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Estimating Long to Short-Term Erosion Rates of Fluvial *vs* Mass Movement Processes: An Example from the Axial Zone of the Southern Italian Apennines

Maurizio Lazzari[1*], Marcello Schiattarella[2]

[1]*CNR-Istituto per i Beni Archeologici e Monumentali*
Contrada Santa Loja, Zona Industriale, 85050 Tito Scalo (Potenza), Italy
[2]*Dipartimento di Scienze Geologiche, Università della Basilicata*
Via dell'Ateneo Lucano 10, 85100 Potenza, Italy

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Abstract

Estimates of erosion rates related to fluvial and landslides processes have been performed for several temporal ranges on the basis of different viable methods. The study area includes three catchment sub-basins of the north-eastern flank of the Agri Valley, a tectonically active morpho-structural low located in the axial zone of the southern Apennines and affected by desertification processes in its middle part. Long and mid-term rates have been estimated evaluating the missing volume of eroded rocks, on the grounds of GIS-aided calculations linked to geomorphological markers corresponding to ancient base-levels of the erosion. Short-term rates have been calculated converting the parameter related to the turbid transport of streams (*Tu*), derived from the quantitative geomorphic analysis, adopting an average value for the specific weight of the outcropping rocks, Such an approximation has to be considered acceptable because of the presence of conditions of lithological homogeneity in two of the chosen basins. In the light of this, the third basin, characterized by a certain geological heterogeneity, has been assumed as test-site with regard to the other two sub-basins. The average value of the long-term erosion rate from the entire study area is 0.25 mm/y, mainly due to fluvial processes. The comparison of the erosion rates related to the fluvial network activity from early Pleistocene to Present with those related to the mass movements occurred in a more recent (and shorter) time-span indicates that mass movements contribute just for the 1% of the whole erosion estimated in the two homogeneous basins, but they refer to a short time-span (10 ky to Present). A theoretical extrapolation to the past (0.5 to 1 My) allows to consider the contribution of landslides to the total erosion inside the catchment areas as almost equal to the fluvial aliquot. The conversion of the *Tu* values shows that the short-term rates are generally greater than the rates calculated on the basis of the "volumetric" method, being the average value about 0.46 mm/y. This may mean that the present-day trend of the linear erosion rate could increase respect to the long- and mid-term trend as a response to climate triggering (i.e. more rainfalls and/or sediment supply), or simply represent an instantaneous trivial fluctuation in the long-lasting behavior of the fluvial nets under variable climate conditions. The comparison of all these data with the uplift rates calculated on a regional scale (0.6-1.1 mm/y) confirms that the southern Apennines may represent a non-steady state system.

Key-words: geomorphology, erosion rate, landslide, GIS-aided calculations, southern Italy.

1. Introduction

Three catchment sub-basins of the Agri Valley, a tectonically active morpho-structural low located in the axial zone of the southern Apennines (Giano et al., 2000; Boenzi et al., 2004; Capolongo et al., 2005) and affected by desertification processes in its middle part (Basso et al., 2000), have been studied from a geomorphological point of view to compare the erosion rates related to the fluvial network activity from early Pleistocene to Present with those related to the mass movements occurred in a more recent (and shorter) time-span. The sampled area is about 70 km^2 wide and includes the adjacent hydrographic basins of the Rifreddo, Casale and Alli rivers, sited in the north-eastern flank of the upper valley. This choice has been driven by

* Corresponding Author: Tel.: +39 0971 427326; Fax: +39 0971 206277. E-mail address: m.lazzari@ibam.cnr.it; marcello.schiattarella@unibas.it.

the following criteria: i) position of the basins in the chain; ii) lithological homogeneity of two of them, constituted by flysch units (Rifreddo and Casale basins), and geological heterogeneity of the third one (Alli River basin), assumed as test-site with regard to the other two sub-basins; iii) same hierarchic rank (V order). The study area is characterized by morphogenetic processes, including superficial and deeper mass movements (Monaco, 1991), strongly controlled by neo-tectonic activity (Giano et al., 2000; Capolongo et al., 2005).

The geomorphic quantitative analysis has been addressed to the evaluation of the eroded rock volumes by both fluvial and landslide processes. Estimates of the volumes eroded during different time-spans (using the terraced surfaces as age constraints, cf. Schiattarella et al., 2004) have been obtained by a surface analysis special function applied to a GIS platform based on a geo-database of field and multi-temporal aerial-photo-interpreted data. This allowed the calculation of different erosion rates for different Quaternary time intervals and their comparison with the regional uplift and erosion rates from literature relative to southern Italy (Schiattarella et al., 2006, 2008, and references therein).

2. Geological setting and geomorphological features

The geological backbone of the study area (Fig. 1) is constituted by Mesozoic pelagic units (Lagonegro units, Scandone, 1972; D'Argenio et al., 1973; Pescatore et al., 1999; Di Leo et al., 2002; Tanner et al., 2006, and references therein) unconformably covered by Miocene syn-orogenic formations (Albidona and Gorgoglione Fms, Carbone et al., 1991). In the neighbourhood of the Viggiano village, the Mesozoic shallow-water limestone of the Campania-Lucania Platform (D'Argenio et al., 1973) thrust the Lagonegro units forming the Mt. S. Enoc - Mt. Caldarosa ridge.

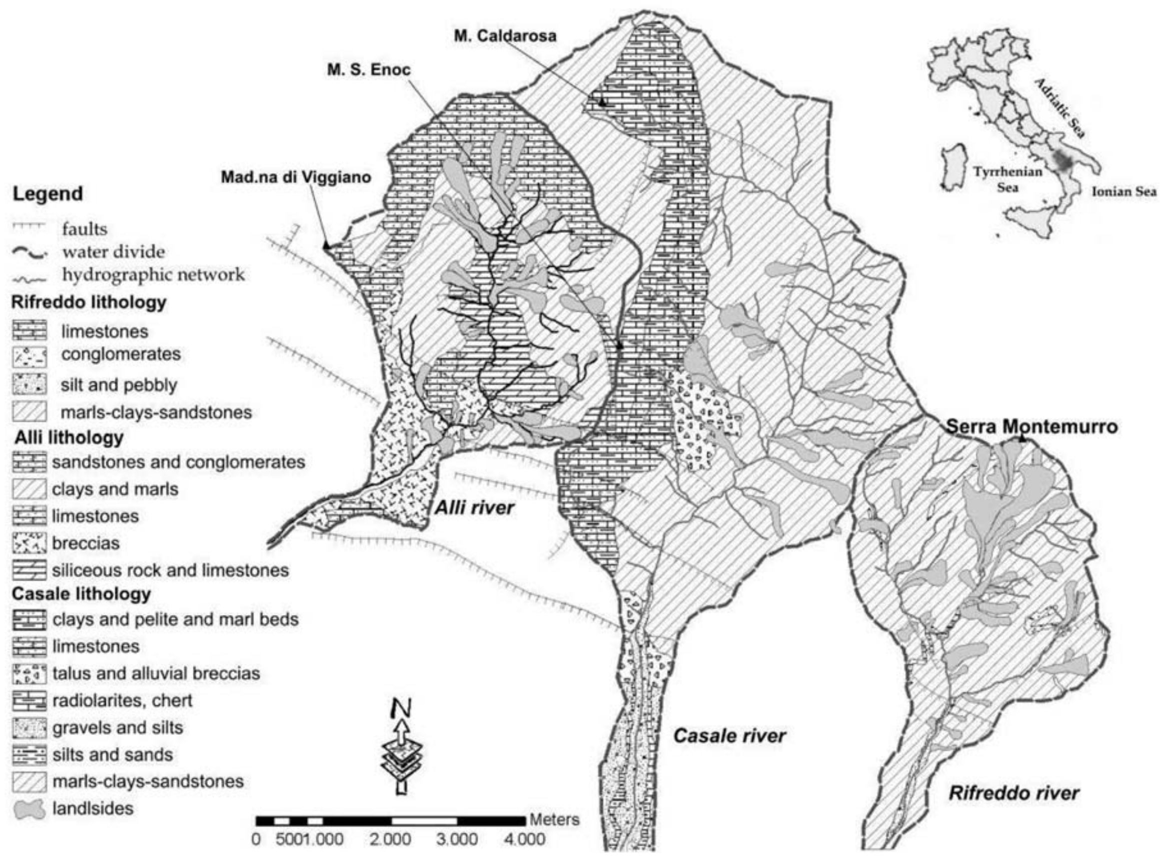

Figure 1. Geolithological map of the studied hydrographical basins and their location in southern Italy.

The upper valley of the Agri River is a N-S to NW-SE trending morpho-structural low, characterized by an articulated planimetric geometry and entirely bordered by faults. In particular, the north-eastern side of the valley is severely affected by the structures of the Quaternary brittle tectonics (Di Niro and Giano, 1995; Giano et al., 1997, 2000; Cello et al., 2000), generating a staircase profile of the slopes and strongly controlling the geomorphological evolution of this flank of the basin. Such structures are expressed by left-lateral strike-slip faults, reactivated as normal faults in mid-Pleistocene times on a regional scale (Schiattarella, 1998). They show the major morphological evidence in correspondence of the Galaino-Marsicovetere-Viggiano alignment (Boenzi et al., 2004).

The top of the ridges of the study area is often characterized by flat or scarcely waved land surfaces related to morphological relics of an huge ancient low-potential topography. Since they cut stratigraphic successions and different kinds of tectonic structures, it is possible to interpret them as erosional surfaces linked to ancient base-levels of the erosion. Such land surfaces are diffused in all the sector of the orogenic belt and grouped in several orders, the higher and older of which is commonly known as *Paleosuperfice* or summit palaeosurface (Brancaccio et al., 1991; Russo and Schiattarella, 1992; Amato and Cinque, 1999; Schiattarella et al., 2003; Amato et al., 2003; Martino and Schiattarella, 2006; Putignano and Schiattarella, 2008; Martino et al., 2009, among others).

3. Erosion rates calculations

Long lasting geomorphological researches (Ciccacci et al., 1980, 1986, 2003; Del Monte et al., 2002; Del Monte, 2003; Della Seta et al., 2007) produced many data about denudation rates from some of the major catchments of central Italy. It was observed a noticeable spatial variability of the "denudation index" (*Tu*) values (Ciccacci et al., 1980).

In order to calculate the erosion rates related to the fluvial processes acting in the past and still working in the three catchment basins investigated in this study, two methods have been here used: the first allows to attain long-term fluvial erosion rates on the basis of the evaluation of rock volumes eroded during the last 1.8 My; the second approach is suitable to the inference of short-term fluvial erosion rates through the assessment of the suspended sediment yield (*Tu*).

The morpho-tectonic analysis of the study area, integrated by GIS-aided topographic calculation techniques, aimed to evaluate the volumes eroded by streams and relative rates from early Pleistocene to Present, then compared with those due to landslides occurred in a more recent (and shorter) time-span and also matched with the regional uplift rates from literature (Schiattarella et al., 2003; 2006, and references therein).

3.1 Long-term fluvial erosion rate

The erosional land surfaces of the study area are arranged in several orders, included in a wide altitudinal range (750 to 1720 m a.s.l.), dissected by fluvial incision and displaced by high-angle faults. The greater remnants are distributed mainly along the water divides, whereas minor fragments are observable inside the catchments: they have been grouped in four orders (S1 to S4 in Figure 2, after Lazzari and Schiattarella, 2008). The attribution of the land surfaces to the different orders has been achieved taking into account their altitudinal arrangement (Fig. 3), also considering the displacement and the consequent morphological reworking of the summit palaeosurface, in agreement with the previous studies performed in the upper Agri Valley (Giano and Schiattarella, 2002; Schiattarella et al., 2003, 2006; Boenzi et al., 2004; Capolongo et al., 2005). The ages of the morphological deactivation (i.e. tectonic uplift) of the land surfaces as base-levels (Tab. 1) have been used to calculate the erosion rates of the study area for different temporal ranges (Tabs. 2 and 3), according to the method proposed by Schiattarella et al. (2004).

The field surveyed and multi-temporal aerial-photo-interpreted geomorphological data (inventory landslide map, distribution and classification of ancient erosive surfaces, morphotectonic features, lithology) has been georeferenced in a Gauss-Boaga coordinate system and analyzed in a geodatabase including linear and areal elements. The topographic base map (1:10000 scale) permitted to create a DEM for each sub-basis, whereas a special function ("area

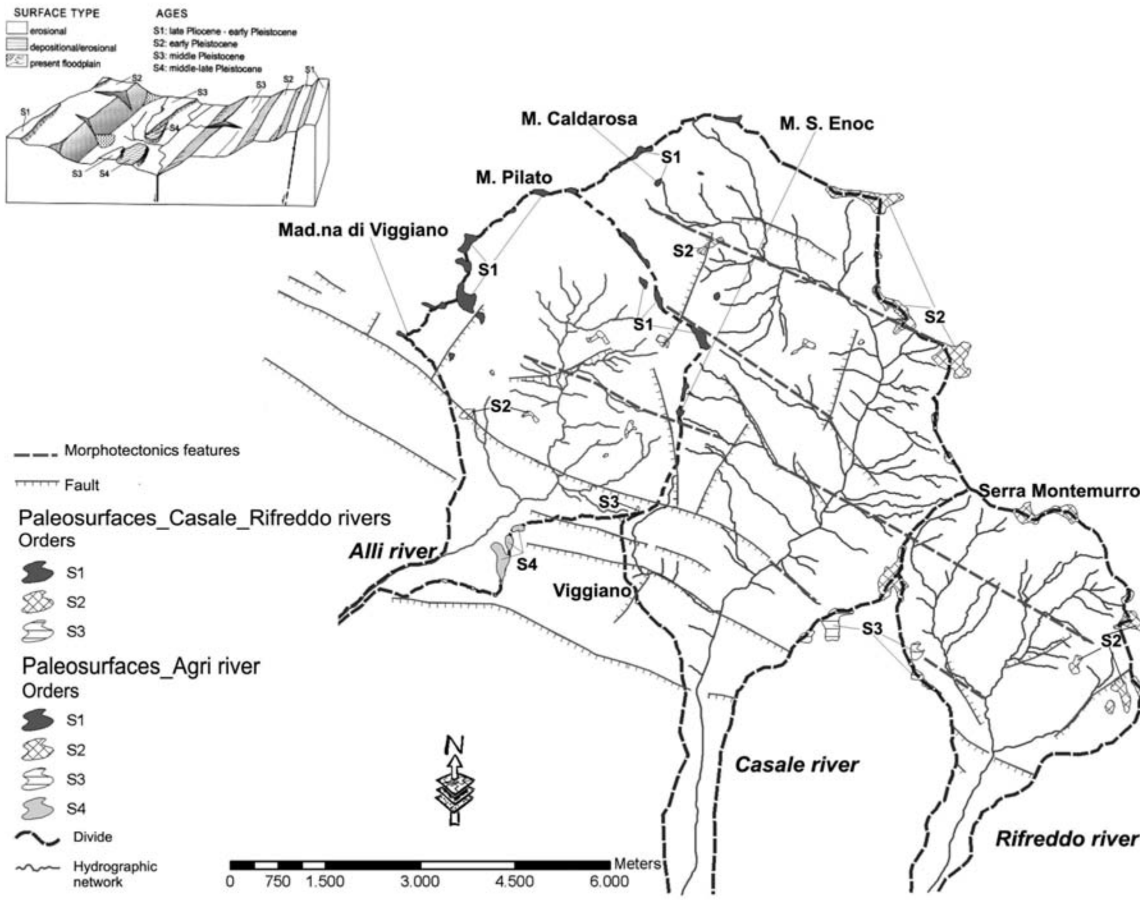

Figure 2. Morphostructural map of the studied hydrographical basin and block-diagram of the arrangement of the land surfaces (not in scale).

and volume") of surface analysis using 3D Analyst (ArcGIS) allowed to calculate the total eroded volumes between the main higher erosional palaeosurface (S1) and the other lower land surfaces (S2, S3 … Sn) during different time-spans (using the terraced surfaces as age constraints, cf. Schiattarella et al., 2004). This automatic method implemented with ArcGIS software is proposed as an alternative to that used by Schiattarella et al. (2004), based on a graphic method to calculate the eroded volume between two contiguous palaeosurface orders or among several orders of land surfaces and present-day thalwegs, using the average elevation value of every single order (Fig. 4).

3.2 Short-term fluvial erosion rate

In order to evaluate the short-term erosion rate of the study area, a quantitative geomorphic analysis of the hydrographic networks has been

Table 1. Age of land surfaces and time intervals used to calculate the erosion rates (after Schiattarella et al., 2003, 2006; Boenzi et al., 2004).

Land Surfaces	Age (My)	Time-Span (My)
S1-S2	1,8-1,2	0,6
S2-S3	1,2-0,73	0,47
S3-S4	0,73-0,125	0,605

carried out following the classical geomorphological approach (Horton, 1945; Strahler, 1957), applied and widened by some Italian authors (Avena et al., 1967; Ciccacci et al., 1980). The morphometric parameters gathered from this type of analysis would represent the development and geometry of the drainage basins, that are in turn expression of the erosion, transport and sedimentation processes linked to the river dynamics.

Table 2. Synthesis of the main erosion parameters (eroded volumes and rates) calculated for time intervals included between two consecutive base erosion paleo-levels.

Basin	Erosional Surfaces	Eroded Volume/Year (m^3/y)	Area (m^2)	Erosion rate (mm/y)
RIFREDDO	S2-S3	3.375	9.629.933	**0,35**
CASALE	S1-S2	875	17.311.705	**0,05**
CASALE	S2-S3	6.574	3.887.163	**1,69**
ALLI	S1-S2	909	5.913.463	**0,15**
ALLI	S2-S3	5.618	7.442.262	**0,75**
ALLI	S3-S4	5.344	3.188.966	**1,67**

Table 3. Eroded volumes calculated for different temporal ranges (the erosion rate average value is equal to 0.25 mm/yr).

Basin	Erosional Surfaces	Eroded Volume/Year (m^3/y)	Area (m^2)	Erosion rate (mm/y)
RIFREDDO	S2-S3	3.375	9.629.933	**0,35**
CASALE	S1-S3	3.378	21.198.868	**0,16**
CASALE	S1 - minimum altitude	9.055	34.838.060	**0,26**
ALLI	S1-S3	2.977	13.355.725	**0,22**
ALLI	S1-S4	3.832	16.544.691	**0,23**
ALLI	S1 - minimum altitude	5.273	18.441.024	**0,28**

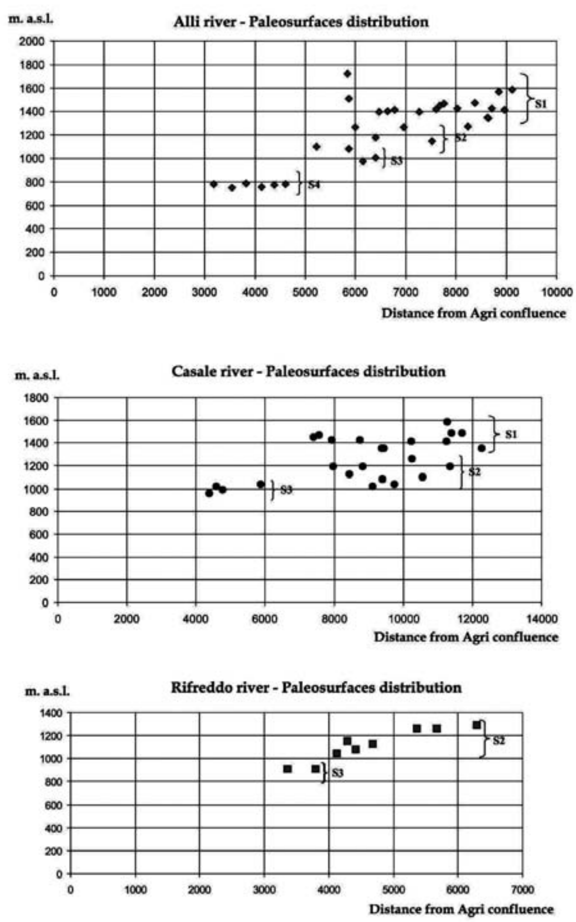

Figure 3. Diagrams showing the land surfaces distribution for each investigated basin.

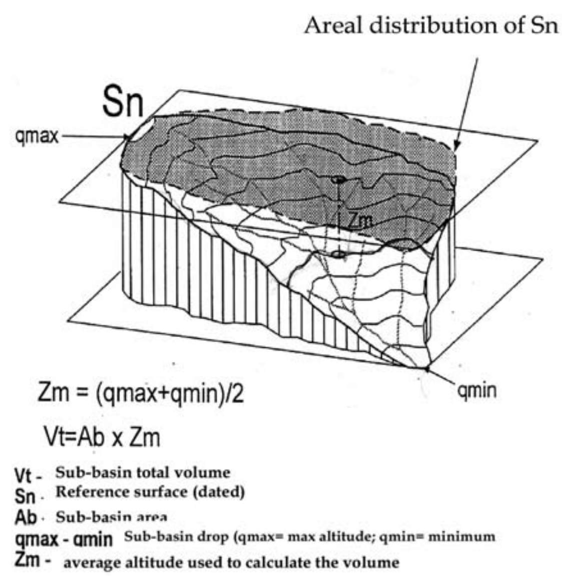

Figure 4. Graphic methods of the average elevation (after Schiattarella et al., 2004).

The quantitative analysis of the hydrographic network has been subdivided in partial sub-basins, to be studied as individual geomorphological units (Fig. 2).

The fluvial net has been organized according to the Strahler method and digitized with the software ArcGIS on geo-referred topographic maps. Starting from the topography and using the software GIS, the main morphometric parameters have been calculated for every basins, such as length and frequency of fluvial streams for each order, calculation of the anomalous streams in relation to their affiliation order (streams that do not feed the collectors of the immediately upper rank), area and perimeter of every basin.

From a morpho-tectonic point of view, the meaningful geomorphic parameters are those whose values stress the state of maturity of the basin and give useful elements to point out landscape rejuvenation phenomena. Bifurcation ratio and index (Rb, Rbd and R), elongation and circularity ratios (Re, Rc), and the relief ratio (Rh) absolve to this purpose. Rb, Rbd and R express the state of hierarchical organization of the drainage network, which is related to the maturity of the basin and to its geomorphological processes. Re and Rc describe shape and geometry of the basins and depend on the evolutionary stage of the geomorphological entity. Intersected divides and elongated forms (or low values of these indexes) are typical of young systems. Finally, the relief ratio Rh represents the average slope of the basin and its value tends to zero in the maturity stage.

Table 4 shows many critical values of the quantitative parameters for the sub-basins of the study area. The bifurcation ratio of Alli and Casale sub-basins assumes values close to 5, that are expression of a tectonic control on the organization of the drainage network, whereas the same parameter related to the Rifreddo basin has a value grater than 2, pointing out a complex structural setting and a transient geomorphological system. This tendency is also confirmed by the parameters Re, Rc e Rh, describing elongated basins with intersected water divides and slope gradients that locally increase the relief.

3.2.1 Alli River. The Alli River net develops overall on clay, sandstone and conglomerate in the parts of the basin surrounding the main stream, whereas the central sector is characterized by the presence of cherty limestone and sedimentary siliceous rocks. The main fluvial axis is about 10 km long (V order, *sensu* Sthraler, 1957), with a straight channel that in the upper part of the stream cuts an anticline core made of cherty limestone, whereas in its lower segment is entrenched in alluvial fan deposits as a result of the Quaternary uplift.

This basin (18 km^2) shows the higher value of "hierarchical anomaly density" (ga = 21.23) with regard to the entire orographic left of Agri River. In fact, such a value is due to several first order segments with a very low mean length, flowing directly into the V order main stream (Tab. 5). This situation is typical of hydrographic networks strongly controlled by tectonics.

3.2.2 Casale River. The Casale River basin covers an area almost 34 km^2 wide and represents the main tributary on the Agri River orographic left.

The hydrographical network develops mainly on clayey-marly deposits, sandstone and conglomerate and, in minor amount, on cherty limestone and sedimentary siliceous rocks in its north-western sector. In addition, sands, con-

Table 4. Summary of the average value of the geomorphic quantitative parameters.

Basins	Area (km^2)	Rb	Rbd	R	Ga	Da	ga	D	F	Re	Rc	Rh
ALLI	18,42	4,11	3,41	0,7	391	1,36	21,23	5,36	20,54	0,4	0,16	0,09
CASALE	33,99	4,69	3,76	0,93	619	1,47	18,21	4,59	16,5	0,4	0,2	0,07
RIFREDDO	15,17	3,71	3,04	0,67	159	0,99	10,48	4,8	12,96	0,59	0,34	0,1

Table 5. Synthesis of the main quantitative geomorphic parameters of Alli River basin.

Order	N	Rb	Rbd	R	Rb mean	Rbd mean	R mean
I	277	3.74	2.74	1	4.11	3.41	0.7
II	74	3.52	2.9	0,62			
III	21	4.2	3	**1,2**			
IV	5	**5**	**5**	-			
V	1						

Table 6. Synthesis of the main quantitative geomorphic parameters of Casale River basin.

Ordine	N	Rb	Rbd	R	Rb mean	Rbd mean	R mean
I	420	4	3.08	0.92	4.69	3.76	0.93
II	105	4.2	2.84	1.36			
III	25	3.57	2.14	**1.43**			
IV	7	**7**	**7**	/			
V	1						

Table 7. Synthesis of the main quantitative geomorphic parameters of Rifreddo River basin.

Ordine	N	Rb	Rbd	R	Rb mean	Rbd mean	R mean
I	153	4,5	2,94	**1,56**	3,71	3,04	0,67
II	34	**4,86**	**3,71**	1,15			
III	7	3,5	3,5	/			
IV	2	2	2	/			
V	1						

glomerates and lacustrine deposits characterize the southern portion of the basin, where the main fluvial channel is deeply entrenched in a wide Pleistocene-Holocene alluvial fan.

These lithological peculiarities drive the hydrographical network trends. High value of density (4.59) and frequency (16.5) of drainage are due to low permeability and a certain tendency to the erosion, whereas the Rb and Rbd mean values emphasize a tectonic control on hydrographic setting (Tab. 6). An evident disorganization of drainage network, due to several segments of I and II order directly connected with main fluvial axis, is underlined by Ga, Da and ga high values. Tectonic features exert a direct influence on the fluvial net and the basin geometry, with Re and Rc values close to 0 (elongated and irregular shape).

3.2.3 Rifreddo River. The Rifreddo river basin covers an area almost 16 km^2 wide and develops mainly on clayey-marly deposits and less on sands and conglomerates of an alluvial fan located along NNW-SSE striking faults.

Quantitative parameters relative to I and II order segments (Tab. 7) show an evident tectonic control on these elements. As a matter of fact, several fluvial channels are directly constrained by fault lines. The high value of ga (10,48) is probably due to both the presence of landslides in the higher part of the basin and the influence of the I order segments of the western slope, where the badlands are mostly developed.

3.2.3 Tu calculation and conversion rates. Denudation rates were indirectly estimated at the catchment scale in terms of suspended sediment yield (*Tu*). The relationships existing between *Tu* (Ciccacci et al., 1980), the drainage density and density of hierarchical anomaly are expressed by the following formula:

$$\text{Log } Tu = 1{,}82818 \log D + 0{,}01769\, ga + 1{,}53034 \quad (1)$$

Tu was calculated (Tab. 8) using the equation (1) computed by means of morphometric parameters (Horton, 1945; Strahler, 1952, 1957; Avena et al., 1967; Lupia Palmieri, 1983). Ciccacci et al. (1980) experimentally derived these equation measuring suspended sediment yield at the outlet of several Italian catchments showed the best simple statistical correlation with "drainage density" (D) and multiple correlations with D and "hierarchical anomaly density" (ga). On the contrary, measured *Tu* values didn't correlate with climatic parameters *p2/P* (Fournier, 1960) and $P \times \sigma$ (Ciccacci et al., 1977).

Table 8. Suspended sediment yield (*Tu*) for each analyzed basin converted in erosion rate.

Basins	logTu	Tu t/km^2.yr	Erosion Rate mm/yr
ALLI	3,2389387	1733,56	0,64
CASALE	3,06238	1154,46	0,42
RIFREDDO	2,9611622	914,45	0,33

The *Tu* value has been converted in erosion rate (T*a* or incision velocity expressed in mm/yr) considering the average density of outcropping rocks of sample areas according to following expression:

$$Ta = Tu / \gamma s * 10^{-3} \quad (2)$$

where *Tu* is the suspended sediment yield and γs is the specific weight of the drained rocks. Considering the different formations outcropping in the sampled sub-basins, a γs value equal to 2.7 gr/cm^3 has been here used. The erosion rates so obtained are reported in Table 8.

3.3 Slope mass movement contribution to erosion rate. In order to compare the eroded rock volumes due to fluvial processes with those due to mass movements, an inventory landslides map by field survey and multi-temporal aerial-photo-interpreted data has been created. Data have been implemented and georeferenced in a geodatabase using a GIS platform, whereas the volumes of the landslide deposits have been calculated for each single landslide approximating it to a parallelepiped and assigning a mean depth of the shear surface (Tab. 9).

4. Rates comparison and final remarks

The most widely available data on erosion rate are those calculated from the discharge of river transported, bedload, suspended and dissolved sediment. In general, these rates are not directly comparable to the erosion rate calculated for landslides because the landslide movement is typically only the first in a series of processes by which material may be removed from slopes and eventually transported out of a region by fluvial action (Keefer, 1994). Much landslide material does not immediately enter the fluvial system but rather is reworked by subsequent landslides or other processes, perhaps several times, before entering a river. Previous studies have shown that material from landslides and related slope-movement processes not directly deposited in river channels can remain in storage for periods of time ranging from a few months or less to thousand of years. Thus, comparisons of erosion rates calculated by the fluvial discharge method to those calculated for landslides only provide a general index for evaluating the effects of the latter processes.

First results of this study indicate that mass movements contribute just for the 1% of the whole erosion estimated in the two homogeneous Rifreddo and Casale basins (Tab. 10), but they refer to a short time-span (10 ky to Present). A theoretical extrapolation to the past (0.5 to 1 My) allows to consider the contribution of landslides to the total erosion inside the catchment areas as almost equal to the fluvial aliquot. The erosion rate from the Rifreddo basin is 0.35 mm/y in the time interval comprised between the upper part of the early Pleistocene and the beginnings of the middle Pleistocene. The behavior of the studied basins appears to be significantly different in this chronological interval but is comparable in a long-term temporal scale. As a matter of fact, the erosion rate estimated for the Casale basin starting from 1.8 My (age of the palaeosurface at the top of the mountains in the axial zone of the chain, cf. Schiattarella et al., 2003, and references therein) is about 0.26 mm/y. Data from the more complex Alli basin confirm this framework. The average value of the long-term erosion rate from the entire study area is 0.25 mm/y.

The conversion of the *Tu* values (Ciccacci et al., 1980), obtained from the three sub-basins of the Agri River upper valley according to the methodology recently proposed by Beneduce et al. (2008), showed that the short-term rates are generally greater than the rates calculated on

Table 9. Relative and total landslide volumes for the Casale and Rifreddo basins.

Basin	Active Landslide Volume (m^3)	Quiescent Landslide Volume (m^3)	Total Landslide Volume (m^3)
RIFREDDO	10.661.587	5.195.374	15.856.961
CASALE	5.963.574	29.174.923	35.138.497

Table 10. Comparison between the landslide and fluvial eroded volumes expressed in percentage.

Bacino	Landslide Eroded Volume (m^3)	Fluvial Eroded Volume (m^3)	Contribution of Landslide Eroded Volume (m^3)
CASALE	35.138.497	3.615.288.180	0,97
RIFREDDO	15.856.961	1.586.251.576	1

the basis of the "volumetric" method (Schiattarella et al., 2004), being the average value about 0.46 mm/y. This may mean that the present-day trend of the linear erosion rate (note that the turbid transport of the streams expressed by the *Tu* parameter refers to the present hydrographic network) could increase respect to the long- and mid-term trend as a response to climate triggering (i.e. more rainfalls and/or sediment supply), or simply represent an instantaneous trivial fluctuation in the long-lasting behavior of the fluvial nets under variable climate conditions.

Finally, the comparison of all these data with the uplift rates calculated on a regional scale (0.6-1.1 mm/y) confirms that the southern Apennines may represent a non-steady state system (Schiattarella et al., 2006).

References

Amato A., Cinque A. 1999. Erosional landsurfaces of Campano-Lucano Apennines (S. Italy): genesis, evolution and tectonic implications. Tectonophysics, 315, 251-267.

Amato A., Aucelli P.P.C., Cinque A. 2003. The long-term denudation rate in the Southern Apennines Chain (Italy): a GIS-aided estimation of the rock volumes eroded since middle Pleistocene time. Quaternary International, 101-102, 3-11.

Avena G.C., Giuliano G., Lupia Palmieri E. 1967. Sulla valutazione quantitativa della gerarchizzazione ed evoluzione dei reticoli fluviali. Boll. Soc. Geol. It., 86, 781-796.

Basso F., Bove E., Dumontet S., Ferrara A., Pisante M., Quaranta G., Taberner M. 2000. Evaluating environmental sensitività at the basin scale through the use of geographic information system and remotely sensed data: an example covering the Agri basin (southern Italy). Catena, 40, 19-35.

Beneduce P., Boenzi F., Capolongo D., Di Leo P., Giano S.I., Gioia D., Martino C., Schiattarella M. 2008. Aspetti metodologici e prime considerazioni sul confronto tra tassi di sollevamento ed erosione di aree dell'Italia meridionale. In: Studi di base sull'interazione tra clima, tettonica e morfoevoluzione in Italia meridionale durante il Quaternario, Bonzi F., Capolongo D., Giano S.I., Schiattarella M. (eds.), Dibuono Edizioni. Villa d'Agri (PZ), 19-36.

Boenzi F., Capolongo D., Cecaro G., D'Andrea E., Giano S.I., Lazzari M., Schiattarella M. 2004. Evoluzione geomorfologica polifasica e tassi di sollevamento del bordo sud-occidentale dell'Alta Val D'Agri (Appennino meridionale). Boll. Soc. Geol. Ita, 123, 357-372.

Brancaccio L., Cinque A., Romano P., Rosskopff C., Russo F., Santangelo N., Santo A. 1991. Geomorphology and neotectonic evolution of a sector of the Tyrrhenian flank of the southern Apennines (region of Naples, Italy). Zeitschrift für Geomorphologie Supplementbände, 82, 47-58.

Capolongo D., Cecaro G., Giano S.I., Lazzari M., Schiattarella M. 2005. Structural control on drainage pattern of the south-western side of the Agri River upper valley, southern Apennines, Italy. Geogr. Fis. Dinam. Quat., 28, 169-180.

Carbone S., Catalano S., Lazzari S., Lentini F., Monaco C. 1991. Presentazione della carta geologica del bacino del Fiume Agri (Basilicata). Mem. Soc. Geol. It., 47, 129-143.

Cello G., Gambini R., Mattioni L., Mazzoli S., Read A., Tondi E., Zucconi V. 2000. Geological analysis of the High Agri Valley (Lucania Apennines, Southern Italy). Mem. Soc. Geol. It., 55, 149-155.

Ciccacci S., Fredi P., Lupia Palmieri E. 1977. Rapporti fra trasporto solido e parametri climatici e geomorfici in alcuni bacini idrografici italiani. Atti del Convegno "Misura del trasporto solido al fondo nei corsi d'acqua", CNR, Firenze: C-4.1 - C-4.16.

Ciccacci S., Fredi P., Lupia Palmieri E., Pugliese F. 1980. Contributo dell'analisi geomorfica quantitativa alla valutazione dell'entità dell'erosione nei bacini fluviali. Boll. Soc. Geol. It., 99, 455-516.

Ciccacci, S. Fredi, P. Lupia Palmieri E., Pugliese F. 1986. Indirect evaluation of erosion entity in drainage basins through geomorphic, climatic and hydrological parameters. International Geomorphology, 2:33-48.

Ciccacci S., Del Monte M., Marini R. 2003. Erosion and recent morphological change in a sample area of the Orcia River upper basin (Southern Tuscany). Geografia Fisica e Dinamica Quaternaria, 26: 97-109.

D'Argenio B., Pescatore T., Scandone P. 1973. Schema Geologico dell'Appennino Meridionale (Campania e Lucania). Atti del Convegno "Moderne vedute sulla Geologia dell'Appennino", Quad. Acc. Naz. Lincei, 182, 51-58.

Della Seta M., Del Monte M., Fredi P., Lupia Palmieri E. 2006. Direct and indirect evaluation of denudation rates in Central Italy. Catena, 71, 21-30.

Del Monte M. 2003. Caratteristiche morfometriche e morfodinamiche dell'alto bacino del Fiume Orcia (Toscana meridionale). Atti del XXVIII Congresso Geografico Italiano, Roma, 1938-1975.

Del Monte M., Fredi P., Lupia Palmieri E., Marini R. 2002. Contribution of quantitative geomorphic analysis to the evaluation of geomorphological hazards. In: Applied Geomorphology: Theory and Practice, Allison R.J. (ed.), J. Wiley & Sons: 335-358.

Di Leo P., Dinelli E., Mongelli G., Schiattarella M. 2002. Geology and geochemistry of Jurassic pelagic sediments, Scisti silicei Formation, southern Apennines, Italy. Sedimentary Geology, 150, 229-246.

Di Niro A., Giano S.I. 1995. Evoluzione geomorfologica del bordo orientale dell'Alta Val d'Agri (Basilicata). Studi Geol. Camerti, Spec. Vol., 1995/2, 207-218.

Fournier F. 1960. Climat et érosion: la relation entre l'erosion du sol par l'eau et les précipitations atmosphériques, Presses Univ. de France, Paris. 201 pp.

Giano S.I., Lapenna V., Piscitelli S., Schiattarella M. 1997. Nuovi dati geologici e geofisici sull'assetto strutturale dei depositi continentali quaternari dell'alta Val d'Agri (Basilicata). Il Quaternario, 10, 591-596.

Giano S.I., Maschio L., Alessio M., Ferranti L., Improta S., Schiattarella M. 2000. Radiocarbon dating of active faulting in the Agri high valley, southern Italy. Journal of Geodinamics, 29, 371-386.

Giano S.I., Schiattarella M. 2002. Geomorfologia e Neotettonica dell'alta Val d'Agri. In: Boenzi F., Schiattarella M. (eds.): Guida all'Escursione Geomorfologica: dalla Val d'Agri a Matera. Assemblea-Escursione AIGeo, Potenza, giugno 2002, TecnoStampa, Villa d'Agri (PZ), 22-34.

Horton R.E. 1945. Erosional development of stream and their drainage basins: hydrophisical approach to quantitative morphology. Bull. Geol. Soc. Am., 56, 275-370.

Keefer K.D. 1994. The importance of earthquake-induced landslides to long-term slope erosion and slope-failure hazards in seismically active regions. Geomorphology, 10, 265-284.

Lazzari M., Schiattarella M. 2008. Confronto tra tassi di erosione fluviale e da franosità in alta Val d'Agri (Appennino meridionale). In: Boenzi F., Capolongo D., Giano S.I., Schiattarella M. (eds.): Studi di base sull'interazione tra clima, tettonica e morfoevoluzione in Italia meridionale durante il Quaternario, Dibuono Edizioni, Villa d'Agri (PZ), pp. 105-114.

Lupia Palmieri E. 1983. Il problema della valutazione dell'entità dell'erosione nei bacini fluviali. Atti del XXIII Congresso Geografico italiano, Catania, 143-176.

Martino C., Nico G., Schiattarella M. 2009. Quantitative analysis of InSAR Digital Elevation Models for identification of areas with different tectonic activity in southern Italy. Earth Surface Processes and Landforms, 34, 3-15.

Martino C., Schiattarella M. 2006. Aspetti morfotettonici dell'evoluzione geomorfologica della valle del Melandro (Appennino campano-lucano). Il Quaternario, 19, 119-128.

Monaco C. 1991. Relazione tra dissesti e tettonica nel bacino del Torrente casale (Appennino Lucano). Boll. Soc. Geol. It., 110, 405-416.

Pescatore T., Renda P., Schiattarella M., Tramutoli M. 1999. Stratigraphic and structural relationships between Meso-Cenozoic Lagonegro basin and coeval carbonate platforms in southern Apennines, Italy. Tectonophysics, 315, 269-286.

Putignano M.L., Schiattarella M. 2008. Struttura, esumazione ed evoluzione morfologica del nucleo mesozoico del Monte Motola (Cilento, Italia meridionale). Boll. Soc. Geol. It., 127, 477-493.

Russo F., Schiattarella M. 1992. Osservazioni preliminari sull'evoluzione morfostrutturale del bacino di Castrovillari (Calabria settentrionale). Studi Geol. Camerti, Spec. Vol., 1992/1, 271-278.

Scandone P. 1972. Studi di geologia lucana: Carta dei terreni della serie calcareo-silico-marnosa e note illustrative. Boll. Soc. Natur. Napoli, 81, 225-300.

Schiattarella M. 1998. Quaternary tectonics of the Pollino Ridge, Calabria-Lucania boundary, southern Italy. In: Holdsworth R.E., Strachan R.A., Dewey J.F. (eds.): Continental Transpressional and Transtensional Tectonics. Geological Society Special Publication, 135, 341-354.

Schiattarella M., Beneduce P., Pascale S. 2004. Comparazione tra i tassi di erosione e sollevamento dell'Appennino lucano: l'esempio della Fiumara di Tito e Picerno. Boll. A.I.C., 121-122, 367-385.

Schiattarella M., Di Leo P., Beneduce P., Giano S.I. 2003. Quaternary uplift vs tectonic loading: a case-study from the Lucanian Apennine, southern Italy. Quaternary International, 101-102, 239-251.

Schiattarella M., Di Leo P., Beneduce P., Giano S.I., Martino C. 2006. Tectonically driven exhumation of a young orogen: an example from southern Apennines, Italy. In: Willett S.D., Hovius N., Brandon M.T., Fisher D. (eds.), Tectonics, climate, and landscape evolution, Geological Society of America Special Paper, 398, Penrose Conference Series, 371-385.

Schiattarella M., Beneduce P., Capolongo D., Di Leo P., Giano S.I., Gioia D., Lazzari M., Martino C. 2008. Uplift and erosion rates from the southern Apennines, Italy. Boll. Geof. Teor. Appl., 49, Suppl. 2, 470-475.

Strahler A.N. 1952. Hypsometric (area-altitude) analysis of erosional topography. Geological Society of America Bulletin, 63:1117-1142.

Strahler A.N. 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geoph. Un. 38, 913-920.

Tanner L.H., Schiattarella M., Di Leo P. 2006. Carbon isotope record of Upper Triassic strata of the Lagonegro Basin, Southern Apeninnes, Italy: preliminary results. In: Harris et al. (eds.), The Triassic-Jurassic Terrestrial Transition. New Mexico Museum of Natural History and Science Bull., 37, 23-28.