multisecular timescales. As a test site, the Calore River basin (3015 km$^2$ in southern Italy) provides a peculiar and unique opportunity for modelling erosion responses to climate and land cover changes, where input-data generation and interpretation results were also supported by documented hydrogeomorphological events that occurred before and after land deforestation. In this way, $ANE_{ADT}$-values were reconstructed for the period 1675–2004 by using precipitation indexes, complemented by recent instrumental records, and by using land cover statistics from documented agrarian sources. Pulses of natural sedimentation in the predeforestation period have been related to Vesuvius volcanic activity and changes in rainstorm frequency. After deforestation, the basin system became unstable with sudden fluctuations in the hydrogeomorphological regime contributing significantly to increased erosion and, in turn, sediment transport sequences via river drainage towards the Tyrrhenian coast.


*Keywords:* Rainfall erosivity; Land cover; Net erosion; Empirical model; Climate change; Calore River basin (southern Italy)

## 1. Introduction

Environmental changes have always been a topic of Earth's science and environmental research, but its importance increases during crucial changes and extremes (after Stehr and von Storch, 1995), often associated with land degradation driven by weather and external anthropogenic forcing (Riebau and Fox, 2005). However, while the major focus on causes of soil erosional degradation has been the relative significance of agricultural activities and practices, the possible impact of changing weather patterns and more sustained shifts in climate have also been implicated (Foster, 2001). Understanding how landscape components respond to forced conditions of land use change and to the climatic regime has implications for modeling the geomorphological processes hazard (Leeder et al., 1998;

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Coulthard et al., 2002) and for assessment of future planning (Higgitt, 2001; Verstraeten and Poesen, 2001). In this way, modeling has been a fascination for millennia, such as mean the words of Mulligan and Wainwright (2004) and Wainwright and Mulligan (2004, p. 8):

> "Modelling is described as an art because it involves experience and intuition as well as the development of (mathematical) skill."

especially in mountainous agricultural landscapes where land degradation is manifested in a variety of processes (Shrestha et al., 2004). Modelling is a crucial issue in assessing climate variability and land cover (Morgan et al., 1998; Renschler and Harbor, 2002; Ramos and Mulligan, 2003), which are very important factors affecting the environmental sustainability in these dynamic and sensitive landscape systems (Alexandrov, 1997; Thomas, 2001; Reinhard et al., 2003), highly controlled by a set complex of climatic, geomorphic, and ecologic processes (Krishnaswamy et al., 2000).

Amid current concerns over the consequences of recent enhanced climate variability of human and rainfall-induced agricultural and environmental impacts (Sivakumer, 2005), the modelling and reconstruction of the response of a river basin to past environmental changes is increasingly viewed as vital in the context of developing scenarios for future response (Rumsby, 2001). Much information regarding the geomorphological process, slope, and river response to climate change has been reported in numerous historical studies (Orbock Miller et al., 1993; Rumsby and Macklin, 1996; Brooks and Brierley, 1997; Wilby et al., 1997; Eden and Page, 1998; Arnaud-Fassetta and Provansal, 1999; Grove, 2001; Jacobeit et al., 2003; Hunt and Wu, 2004; Schmidt and Dikau, 2004). Many of them were concerned specifically with sediment and erosional processes from European archival data, such as in English catchments (David et al., 1998), German (Zolitschka, 1998), Welsh (Beavis et al., 1999), Irish (Huang and O'Connell, 2000), Spanish (Lasanta et al., 2001), Iceland (Lamoureux, 2002), Belgian (Van Rompay et al., 2002), Greek (Lespez, 2003), Turkish (Wick et al., 2003), Bavarian (Dotterweich et al., 2003), and French (Piégay et al., 2004). Although many of these studies form an attractive research field, the information derived from paleogeomorphological evidence [such as sedimentation traps in fluvial terraces (Prózynska-Bordas et al., 1992), in lakes (Slaymaker et al., 2003; Evans and Slaymaker, 2004), or in deglacierizing basins (Orwin and Smart, 2004)] are not continuous in time with less rigorous chronological control (Schulte, 2002; Bradley et al., 2003). Research developed in Italy have been carried out dealing with the influence of climatic modifications on the natural environment and on impacts of extreme events on human activities since A.D. 1000 (Camuffo and Enzi, 1992; Delmonaco et al., 2000) or earlier (Ramrath et al., 2000). An overview of paleoclimatic investigations on sediments from volcanic lakes in central Italy is given by Follieri et al. (1993). All these studies suggest that the Little Ice Age (LIA), variously assessed as AD 1300–1900, is not expected to be hydrogeomorphologically homogeneous and sustained over large geographical areas (see also Bradley and Jones, 1993; Ogilvie and Jonsson, 2001; Soon and Baliunas, 2003 for climate forcing). Thornes (1995) and Viles and Goudie (2003) agreed, declaring that in-depth research in a regional context would likely to provide meaningful answers questions of magnitude impact by combinations of modes of internal and forced climate variability (Goosse et al., 2005). For this topic, dynamically or stochastically driven models (see Nearing, 2004, for a synthesis) can be used. However, these models still have limitations for predicting basin sediment yield (de Vente et al., 2005), especially over long timescales, requiring a powerful computer, extensive computer run time (Toy et al., 2002), and validation that is difficult because scarcity of measurements (Instanbulluoglu et al., 2004).

To deal with these problems in this paper, I propose an integrative methodology incorporating bioclimate documentary data in a regression-derived erosion model offering the opportunities to account for parsimonious interpretation between input data and a basin-response erosion variable. This model is to revise the Douglas (1967) and Thornes (1990) empirical algorithms to an adapted-Douglas–Thornes (ADT) nonlinear model ($ANE_{ADT}$) by replacing the RUSLE erosivity factor with runoff data and by updating a vegetation-protection climatic function with improved net erosion time-series estimates. For ($ANE_{ADT}$)-model calibration a SIMN-dataset (1957–1972), with a total of 20 samples was used, providing a unique opportunity to explore geomorphological processes in the Calore River basin (CRB) of southern Italy. The use of an $ANE_{ADT}$ time-series model is motivated by its potential for capturing the significant and changing environment (including climate, vegetation cover, and erosive-resistance climate changes) with easily available data. Results show an important increase of sediment rate from 1811 to 1860, with higher fluctuations of the erosion peak from preceding and successive periods.

## 2. Area description, methods, and material studied

This work is the continuation of three previous papers where the last Millenniums extreme hydrometeorological events (Diodato, 1999), the last four century rainfall erosivity data (Diodato and Ceccarelli, 2005), and rainfall anomalies (Diodato, in press) in the Calore River basin were reconstructed. Operational procedures, rain gauges, sites, and data quality of this series of papers were also carefully investigated in a recent work (Diodato, 2005a).

### *2.1. Climate, geomorphology, and vegetation*

Italian territory is located at the centre of the Mediterranean sea basin (Fig. 1a). Therefore, it is strongly affected by a complex geographic system, including perturbing action of the Apennines and the sea. The main synoptic situations responsible for abundant rains over the region are generally characterized by northwesterly or westerly airflow and eastward-moving wintry cyclonic depressions. In the summer, intense drought events can be associated with hemispheric meridional circulation (i.e., subtropical anticyclone), often interrupted by atmospheric instability with showers and thunderstorms. The Calore River basin (CRB) test site is located at the transition from the central and southern Italian Apennines (elevation 50–1800 m), with an extension of 3000 km$^2$ (Fig. 1b). The climate over the CRB is of *Mediterranean* type, with average annual precipitation ranging from 650 to 2000 mm ($1289_{M} \pm 218_{S.D.}$ mm) and rainfall erosivity from 900 to 4119 MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$ ($1497_{M} \pm 389_{S.D.}$ MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$) for the period 1921–1988. As consequence of climate conditions, the soil moisture regime is definitely *xeric*, whereas soil temperature regime results tend to be *mesic*, between 500 and 600 m above sea-level, and *thermic* to *mesic* above (Buondonno et al., 1989). The morphology of the land is characterised by a meandering river area from the Calore and Sabato rivers and surrounded by hills, in middle basin, and by mountainous areas with a topography ranging from 600 m to 1800 m, in northwestern and southern territory. Quaternary sediments are essentially detrital, coarse colluvial or alluvional: they are for the most part undeformed and mainly occupy valley bottom or piedmont positions. The clayey–marly–arenaceous nature of the sediments that make up most of the relief in the study area are particularly susceptible to erosive phenomena in general, or more specifically to landslide-type instability and climatic effects have a certain relevance in the morphoevolution of the relief (Diodato and Russo, 2003). Here lithology and morphology were major factors on soil genesis and evolution processes in the Late Holocene (Leone et al., 1996). Over claystones, the dominant soils are Vertisols, over sandstones are Entisols and Inceptisols, and over carbonates, soil are ascribed to the Mollisols and Inceptisols. Finally, over flood plain alluvial deposits we find soils with typical morphological characteristics of “Alluvial soils”.

Approximate actual spatial erosion pattern in Italy was predicted by van der Knijff et al. (2000) using a GIS-based RUSLE procedure. An illustration of this pattern is presented for the CRB in Fig. 2a, with an

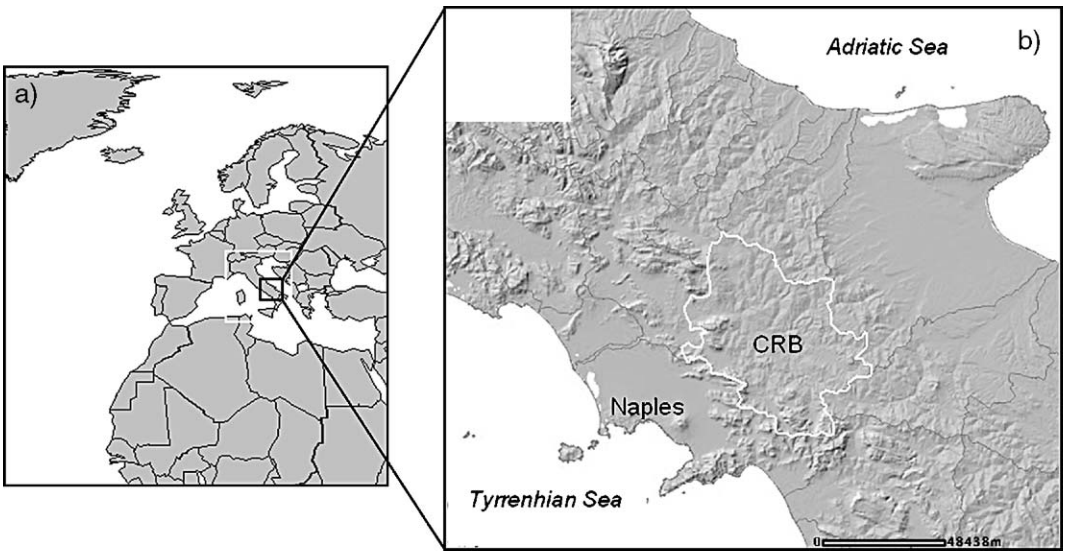


Fig. 1. Geographic location of Italy (a) and limits of the Calore River Basin (white line) overlain hillshade terrain-map by SICI (2001) (b).

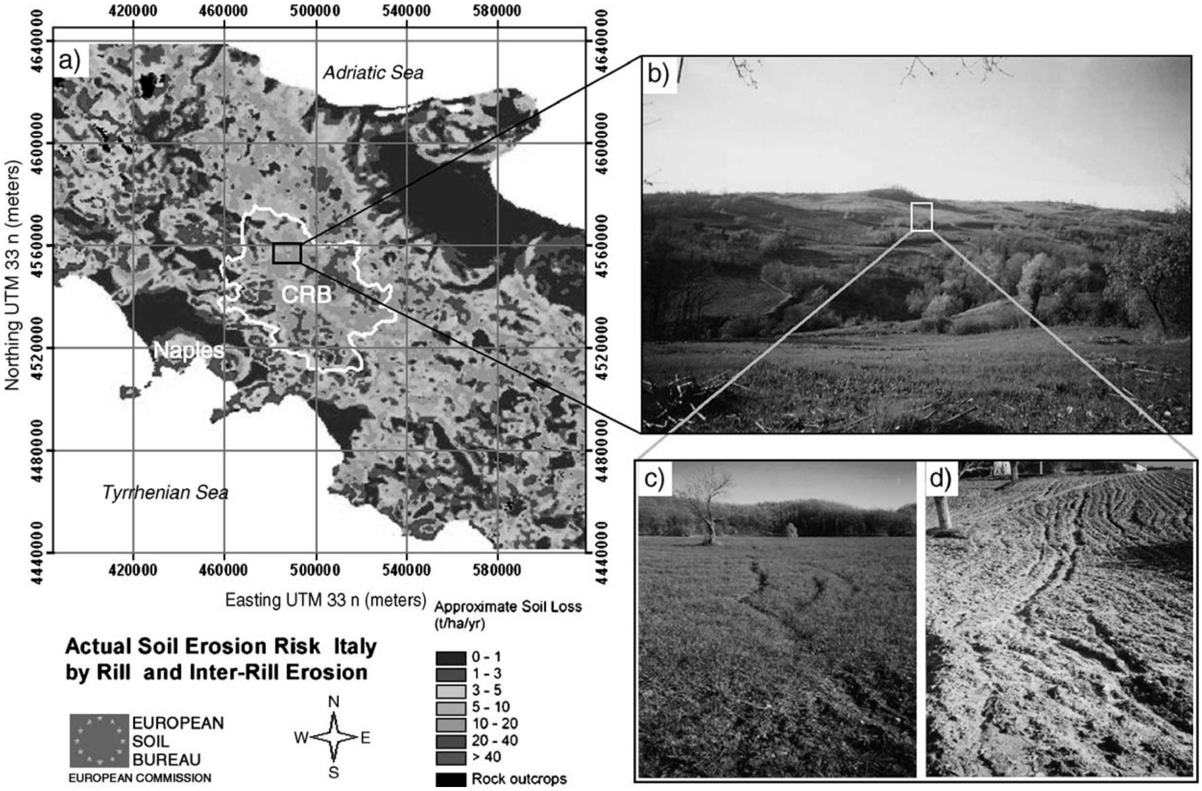


Fig. 2. Actual soil erosion map by van der Knijff et al. (2000) modified (a); panoramic viewed of the Tammaro agricultural catchment at north of the CRB (b); rill-erosion in grassland (c) and in tillage field (d) at hillslope scale during rainstorm on October 2002.

annual average soil loss rate varying between 0 and 40 Mg ha$^{-1}$. Fig. 2b shows a panoramic view of an agricultural subcatchment (Tammaro basin) with rill erosion in grassland (Fig. 2c) and in a tilled field (Fig. 2d) at hillslope scale during a rainstorm in October 2002. From their comparison, we may argue that vegetation cover negatively influences erosion magnitude. Beyond grassland, the natural vegetation of these zones of the Italian Apenninic inland is that typical of the *Mediterranean mountainous* and *submountainous* sectors (Blasi et al., 1988). The combination of wet winter and dry summers produce a thermophyla vegetation such as *Quercus pubescens*, *Colutea arborescens*, *Acer campestre*, and for a high-mountainous sector, *Fagus sylvatica*, *Acer obtusatum,* and *Ilex aquifolium*. The secondary formation of agricultural shrublands, originating from environmental degradation, is composed of *Robinia pseudoacacia*, *Pinus pinea*, and a variety of resinous plants.

## 2.2. Input data collection

Enviroclimatic data were collected from two rural agricultural basins: one covering the same study area (which is the Calore River basin with an extension of 3015 km$^2$ and slope of 8%) and one adjacent basin (which is the Volturno River basin, northwest of the CRB, with an extension of 2050 km$^2$ and slope of 11%). Rainfall and sediment data were assessed using records of 34 rain gauges and 2 turbidity sampling stations, respectively, of the former network of the Servizio Idrografico and Mareografico Nazionale (SIMN, 1922–2004). However, sediment data were available for a shorter period, 1957–1972, which were used for erosion model calibration (Table 1). Sediment was collected in the buckets once in a month. Some of the sediment settled out in the trough and was transferred in to one of the buckets. Each bucket was weighed in the lab to determine total runoff (sediment and water). Total runoff was converted to a volume (liters) by assuming the density of the sediment–water mixture was 1.0 g cm$^{-3}$. In the laboratory the samples were left setting for amount to allow the suspended sediment to settle. Water was decanted from the buckets and the sediment was oven dried for 24 h at 98 °C. Samples of the water were taken, dried in a bowl, and weighed to determine the amount of sediment still remaining in suspension. Rainfall erosivity data were explored following the

Table 1
Data use in generating model output

| Year | $R$ (MJ mm ha$^{-1}$ h$^{-1}$) | $P$ (mm) | WVC (%) | Pw (mm) | Net erosion (MG km$^{-2}$) |
|---|---|---|---|---|---|
| *Volturno basin* | | | | | |
| 1957 | 1389 | 1146 | 26 | 1151 | 200 |
| 1958 | 2066 | 1330 | 26 | 1151 | 560 |
| 1959 | 1959 | 1556 | 26 | 1151 | 710 |
| 1960 | 2373 | 1716 | 26 | 1276 | 600 |
| 1961 | 2035 | 1213 | 26 | 1276 | 510 |
| 1962 | 2046 | 1519 | 26 | 1330 | 510 |
| 1963 | 2658 | 1467 | 26 | 1467 | 680 |
| 1964 | 3511 | 1603 | 26 | 1519 | 1240 |
| 1965 | 2493 | 1245 | 26 | 1519 | 540 |
| 1966 | 2513 | 1466 | 26 | 1467 | 690 |
| 1967 | 2434 | 1080 | 26 | 1466 | 790 |
| 1968 | 2438 | 1147 | 26 | 1466 | 500 |
| 1969 | 1963 | 1721 | 26 | 1466 | 490 |
| 1970 | 2545 | 1349 | 26 | 1349 | 710 |
| 1971 | 2242 | 1457 | 26 | 1349 | 490 |
| 1972 | 2083 | 1604 | 26 | 1457 | 430 |
| *Calore basin* | | | | | |
| 1957 | 1120 | 912 | 10 | 981 | 550 |
| 1959 | 1491 | 1225 | 10 | 932 | 660 |
| 1960 | 1667 | 1275 | 10 | 981 | 980 |
| 1961 | 1894 | 1099 | 10 | 1046 | 1090 |

RUSLE procedure (Renard et al., 1997) as adapted by Diodato (2004) for Italian climate records. In this way, an erosivity series was reconstructed by using a precipitation index complemented by recent instrumental records (Diodato and Ceccarelli, 2005). Finally, the evolution of the woody cover was derived from documented local agrarian statistical sources (Galanti, 1781; Del Re, 1836; Albino, 1870; Orsi, 1956; Lalli, 1965) and regional literature (Massafra, 1984; Sereni, 1996).

### 2.3. Model development

Net water erosion is a measure of average sediment yield over the time and space-unity from basin (Lane et al., 1997). Sediment yield is the sum of the sediment produced by all erosional sources, including that from overland flow, ephemeral gully, and stream channel areas (Toy et al., 2002) less the amount of sediment deposited on these areas and on the valley floodplains (Fig. 3). The four environmental factors that determine water erosion and sedimentation are climate, soil, topography, and land-use which operate independently and interactively.

The concept of the balance between driving and resisting forces in sediment budget and yield modelling was originally proposed by Douglas (1967) that provides an empirical climate index converted into metric units:

$$E_D = \frac{1.631(0.03937P_e)^{2.3}}{1 + 0.0007(0.03937P_e)^{3.3}} \tag{1}$$

where $E_D$ is the suspended sediment yield (m$^3$ km$^{-2}$ year$^{-1}$) over long-period; $P_e$ is the effective precipitation (mm), and where the numerator represents the driving force in the power of rainfall; and the denominator, the vegetation-protection factor. This model is suitable for large basins and is not universally applicable.

Later on, Thornes (1990) builds a finer model to simulate monthly wash erosion by water running across the land surface that can be expressed as:

$$E_T = \sum_{j=1}^{12} \left(kQ^a S^d e^{-iV}\right) \tag{2}$$

where $E_T$ is the annual erosion amount (mm year$^{-1}$) over the months from 1 = January to December = 12; $k$ is the erodibility; $Q$ is the overland flow (mm month$^{-1}$); $a$ is the flow power coefficient equal to 1.66; $S$ is the tangent of slope (mm$^{-1}$); $d$ is the slope constant equal to 2.0; $V$ is the vegetation cover (%); $i$ is the erosion exponential function equal to 0.07.

Formal integration achieves upscaling may have very different variables and parameters (Kirkby and Cox, 1995). For example, there is some overlap between basin and catchment erosion processes, but some of the dominant processes are described in different manners. In this way the Thornes's model was revised for a (ANE$_{ADT}$)-Adapted Douglas–Thornes models by replacing RUSLE erosivity factor (Wischmeier and Smith, 1958; Renard et al., 1997) to runoff, updating vegetation cover erosive-resistance climatic function and reducing erodibility and slope factors. Saturation overland flow provides very little information on the potential for splash erosion and erosion by Hortonian overland flow (Mulligan, 1998). Thus, at basin scale such erosion is not the result of amount runoff, but of rainfall erosivity by both raindrop impact and surface peak runoff (storm erosivity) and vegetation cover up to several decades, over which these patterns may change (Kirkby et al., 1998). In this way, for time-series prediction (net erosion, variable over time), two conceptual components have been adopted with soil-erodibility, land- and discharge slope assumed temporally constant:

– a weather erosivity dataset for a changed climate forcing;

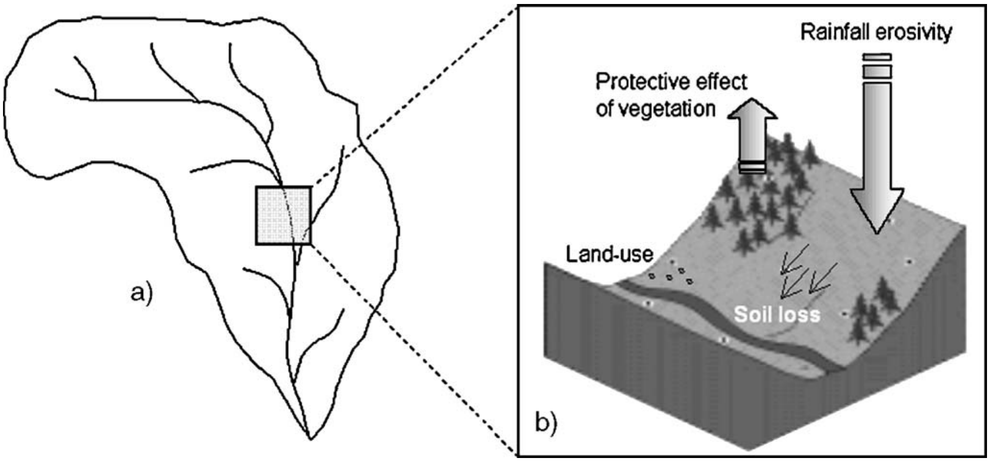


Fig. 3. River basin (a) and discretized unit with representation of its erosion cycle (b).

– a vegetation-cover and erosive-resistance climate factors.

Considering the two components, a central assumption is that if the erosion model gives adequate results for the twentieth century, then it will also give acceptable results when run with changed climate and changed land-cover (after Favis-Mortlock and Boardman, 1995). In this way, soil erosion by water most occurs when the detachment of particles and their subsequent transportation experience a greater driving force than the force binding it into the vegetated slope. Within this process the rainfall is used by nature as both a driving and resisting factor. Firstly, the erosive influence of rainfall increases with its amount and intensity; secondly, and opposing this influence, is the protective effect of vegetation which also increases with precipitation amount. The balance between these forces can be expressed, according the following revised Douglas-and-Thornes-non-linear equation, as:

$$\mathrm{ANE}_{\mathrm{ADT}_j} = k\frac{R_j^m \mathrm{e}^{-b\mathrm{WVC}_j}}{(\mathrm{Med}_w(P))^c} \tag{3}$$

where

- $\mathrm{ANE}_{\mathrm{ADT}}$ is the net soil-loss from basin in the $j$th year, in MG km$^{-2}$ year$^{-1}$;
- $R$ is the rainfall erosivity factor in MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$, which provides the forces applied to the soil to cause water erosion, which was evaluated in preinstrumental period following Diodato and Ceccarelli (2005):

$$R = 0.880[0.0897(6 + \mathrm{WIS_S})(2 + \sigma^2_{\mathrm{WI}})P - 1306] + 1271 \tag{4}$$

where $\mathrm{WIS_S}$ is the Weather Index Sum which was obtained by summing monthly values index WI in June–October period following the classification: rainy without floods (WI=+1), stormy or rainy with floods (WI=+2), droughts (WI=0); moreover, also the variance of the *WI* index ($\sigma^2{}_{WI}$) over January–December period was takes into account such as an indicator of the erosivity (after Aronica and Ferro, 1997); $P$ is the annual precipitation amount (mm);
- $\mathrm{e}^{(-b\cdot\mathrm{WVC})}$ is the Thornes's vegetation erosion exponential function that represents the short-term resisting force, where WVC is the woody vegetation cover (%), and $b$ is a parameter whose value is a function of the ratio of rill to interrill erosion with bare soil conditions (Thornes, 1990);
- the term at denominator is the patterns of long-term resisting force occurring on a window timescales, represented by ground cover erosive-resistance climatic function (after Douglas, 1967), where precipitation median value $\mathrm{Med}_w(P)$ is expected on a time moving window ($w$) antecedent the year $j$, with $w$=7 years. Although many studies (e.g., Grist et al., 1997; Foody, 2003; Wang et al., 2003) have differed in detail, notably in terms of how the variables are expressed (e.g., vegetation-indices, daily, monthly or annual precipitation), each has essentially detected a strong positive relationship between rainfall and vegetation-indices. In fact, precipitation variable affect vegetative growth and decomposition of plant materials left by the vegetation, which in turn reduces soil susceptibility to erosion (Toy et al., 2002, p. 30); in this way the median value is favourite than precipitation mean because the precipitation median is a variable more

stable, representing better the vegetation-protection bioclimatic function over time.

- the four empirical coefficients ($k$=0.0168; $m$=2; and $b$=−0.050, and $c$=0.70) and the length of the window ($w$) were estimated by minimizing the sum squared errors (SSE) over $\eta$ data:

$$\mathrm{SSE} = \sum_{j=1}^{\eta} \left(\mathrm{ANE}_{\mathrm{Measured}(\eta)} - \mathrm{ANE}_{\mathrm{ADT}(\eta)}\right)^2 \quad (5)$$

So, a goodness-of-fit measure that minimizes the absolute errors rather than relative errors fir high soil-loss values is used to develop model that estimate net erosion for use in sedimentation problems where mass of sediment must be estimated accurately (Toy et al., 2002).

### 2.3.1. Model evaluating

Before a user implements a model for reconstruction data, the user should evaluate the model thoroughly too (Toy et al., 2002). Users evaluate the model at this stage is the last opportunity for the user to have a major impact on the model. For scarcity in the sample, validation for $\mathrm{ANE}_{\mathrm{ADT}}$ was not possible. In this way error assessment was by using cross-validation (Isaaks and Srivastava, 1989). The idea consists in re-estimating $\mathrm{ANE}_{\mathrm{ADT}}$ at $j$th year after removing, a turn, one datum from the data set. In this way, 19 of the data were used for model calibration, after which the model was applied for predicting $\mathrm{ANE}_{\mathrm{ADT}}$ for the remaining data. This was repeated 20 times so that for each reservoir a predicted $\mathrm{ANE}_{\mathrm{ADT}}$-value was obtained by a model calibrated for the other 19 data.

In Fig. 4a the reduced major-axis lines for net erosion shown 1:1 relationships between measured and expected values ($r^2$=0.86). In addition, Fig. 4a was complemented by dialog box scatterplots of Fig. 4b,c where net erosion measured were compared to Douglas and Thornes recalibrated models outputs, respectively. It can be seen that Douglas-model, which is sustained only by effective precipitation, yields the largest prediction errors. Smaller prediction errors are produced by Thornes-model including vegetation-cover, soil-erodibility and slope factors too. However, the results clearly favour the $\mathrm{ANE}_{\mathrm{ADT}}$-model integrating the same information present in both Douglas- and Thornes-models.

## 3. Results and discussions

The final result of the rain-erosivity reconstruction is shown in Fig. 5 allowing a view of temporal evolution of annual $R$. That is, after several years of high climatic variability during the first two century of the series, a clear smoothed period. In particular, 18th and 19th centuries were crossed from very frequent and extreme storm with anomalies greater of +1 standard deviation and from 13 anomalies greater of +2 standard deviation spaced from abrupt climatic changes. In Mediterranean region, rainfall fluctuations are forced by changes and strength in the zonal circulation (Hurrell, 1995; Slonosky et al., 2000) that for middle latitudes can be taken as a measure of the distance from climatic system equilibrium (Lockwood, 2001). On the climatological scale, it exhibits jumps in the long-term rate of precipitation change, which are often associated with changes in atmospheric flow pattern. In this way, rainfall impacts are often dominated by weather and climate extremes (Larson et al., 1997; Mulligan, 1998; Coppus and Imeson, 2002; Renschler and Harbor, 2002). These events may be grouped in some particularly rainy years or months according to storms climatic variability over interannual to century scales (Garcia-Oliva et al., 1995; D'Odorico et al., 2001; Peterson et al., 2002; Cavazos

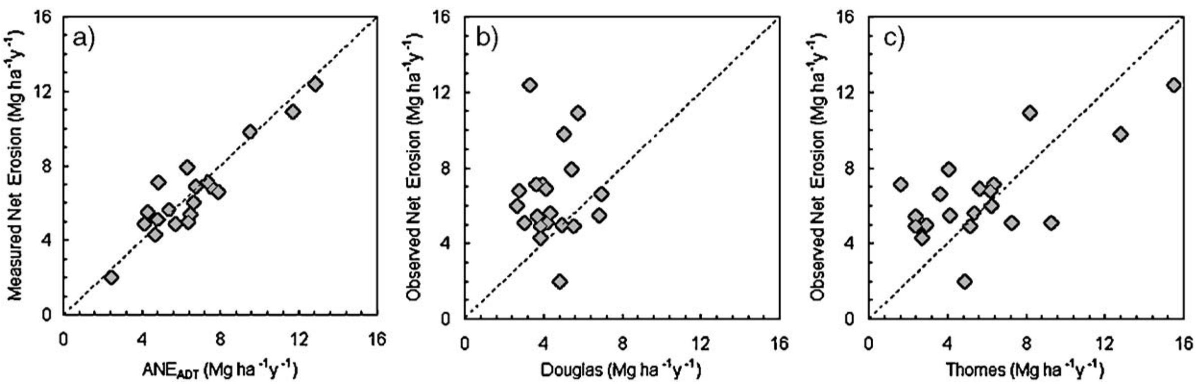


Fig. 4. Dialog box scatterplots of observed and expected net erosion values by $\mathrm{ANE}_{\mathrm{ADT}}$-model (a), Douglas-model (b) and Thornes-model (c).

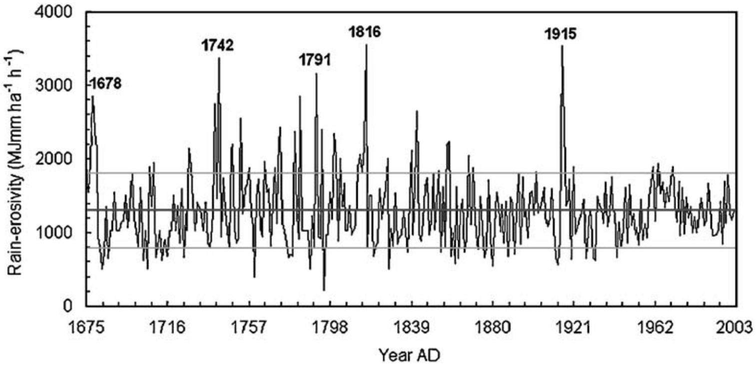


Fig. 5. Chronological series of rain-erosivity (1675–2004) in the Calore River Basin by Diodato and Ceccarelli (2005). Horizontal dashed bold line is the mean value while dotted lines are threshold corresponding to ±1 of the standard deviation (S.D.).

and Rivas, 2004), and affecting the sequence of dry periods and disastrously geomorphologically years.

There is strong relationship between climate–especially annual rainfall–and vegetation pattern (Yang et al., 1998; Li et al., 2004). However, the total annual rainfall amount is mostly not effective in terms of vegetation growth (du Plessis, 1999) under relatively poor vegetation response (e.g., very high rainfall over a short period). To alleviate this uncertainty, a vegetation dynamic function derived from median precipitation where each rain value is dated on the previous 7-years window included the current year was used. Output of this function is shown in Fig. 6a.

Presence of large green vegetation during past time is testified by spreading of woody lands which covered until 16th and 17th centuries very large portions of the CRB, as referred by Dominican Leandro Alberti (Narciso, 1999). However, original vegetation subjected changes due to land human-use (Fig. 7a). Vegetation patterns change is modelled in Figs. 6b and 7b,c again exhibit for 18th century a soft land-use, with vast areas of territory dedicated to wood. The abolition of feudality and the start, in 1806, of an agrarian reform based on the distribution to poor citizens of the feudal and municipal lands, marked for CRB, as moreover for the whole South of Italy, the start of the documented environmental disaster (Rovito, 2001). As a result of these historical records, the cultivation of mountain areas, till then reserved to common pasture, provoked the destroying of woods and, in consequence, the degrade of slopes. To the deforestation, gone on for the whole 19th century, no economic advantages returned: besides being unsuitable to cultivation the “divided” lands were acquired by a parasitic and backward notability, in some ways worse than feudality with particularly serious consequences in the CRB, both on the environmental and social ground.

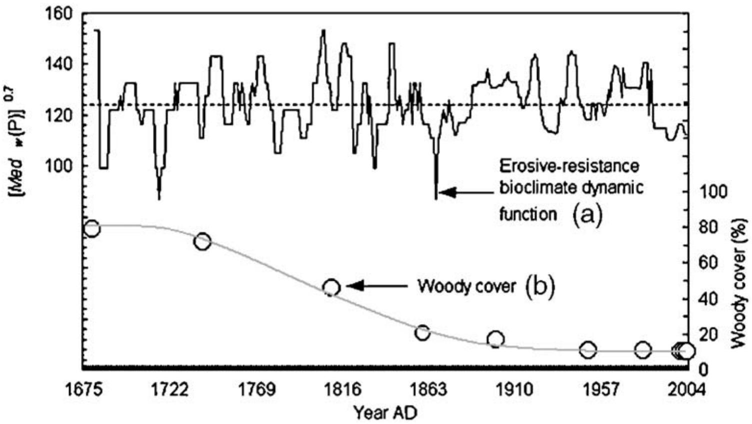


Fig. 6. Evolution of the erosive-resistance bioclimate dynamic function from median precipitation where each rain value is dated on the previous 7-years window included the current year (a) and woody cover by agrarian statistics (circles) with historical reconstruction by mean 5 order polynomial regression (grey line) (b).

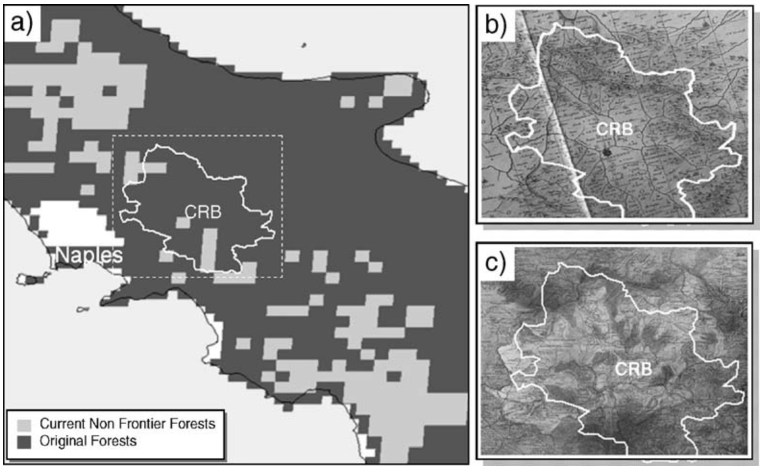


Fig. 7. Original forests map by Global Forest Watch Project—www.globalforestwatch.org (a), historical map dating from the end of the 18th century (b), and the end of the 19th century (c); the spots more dark indicate the woods extension.

### 3.1. Detection of soil erosional changes

Monthly as well as annual measured sediment concentration in 1957–1972 period was highly variable reflecting differences in vegetative, geomorphic, and land use characteristics. Average sediment yields in Volturno basin search a value of 603 MG km$^{-2}$ year$^{-1}$ with a skewed distribution. The highest and lowest sediment yields were of 1240 MG km$^{-2}$ (in 1964 year) and 200 MG km$^{-2}$ (in 1957 year), respectively. Although these values do not provide proof that increased erosion actually occurred, it is however possible to predict them upon the past times using the ANE$_{ADT}$-model outputs. A typical sequence of the processes involving in the soil mobilization from CRB during the 1675–2004 period are depicted in Fig. 8 that illustrates a comprehensive hydroclimatic factors liable to possible feedbacks, which act to augment or dampen response of river systems. In particular, black line illustrates, as in middle of the LIA, that when soils developed mainly under the

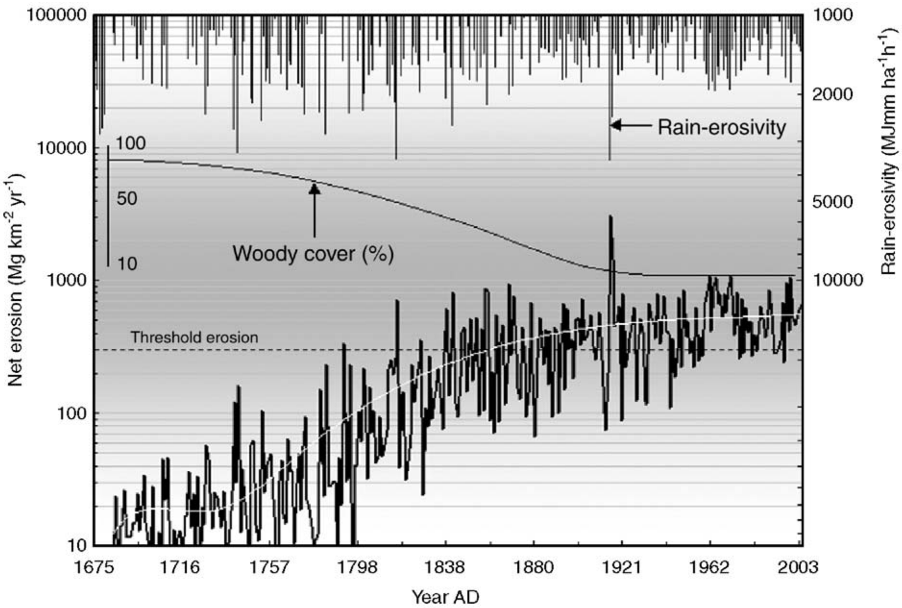


Fig. 8. Reconstructed (ANE$_{ADT}$)-Annual Net Erosion (black bold line) and long-term polynomial fitting (white curve) during 1675–2004 period with rain-erosivity exceeding 1000 MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$ (histogram), vegetation cover (black curve) and precipitation (not shown) superimposed; *Y*-axes are in log-scale.

natural woodlands, net erosion rates were extremely low (about 10 MG km$^{-2}$). At the beginning of the clearance of forest, between AD 1780 and 1810, erosion increased and reached annual rates of about 20–100 MG km$^{-2}$. According to rain-erosivity histogram (always Fig. 8), the successive period (1811–1860) interact with major variations in vegetation, and long-term curve fitting indicates that soil erosion exponentially increases to exceed the threshold rate of 300 MG km$^{-2}$. Sediment yielded in this time-interval are supported from geo-archaeological researches referred by Caiazza et al. (1998, p. 70), which indicate a large progression of the Volturno delta between 1809 and 1883 period. A similar trend is verifiable also in other parts of the Campania region, where a large majority of damage hydrogeomorphological events are documented in the 1805–1860 period (Mazzarella and Diodato, 2002; Parise et al., 2002). These results according to geomorphic response simulations over time-scales ranging from 10 to 100 years (Coulthard et al., 2000), which have showed that decreasing tree cover and increasing rainfall magnitude individually produced similar 25% to 100% increases in sediment discharge, whereas in combination they generated a 1300% rise.

From 1861 in forwards, erosion is suffered to slow but constant and extent new increases with aridity growth (Brunetti et al., 2002; Piccarreta et al., 2004), especially after the 1970 (Bordi and Sutera, 2004) fluctuating around at an average annual rate of about 550 MG km$^{-2}$ year$^{-1}$. Since the protective effect of vegetation decreases with less precipitation and higher evapotranspiration rates, this, in turn, could increases soil susceptibility to erosion in future.

### 3.2. Historical record and landscape evolution

Significant hydrogeomorphological past events have been recorded in journal or diaries. However, these sources provide only a limited picture of the last 400 years. It is possible to use such sources to define the major hydrogeomorphological events on the river. On the Calore basin, for example, pulses of natural sedimentation in the predeforestation period have been related to Vesuvius volcanic activity such as in the years 1631 (Terone, 1954) and 1808–1809 (Nazzaro, 1997), and changes in frequency of rainstorms. During this last episode, deluges and mudflow occurred in November 1809 as supplied by Romanelli in his Diary (Mazzacca, 1992):

> The day 20 of the month of November there was a powerful rain, so continuous from its beginning, it kept on to four o'clock in the night; the stream was the biggest ever seen in the past, (…), the mudflow coming blown the mountain trough the town horrified greatly for stones din, the Calore river broke the bow bridge (…), and flooded only neighbour field in extraordinary way and incredible for the posterity (…).

The sequence of weather and slope reactions repeating from autumn 1815 to summer 1816, when severe conditions (with switches of cold, snow and heavy rain) concerned many Italian region (Iampieri, 1983). After 1830, newspapers have become an important vehicle for recording dramatic events. For example, the major damage hydrogeomorphological events, such as those of September 1857 (Perugini, 1878) and November 1851 (chronicles in Laudato, 1989), were described in detail. Sometimes occupying almost the entire newspapers, such as the report of the agronomist Nicola Albino (Albino, 1870): by describing the frequent torrential rainfall which had caused heavy damage to the hills and valley due to the materials transported downvalley by water, Albino remarks the importance of agricultural practices in favouring the slope susceptibility to erosion:

> The mountains and the hills of Cautano, Solopaca, Paupisi, Cirreto, Pietraroia, Sassinoro and San Marco makes perpetual damage to the plains, and the flows were threatening so much, that the same inhabitants of Tocco Caudio, Apice and Pietrelcina have lost the solid ground due to the continuous fluvial erosion that lap against them. For the wrong mountainous and hilly tillage, as well as we observed, each rivulet turned in flow.

More subtle changes or less dramatic events are not regularly recorded in the historical archive. Thus, while we might know something of the suspected increase in major floods activity during the late LIA (1800–1900), we know relatively little about hillslope erosion and other less geomorphological processes throughout the period. In this context, ANE$_{ADT}$-model results are expected to be very important for homogeneous time-reconstruction of sedimentation processes, including accelerated erosion caused by human activities. In this context, climatic anomalies in CRB show a fluctuating time evolution from 1675 onwards, with alternate stormy and dry period. In this long timescale, differences on mean values are remarkable: in 1798–1919 stormy, and 1710–1797 and 1920–2002 dry periods, with different interaction with vegetation evolution. However, while in the predeforestation period the system resist to changing until threshold values of system parameters are exceeded ($\sigma = \pm 60$ MG km$^{-2}$ year$^{-1}$), in post-deforestation period the system become unstable ($\sigma = \pm 330$ MG km$^{-2}$ year$^{-1}$) with sudden fluctuation in hydrological regime contributing significantly to sediment sequences in depositional estuaries and Tyrrhenian coastal. Deforestation may have caused a number of high-magnitude erosion events according to environmental changes occurs at French catchments in the 18th century (Foster et al., 2003).

More recently, between 1990 and today, events have been characterised mainly by isolated rainstorms, with the exception of November 1997 storm (Diodato, 2005b), and by accelerated erosion driven by intensive arable lands. For example, a rainstorm occurred in 23 October 2002, resulted in an erosivity index of 458 MJ mm ha$^{-1}$ h$^{-1}$, causing substantial erosion, sediment-laden floodwaters deposited, and surface landslides in north-eastern Calore river. Exceptionally forceful events occurred in May 2001, when the erosion was accomplished by a heavy thunderstorm with rainfall of 55 mm and maximum intensity in 30-min periods up to 94 mm h$^{-1}$, and losses of soil greater than 200 Mg ha$^{-1}$ in tillage fields at farm Monte Pino (middle Calore river). Similarly, the intense May and July thunderstorms in 1999. May and June 2000 appear to have had great effect on arable land, as did the downpours in June 2003.

## 4. Conclusions

Model results in the Calore basin case study predict strong increased sedimentation after the deforestation confirming the existence of an unrestrainable envirocli-matic changes during the last phase of the Little Ice Age (1780–1900). The results suggest that the response of basin to climate change is highly contingent upon local land-cover conditions too, and that the land-use had a more dramatic increase on erosion rates than to the natural time variability. Particularly vulnerable are hilly and valley areas of Calore basin agroecosystem, where high rainfall erosivities are coupled with reduction of the vegetation-cover at the end of Spring and at beginning of Autumn. Unfortunately, the model used in this paper was not able to capture seasonal variability, so that future studies could include it. It should also be noted that the results presented in this paper derive from model calibration and no validation has been carried out at this stage of the study, except of qualitative and indirect historical data.

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## References

Alexandrov, V.A., 1997. Vulnerability of agronomic systems in Bulgaria. Climatic Change 36, 135–149.

Albino, N.O., 1870. Relazione sullo stato dell'agricoltura della provincia e sui lavori della direzione e dei socii del Comizio Agrario di Benevento per l'anno 1869. Bollettino dei Comizi Agrari dei Circondari di Benevento, Cerreto e S. Bartolomeo in Galdo, pp. 66–68, 77.

Arnaud-Fassetta, G., Provansal, M., 1999. High frequency variations of water flux and sediment discharge during the little ice age (1586–1725 AD) in the Rhone Delta (Mediterranean France). Relationship to the catchment basin. Hydrobiologia 410, 241–250.

Aronica, G., Ferro, V., 1997. Rainfall erosivity over the Calabrian region. Hydrological Sciences Journal 42 (1), 35–48.

Beavis, S.G., Zhang, L., Jakeman, A.J., Gray, S.D., 1999. Erosional history of the Warrah catchment in the liverpool plains, New South Wales. Hydrological Processes 13, 753–761.

Blasi, C., Paura, B., Mazzoleni, S., 1988. Proposta per una regionalizzazione fitoclimatica della Regione Campania, Proceedings of the 2° "Methodological Approaches for the Explanation of the Mediterranean Physical and Biological Environment", Lecce 15–17 November 1988, Orantes editions, pp. 63–82.

Bordi, I., Sutera, A., 2004. Drought variability and its climatic implications. Global and Planetary Change 40, 115–127.

Bradley, R.S., Jones, P.D., 1993. Little Ice Age summer temperature variations: their nature and relevance to recent global warming trend. The Holocene 3, 367–376.

Bradley, R.S., Briffa, K.R., Cole, J., Hughes, M.K., Osborn, T.J., 2003. The climate of the last millennium. In: Alverson, K., Bradley, R.S., Pedersen, T.F. (Eds.), Paleoclimate, Global Change and the Future. Springer-Verlag, Berlin, pp. 105–141.

Brooks, A.P., Brierley, G.J., 1997. Geomorphic responses of lower Bega River to catchment disturbance, 1851–1926. Geomorphology 18, 291–304.

Brunetti, M., Maugeri, M., Nanni, T., Navarra, A., 2002. Droughts and extreme events in regional daily Italian precipitation series. International Journal of Climatology 22, 543–558.

Buondonno, C., Danise, B., Leone, A.P., Tedeschi, P., Terribile, F., 1989. Carta dei suoli della C.M. "Fortore Beneventano". Annali Facoltà di Agraria, Portici, Serie IV (23), 20–33.

Caiazza, D., Guadagno, G., Ortolani, F., Pagliuca, S., 1998. Environclimatic fluctuations and consequences socio-economic in the 'Alta Terra di Lavoro' between ancientness and middle age. Le Scienze della Terra e l'Archeometria, vol. 7, pp. 66–74 (in Italian).

Camuffo, D., Enzi, S., 1992. Critical analysis of archive sources for historical climatology of Northern Italy. In: Frenzel, B., Pfister, C., Glaser, B. (Eds.), European Climate Reconstructed from Documentary Data: Methods and Results. Gustav Fischer Verlag, Stuttgart, Jena, New York, pp. 65–74.
Cavazos, T., Rivas, D., 2004. Variability of extreme precipitation events in Tijuana, Mexico. Climate Research 25, 229–243.
Coppus, R., Imeson, A.C., 2002. Extreme events controlling erosion and sediment transport in a semi-arid sub-Andean Valley. Earth Surface Processes and Landforms 27, 1365–1375.
Coulthard, T.J., Kirkby, M.J., Macklin, M.G., 2000. Modelling geomorphic response to environmental change in an upland catchment. Hydrological Processes 14, 2031–2045.
Coulthard, T.J., Macklin, M.G., Kirkby, M.J., 2002. A cellular model of Holocene upland river basin and alluvial fan evolution. Earth Surface Processes and Landforms 27, 269–288.
David, C., Dearing, J., Roberts, N., 1998. Land-use history and sediment flux in a lowland lake catchment: groby pool, Leicestershire, UK. The Holocene 8 (4), 383–394.
Delmonaco, G., Margottini, C., Serafini, S., 2000. Climate change impact on frequency and distribution of natural extreme events: an overview. Floods and Landslides, vol. 3, pp. 50–70.
Del Re, G., 1836. Descrizione della provincia del Molise, Napoli, p. 41. e ss.
de Vente, J., Poesen, J., Verstraeten, G., 2005. The application of semi-quantitative methods and reservoir sedimentation rates for the prediction of basin sediment yield in Spain. Journal of Hydrology 305, 63–86.
Diodato, N., 1999. Historical reconstruction of extreme hydrometeorological events in the Sannio Beneventano from Medieval epoch to 1998. Bollettino Geofisico, AGI-Research National Council 22 (3/4), 5–39 (in Italian).
Diodato, N., 2004. Estimating RUSLE's rainfall factor in the part of Italy with a Mediterranean rainfall regime. Hydrology and Earth System Sciences 8 (1), 103–107.
Diodato, N., 2005a. Influence of topographic co-variables on the spatial variability of precipitation over little regions of complex terrain. International Journal of Climatology 25, 351–363.
Diodato, N., 2005b. Geostatistical uncertainty modelling for the environmental hazard assessment during single erosive rainstorm events. Environmental Monitoring and Assessment 105 (1–3), 25–42.
Diodato, N., in press. Climatic fluctuations in Southern Italy since 17th century: reconstruction with precipitation records at Benevento. Accepted on Climatic Change.
Diodato, N., Ceccarelli, M., 2005. Erosive rainfall reconstruction since 1580 AD in Calore River Basin (Southern Italy). SCODA Report, University of Sannio. Available on line at: http://www.scoda.unisannio.it/Papers/Archive/Diodato_R_reconstruction%20in%20CRB.pdf.
Diodato, N., Russo, F., 2003. A geostatistical approach to the mapping of rainstorm hazard in the Sannio district of the Campania Apennines—Southern Italy. Geografia Fisica e Dinamica Quaternaria 26, 35–40.
Dotterweich, M., Schmitt, A., Schmidtchen, G., Bork, H.R., 2003. Quantifying historical gully erosion in northern Bavaria. Catena 50, 135–150.
Douglas, I., 1967. Man, vegetation and sediment yield of rivers. Nature 215, 925–928.
D'Odorico, P., Yoo, J., Over, T.M., 2001. An assessment of ENSO-induced patterns of rainfall erosivity in the Southwestern United States. Journal of Climate 14, 4230–4242.
du Plessis, W.P., 1999. Linear regression relationships between NDVI, vegetation and rainfall in Etosha National Park, Namibia. Journal of Arid Environments 42, 235–260.
Eden, D.N., Page, M.J., 1998. Palaeoclimatic implication of a storm erosion record from late Holocene lake sediments, North Island, New Zealand. Palaeogeography, Palaeoclimatology, Palaeoecology 139, 37–58.
Evans, M., Slaymaker, O., 2004. Spatial and temporal variability of sediment delivery from alpine lake basins, Cathedral Provincial Park, southern British Columbia. Geomorphology 61, 209–224.
Favis-Mortlock, D., Boardman, J., 1995. Nonlinear responses of soil erosion to climate change: a modelling study on the UK South Downs. Catena 25, 365–387.
Follieri, M., Magri, D., Narcisi, B., 1993. Paleoenvironmental investigations on long sediment cores from volcanic lakes of Lazio (Central Italy). An overview. In: Negendank, J.F.W., Zolitschka, B. (Eds.), Paleolimnology of European Maar Lakes. Lecture Notes Earth Sci., vol. 49. Springer-Verlag, Berlin, pp. 95–107.
Foody, G.M., 2003. Geographical weighting as a further refinement to regression modelling: an example focused on the NDVI–rainfall relationship. Remote sensing of Environment 88, 283–293.
Foster, D.L., 2001. Fine Particulate Sediment Transfer in Lowland Rural Environments. In: Higgitt, D.L., Lee, E.M. (Eds.), Geomorphological Processes and Landscape Change. Blackwell Publishing, Canada, pp. 215–236.
Foster, G.C., Dearing, J.A., Jones, R.T., Crook, D.S., Siddle, D.J., Harvey, A.M., James, P.A., Appleby, P.G., Thompson, R., Nicholson, J., Loizeau, J.-L., 2003. Meteorological and land use controls on past and present hydro-geomorphic processes in the pre-alpine environment: an integrated lake-catchment study at the Petit Lac d'Annecy, France. Hydrological Processes 17, 3287–3305.
Galanti, M.G. Description of the ancient and present condition of the Molise rural Naples, pp. 50–70 (in Italian).
Garcia-Oliva, F., Maass, J.M., Galicia, L., 1995. Rainstorm analysis and rainfall erosivity of a seasonal tropical region with a strong cyclonic influence on the Pacific Coast of Mexico. Journal of Applied Meteorology 34, 2491–2498.
Goosse, H., Renssen, H., Timmermann, A., Raymond, S.B., 2005. Internal and forced climate variability during the last millennium: a model-data comparison using ensemble simulations. Quaternary Science Review 24, 1345–1360.
Grist, J., Nicholson, S.E., Mpolokang, A., 1997. On the user of NDVI for estimating fields in the Kalahari of Botswana. Journal of Arid Environments 35, 195–214.
Grove, A.T., 2001. The "Little Ice Age" and its geomorphological consequences in Medieterranean Europe. Climate Change 48, 121–136.
Higgitt, D.L., 2001. A brief time of history. In: Higgitt, D.L., Lee, E.M. (Eds.), Geomorphological Processes and Landscape Change. Blackwell Publishing, Canada, pp. 1–26.
Huang, C.C., O'Connell, M., 2000. Recent land-use and soil-erosion history within a small catchment in Connemara, western Ireland: evidence from lake sediments and documentary sources. Catena 41 (4), 293–335.
Hunt, A.G., Wu, J.Q., 2004. Climatic influences on Holocene variations in soil erosion rates on a small hill in the Mojave Desert. Geomorphology 58, 263–289.
Hurrell, J.W., 1995. Decadal trends in the North Atlantic Oscillation and relationships to regional temperature and precipitation. Science 269, 676–679.

Iampieri, A., 1983. The famine of the 1817 in the Vibrata and Salinello valley. Tip. Duemila, Masciano Sant'Angelo (Teramo), pp. 11–17 (in Italian).

Instanbulluoglu, E., Tarboton, D.G., Pack, R.T., Luce, C.H., 2004. Modeling of the interaction between forest vegetation, disturbances, and sediment yield. Journal of Geophysical Research 109, F01009. doi:10.1029/2003JF000041.

Isaaks, E.H., Srivastava, R.M., 1989. An Introduction to Applied Geostatistic. Oxford University Press, New York.

Jacobeit, J., Glaser, R., Luterbacher, J., Wanner, H., 2003. Links between flood events in Central Europe since AD 1500 and large-scale atmospheric circulation nodes. Geophysical Research Letters 30 (4). doi:10.1029/2002GL016433.

Kirkby, M.J., Cox, N.J., 1995. A climatic index for soil erosion potential (CSEP) including seasonal and vegetation factors. Catena 25, 333–352.

Kirkby, M.J., Abrahart, R., McMahon, M.D., Shao, J., Thornes, J.B., 1998. MEDALUS soil erosion models for global change. Geomorphology 24, 35–49.

Krishnaswamy, J., Lavine, M., Richter, D.D., Korfmacher, K., 2000. Dynamic modeling of long-term sedimentation in the Yadkin River basin. Advances in Water Resources 23, 881–892.

Lalli, R., 1965. L'economia del Molise nel settecento. Samnium 38 (1–2), 17–37.

Lamoureux, S., 2002. Temporal patterns of suspended sediment yield following moderate to extreme hydrological events recorded in varved lacustrine sediments. Earth Surface Processes and Landforms 27, 1107–1124.

Lane, L.J., Hernandez, M., Nichols, M., 1997. Processes controlling sediment yield form watersheds as functions of spatial scale. Environmental Modelling and Software 12 (4), 355–369.

Larson, W.E., Lindstrom, M.J., Schumacher, T.E., 1997. The role of severe storms in soil erosion: a problem needing consideration. Journal of Soil and Water Conservation 52 (2), 90–95.

Lasanta, T., Arnaez, J., Oserin, M., Ortigosa, L.M., 2001. Marginal lands and erosion in terraced fields in the Mediterranean mountains. Mountain Research and Development 21 (1), 69–76.

Laudato, A., 1989. A memoirs book. Cultural Institute for Rural Society Study in the Samnium, Campolattaro—Benevento (in Italian).

Leeder, M.R., Harris, T., Kirkby, M.J., 1998. Sediment supply and climate change: implications for basin stratigraphy. Basin Research 10 (1). doi:10.1046/j.1365-2117.1998.00054.x.

Lespez, L., 2003. Geomorphic responses to long-term land use changes in Eastern Macedonia (Greece). Catena 51, 181–208.

Leone, A.P., Tedeschi, P., Wrigt, G.G., Fragnito, F., 1996. Landsat satellite data for soil investigations in an Apennines region of southern Italy. Geografia Fisica e Dinamica Quaternaria 19, 371–380.

Li, J., Lewis, J., Rowland, J., Tappan, G., Tieszen, L.L., 2004. Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series. Journal of Arid Environments 59, 463–480.

Lockwood, J.G., 2001. Abrupt and sudden climatic transitions and fluctuations: a review. International Journal of Climatology 21, 1153–1179.

Massafra, A., 1984. Campagne e territorio nel Mezzogiorno fra Settecento e Ottocento, Dedalo, Bari.

Mazzacca, V., 1992. In: AGM (Ed.), River. The Floods in the Samnium, Fish Fauna, Fishing and Pollution. Benevento (in Italian).

Mazzarella, A., Diodato, N., 2002. The alluvial events in the last two centuries at Sarno, southern Italy: their classification and power-law time-occurrence. Theoretical and Applied Climatology 72, 75–84.

Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., Styczen, E., 1998. The European soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchment. Earth Surface Processes and Landforms 23, 527–544.

Mulligan, M., 1998. Modelling the geomorphological impact of climatic variability and extreme events in a semi-arid environment. Geomorphology 24, 59–78.

Mulligan, M., Wainwright, J., 2004. Modelling and model building. In: Wainwright, John, Mulligan, Mark (Eds.), Environmental Modelling. John Wiley and Sons, Ltd., Chichester, pp. 7–73.

Narciso, E., 1999. The territory of 'Santa Croce'. Agricultural Activity and Until Utensil in 'Santa Croce del Sannio', Istituto Storico Giuseppe M. Galanti, pp. 9–26 (in Italian).

Nazzaro, A., 1997. In: Liguore (Ed.), The Vesuvius. Eruptive History and Volcanological Theory (in Italian).

Nearing, M.A., 2004. Soil erosion and conservation. In: Wainwright, John, Mulligan, Mark (Eds.), Environmental Modelling. John Wiley and Sons, Ltd., Chichester, pp. 277–290.

Ogilvie, A.E.J., Jonsson, T., 2001. Little ice age research: a perspective from Iceland. Climatic Change 48, 9–52.

Orbock Miller, S., Ritter, D.F., Craig Kochel, R., Miller, J.R., 1993. Fluvial responses to land-use changes and climatic variations within the Drury Creek watershed, southern Illinois. Geonorphology 6 (4), 309–329.

Orsi, S., 1956. La sistemazione dei terreni nell'alto bacino del Fortore. L'Italia Forestale e Montana 11, 29–35.

Orwin, J.F., Smart, C.C., 2004. The evidence for paraglacial sediment ant its temporal scale in the deglacierizing basin of small river Glacier, Canada. Geomorphology 58, 175–202.

Parise, M., Calcaterra, D., Palma, B., 2002. Historical data analysis of landsliding and flood events in Campania (Italy), as a tool for the assessment of the landslide hazard. In: Rybar, J., Stemberk, J., Wagner, P. (Eds.), Landslides. Swets and Zeitlinger, Lisse, pp. 259–267.

Perugini, D., 1878. In: Del Progresso (Ed.), Pontelandolfo Monograph. Campobasso (in Italian).

Peterson, T.C., Taylor, M.A., Demeritte, R., Duncombe, D.L., Burton, S., Thompson, F., Porter, A., Mercedes, M., Villegas, E., Semexant Fills, R., Tank, A.K., Martis, A., Warner, R., Loyette, A., Mills, W., Alexander, L., Gleason, B., 2002. Recent changes in climate extremes in the Caribbean region. Journal of Geophysical Research 107 (D21). doi:10.1029/2002JD002251.

Piccarreta, M., Capolongo, D., Boenzi, F., 2004. Trend analysis of precipitation and drought in Basilicata from 1923 to 2000 within a southern Italy context. International Journal of Climatology 24, 907–922.

Piegay, H., Walling, D.E., Landon, N., He, Q., Liebault, F., Petiot, R., 2004. Contemporaney changes in sediment yield in an alpine mountain basin due to afforestation (the upper Drone in France). Catena 55, 183–212.

Prózynska-Bordas, H., Stanska-Prózynska, W., Prózynska, M., 1992. TL dating of river terraces with fossil soils in Mediterranean region. Quaternary Science Reviews 11, 53–60.

Ramos, M.C., Mulligan, M., 2003. Impacts of climate variability and extreme events on soil hydrological processes. Geophysical Research 5, 92–115.

Reinhard, M., Alexakis, E., Rebetez, M., Schlaepfer, R., 2003. Climate–soil–vegetation interaction: a case-study from the forest fire phenomenon in Southern Switzerland. Geophysical Research 5, 24–70.

Ramrath, A., Negendank, J.F.W., Sadori, L., 2000. Sediments from Lago di Mezzano, central Italy: A record of Lateglacial/Holocene climatic variations and anthropogenic impact. The Holocene 10 (1), 87–95.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting Soil Erosion by Water: a Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA, Agricultural Handbook, vol. 703. 384 pp.

Renschler, C., Harbor, J., 2002. Soil erosion assessment tools from point to regional scales the role of geomorphologists in land management research and implementation. Geomorphology 47 (2–4), 189–209.

Riebau, A.R., Fox, D.G., 2005. Damage assessment of agrometeorological relevance from natural disasters: economic and social consequences. In: Sivakumar, M.V.K., Motha, R.P., Das, H.P. (Eds.), Natural Disasters and Extreme Events in Agriculture. Springer, The Netherlands, pp. 119–135.

Rovito, P.L., 2001. From the 'amusing woods' to the 'sterile and slid' plains. Notes about the environment disaster in Campania. Rivista Storica del Sannio 16 (2), 297–338 (in Italian).

Rumsby, B.T., 2001. Valley-floor and floodplain processes. In: Higgitt, D.L., Lee, E.M. (Eds.), Geomorphological Processes and Landscape Change. Blackwell Publisher, Oxford UK, pp. 90–115.

Rumsby, B.T., Macklin, M.G., 1996. River response to the last neoglacial (the 'Little Ice Age') in northern, western and central Europe. In: Branson, J.B., Gregory, K.J. (Eds.), Global Continental Change: the Context of Paleohydrology. Geological Society Special Publication, vol. 115, pp. 217–233.

Schmidt, J., Dikau, R., 2004. Modeling historical climate variability and slope stability. Geomorphology 60, 433–447.

Schulte, L., 2002. Climatic and human influence on river systems and glacier fluctuations in southeast Spain since the last glacial maximum. Quaternary International 93/94, 85–100.

Sereni, E., 1996. Storia del paesaggio agrario italiano. Biblioteca Universale Laterza, Bari.

Shrestha, D.P., Zinck, J.A., Van Ranst, E., 2004. Modelling land degradation in the Nepalese Himalaya. Catena 57, 135–156.

SICI, 2001. Information system on the hydrogeological catastrophes. In: Bianchi, C., Cipolla, F., Guzzetti, F., Lolli, O., Pagliacci, S., Reichenback, P., Salvati, P., Sebastiani, C., Tonelli, G. (Eds.), Historical Archival. Researches National Council, Perugia.

SIMN, 1922–2004. Hydrological Annals. Servizio Idrografico and Mareografico Nazionale Italiano (in Italian).

SIMN, 1957–1972. Hydrological Annals. Servizio Idrografico and Mareografico Nazionale Italiano (in Italian).

Sivakumer, M.V.K., 2005. Impacts of natural disasters in agriculture, rangeland and forestry: an overview. In: Sivakumar, M.V.K., Motha, R.P., Das, H.P. (Eds.), Natural Disasters and Extreme Events in Agriculture. Springer, The Netherlands, pp. 1–22.

Slaymaker, O., Souch, C., Menounos, B., Filippelli, G., 2003. Advances in Holocene mountain geomorphology inspired by sediment budget methodology. Geomorphology 55, 305–316.

Slonosky, V.C., Jones, P.D., Davies, T.D., 2000. Variability of the surface atmospheric circulation over Europe, 1774–1995. International Journal of Climatology 20, 1875–1897.

Soon, W., Baliunas, S., 2003. Proxy climatic and environmental changes of the past 1000 years. Climate Research 23 (2), 89–110.

Stehr, N., von Storch, H., 1995. The social construct of climate and climate change. Climate Research 5 (2), 99–105.

Terone, P.G., 1954. In: Abete (Ed.), Mercy Saint Marie in Benevento. Chronicle of the Temple and Monastery from Origin Today. Benevento (in Italian).

Thomas, M.F., 2001. Landscape sensitivity in time and space—an introduction. Catena 42 (2–4), 83–98.

Thornes, J.B., 1990. The intercation of erosional and vegetational dynamics in land degradation: spatial outcomes. In: Thornes, J.B. (Ed.), Vegetation and Erosion. Jonh Wiley and Sons, pp. 45–55.

Thornes, J., 1995. Global environmental change and regional response: the European Mediterranean. Transaction Institute British Geographers, vol. 20, pp. 357–367.

Toy, T.J., Foster, G.R., Renard, K.G., 2002. Soil Erosion; Prediction, Measurement, and Control. John Wiley and Sons, Inc., New York.

van der Knijff, J.M., Jones, R.J.A., Montanarella, L., 2000. Soil Erosion Risk Assessment in Italy. European Commission—European Soil Bureau. 52 pp.

Van Rompay, A.J.J., Govers, G., Puttemans, C., 2002. Modelling land use changes and their impact on soil erosion and sediment supply to rivers. Earth Surface Processes and Landforms 27, 481–494.

Verstraeten, G., Poesen, J., 2001. Factors controlling sediment yield from small intensively cultivated catchment in a temperate humid climate. Geomorphology 40, 123–144.

Viles, H.A., Goudie, A.S., 2003. Interannual, decadal and multidecadal scale climatic variability and geomorphology. Earth-Science Reviews 61, 105–131.

Wainwright, J., Mulligan, M. (Eds.), 2004. Environmental Modelling. John Wiley and Sons, Ltd., Chichester, p. 8.

Wang, J., Rich, P.M., Price, K.P., 2003. Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. International Journal of Remote Sensing 24, 2345–2364.

Wick, L., Lemcke, G., Sturm, M., 2003. Evidence of lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. The Holocene 13 (5), 665–675.

Wilby, R.L., Dalgleish, H.Y., Foster, D.L., 1997. The impact of weather patterns on historical and contemporary catchment sediment yield. Earth Surface Processes and Landforms 22, 353–363.

Wischmeier, WH., Smith, D.D., 1958. Rainfall energy and is relationship to soil loss. Transactions - American Geophysical Union 39 (2), 285–291.

Yang, L., Wylie, B.K., Lieszen, L.L., Reed, B.C., 1998. An analysis of relationships among climate forcing and time-integrated NDVI of grassland over the U.S. Northern and Central Great Plains. Remote Sensing and Environment 65, 25–37.

Zolitschka, B., 1998. A 14,000 year sediment yield record from western Germany based on annually laminated lake sediments. Geomorphology 22 (1), 1–17.